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DETERMINATION OF THE DEPENDENCE OF FEED MIXTURE HOMOGENEITY ON THE OPERATING PARAMETERS OF A VIBRATORY MIXER

The paper investigates the influence of the operating parameters of a vibratory mixer on the formation of feed mixture homogeneity and establishes quantitative patterns in the variation of the homogeneity coefficient depending on the kinematic and vibration characteristics of the process. The relevance of this study stems from the need to ensure high-quality feed mixtures with minimal time and energy expenditure, as the uniformity of the components directly affects feeding efficiency and the economic performance of livestock farming. The aim of the research is to establish a statistically justified multifactor dependence of the homogeneity coefficient on the operating parameters of a vibratory mixer and to determine rational operating modes.

Experimental studies were carried out using a full factorial experimental design with variation of the paddle shaft rotational speed, container rotational speed, vibration mode coefficient, and mixing time. Based on the processing of experimental data, a second-order regression model describing the variation of the mixture homogeneity coefficient was developed. The statistical significance of the model parameters was evaluated using Student's t-test, and its adequacy was verified using Fisher's F-test at a confidence level of 0.95.

According to the modeling results, rational operating modes of the mixer were determined, under which the homogeneity coefficient reaches $\delta = 0.932$ *at a paddle shaft rotational speed of 40.9* min^{-1} *and a container rotational speed of 23.9* min^{-1}*. The minimum value of* $\delta = 0.851$ *was observed at low values of the operating parameters. An effective operating region was established in which a technologically sufficient level of homogeneity* ($\delta \geq 0.9$) *is ensured. An analytical dependence of the mixing time* $t_{0.9}$ *required to achieve a specified level of homogeneity was obtained, which makes it possible to predict process parameters and perform optimization. The correlation coefficient between experimental and calculated data is 0.87, confirming the adequacy of the developed mathematical model.*

Keywords: *vibratory mixer, feed mixture, homogeneity, operating parameters, mathematical modeling, optimization.*

Introduction. The feed base remains a determining factor in the cost structure of livestock production. According to estimates by the Food and Agriculture Organization of the United Nations (FAO), feed costs in many productions systems account for more than 60–70% of total expenditures; therefore, any improvement in the efficiency of feed production technologies has a direct economic impact. In practical terms, this means that dosing accuracy and the spatial–temporal uniformity of component distribution—particularly micro-ingredients, premixes, and medicated additives–become not merely a «laboratory requirement» but a key factor influencing profitability, biosafety, and the reproducibility of feeding outcomes.

At the level of industrial practice, mixture homogeneity is typically confirmed statistically based on a series of samples by calculating the coefficient of variation (CV), defined as the ratio of the standard deviation to the mean value, or by analyzing the distribution of tracer particles [1, 12]. In particular, the Canadian Food Inspection Agency establishes critical CV limits for different product types (for example, stricter limits for medicated premixes) and provides standard procedures involving the collection of at least nine spot samples during mixer discharge [2]. In parallel, international feed safety schemes (such as GMP+ International) formalize the categories of «good», «acceptable» and «insufficient» homogeneity based both on the CV criterion and on the Poisson/p criterion for direct methods (particle counting), and explicitly require an adequate number of samples taken either within the mixer or during discharge [3].

Vibratory mixers have the potential to intensify particle transport and the breakdown of agglomerates in bulk materials, thereby improving mixture quality while reducing energy consumption; however, this effect can be achieved only under properly selected amplitude-frequency and kinematic operating conditions [4]. Therefore, the scientific and technological problem consists in quantitatively determining the dependence of the homogeneity index (δ) on the set of operating parameters and in substantiating rational operating modes that ensure the required mixture quality with minimal processing time and specific energy consumption.

Analysis of recent research and publications. The dominant applied approach in feed production is the assessment of homogeneity through a series of samples with subsequent calculation of the coefficient of variation (CV). Methodological materials from Kansas State University emphasize that the objective of mixing is to achieve a «uniform mixture», and typical practice includes sampling from multiple locations, selecting an appropriate marker (such as salt or amino acids), and calculating the CV based on the collected samples (often about ten samples). Regulatory guidelines also highlight the existence of an optimal mixing time, noting that excessive mixing duration may lead to demixing under certain conveying and discharge conditions. An alternative “direct” method for homogeneity assessment involves counting tracer particles (microtracers), where the results are interpreted using Poisson statistics (probability p), which is clearly formalized in GMP+ requirements [4].

In fundamental and applied studies on granular media mechanics, the degree of mixing is commonly described using mixing indices (in particular, the Lacey index) as well as particle motion modeling based on the discrete element method (DEM). For vibratory systems, it has been demonstrated that mixing may exhibit both diffusive and convective characteristics, with the vibration regime significantly influencing the relative contribution of these mechanisms. The Lacey index is widely applied as a quantitative measure of the mixing state in DEM models of vibrated granular beds. Within the Ukrainian scientific and engineering domain, the potential of vibratory machines for mixing bulk materials has also been demonstrated, along with the feasibility of controlling operating parameters to achieve high homogeneity with minimal energy consumption [5].

For the empirical determination of “quality–regime” relationships in multifactor technological processes, response surface methodology (RSM) is widely used. This approach is based on experimental design and approximation of the response by a second-order polynomial, enabling the construction of response surfaces, contour plots, and optimization within the factor space. For mixing processes, this methodology is particularly relevant because the dependencies are typically nonlinear (due to saturation effects), and the factors may influence the process to different extents while being constrained by equipment design, productivity, and energy consumption requirements (Table 1) [6].

Table 1 – Comparison of homogeneity assessment methods

Author	Year	Object	Method	Homogeneity criterion
Charles Stark; Marut Saensukjaroenphon	2017	Industrial feed mixers (batch)	Sampling from multiple points/intervals; marker analysis; CV calculation	CV = (SD/Mean) ×100%
Canadian Food Inspection Agency	2013	Batch, TMR, and continuous systems	Regulatory mixer testing procedure; minimum 9 samples; laboratory analysis	CV and critical limits depending on feed type
GMP+ International	2022	Production lines for critical additives/ VMP	Direct and indirect methods; requirements for sampling and tracers	p (Poisson) or CV; scales «good / acceptable / insufficient»
P.M. Clark	2007	Compound feed, «mix uniformity» verification	Comparison of markers and influence of mixing time on CV	CV; comparison of different markers
A. Kottlan	2021	Vibratory mixing of	Video recording/colorimetry;	Lacey index

Author	Year	Object	Method	Homogeneity criterion
		powders (laboratory scale)	analysis of mixing based on vibration parameters	
L.S. Lu	2008	Vibrated granular bed	DEM modeling; analysis of convection and diffusion	Lacey index + convection/diffusion parameters
Vitaliy Yanovych; Tetiana Honcharuk; Inna Honcharuk; Kateryna Kovalova	2017	Vibratory machine for mixing bulk feed materials	Control system for operating parameters; comprehensive analysis of kinematics and material state	% homogeneity; energy consumption

Despite the existence of standards regulating methods for assessing mixture homogeneity (using the CV or Poisson/p criteria) and defining acceptance thresholds, these documents essentially describe only the control (validation) procedures and do not provide a mathematical tool for the systematic selection of rational mixer operating modes while accounting for nonlinearity and multifactor interactions. Scientific studies on vibratory mixing and granular media describe the underlying mechanisms (convection and diffusion) as well as the dependence of process efficiency on amplitude-frequency parameters; however, they often consider either laboratory-scale setups or geometrically simplified systems, without linking the results to the criterion of «technologically sufficient» homogeneity specifically for feed mixtures or to the parameters of real equipment (rotational speeds of working elements, loading conditions, and cycle duration).

In this context, the scientific novelty of the approach proposed in this study lies in the following:

– first, a formalized multifactor relationship δ = f (operating parameters) is introduced in the form of a second-order regression model with subsequent construction of response surfaces, which corresponds to the logic of response surface methodology (RSM) for nonlinear processes;

– second, the mixture quality is linked to an engineering-relevant time characteristic, $t_{0.9}$ – the time required to achieve the specified level δ = 0.9 (conventionally «90% homogeneity»), which is directly applicable for determining the process cycle duration and for the development of mixer control algorithms;

– third, statistical «filtering» of the model terms is performed (including significance testing of parameters and verification of model adequacy), which reduces the risk of random conclusions and enhances the reproducibility of the obtained recommendations.

The aim of the study is to establish a statistically justified multifactor dependence of δ on the operating parameters of a vibratory mixer and to determine rational operating modes that ensure the achievement of the specified level of homogeneity (in particular, δ ≥ 0.9) with minimal mixing time.

Materials and Methods. In order to investigate the influence of operating parameters on the quality indicators of the mixing process in a vibratory mixer, a series of experimental studies was conducted. The main factors varied during the experiment were:

- x_1 – paddle shaft rotational speed n_p, min^{-1};
- x_2 – container rotational speed n_c, min^{-1};
- x_5 – vibration mode coefficient k_v;
- x_6 – mixing time t, s.

The experimental design was carried out using a full factorial experimental method with variation of the factors at three levels: lower (–1), central (0), and upper (+1) [7]. To improve the accuracy of parameter estimation and enable approximation of the results, a coded representation of the variables was used.

The collection and processing of experimental data were carried out using the cloud computing environment Wolfram Cloud [8], which enabled the construction of quadratic regression equations and statistical verification of their adequacy.

The obtained regression models served as the basis for further analysis of the influence of operating parameters and their combinations on the efficiency of the mixing process.

Results of the study. To determine the quantitative influence of operating parameters on mixture homogeneity, a second-order regression modeling approach was applied [9]. Based on the processing of experimental data in the Wolfram Cloud environment [8], an equation describing the dependence of the homogeneity coefficient δ in coded form was obtained:

$$\begin{gathered}\delta = 0{,}918657 + 0{,}002425\,x_1 - 0{,}01005\,x_1^2 + \\ + 0{,}00345\,x_2 - 0{,}00245\,x_1 x_2 - 0{,}0028\,x_2^2 + \\ + 0{,}003375\,x_5 + 0{,}0003\,x_1 x_5 - \\ - 0{,}00175\,x_2 x_5 - 0{,}00765\,x_5^2 + \\ +0{,}0240667\,x_6 - 0{,}0014\,x_1 x_6 + \\ +0{,}00205\,x_2 x_6 - 0{,}00025\,x_5 x_6 - \\ - 0{,}0117143\,x_6^2.\end{gathered} \tag{1}$$

Table 2 presents the results of the statistical analysis of regression equation (1), which describes the dependence of the mixture homogeneity coefficient δ on the main technological factors. The numerical values of the estimated regression coefficients, the corresponding standard errors, Student's t-statistics, and asymptotic significance levels (p-values) are also provided, serving as criteria for assessing the statistical significance of each model term [9, 10].

Table 2 – Statistical analysis of the regression coefficients of equation (1)

Coefficient	Value	Error	Student's t-statistic	Asymptotic Significance (p-value)
a_{00}	0,918657	0,0016818	546,235	$1{,}28897 \cdot 10^{-112}$
a_{10}	0,002425	0,000908275	2,6699	0,0097482
a_{20}	0,00345	0,000908275	3,79841	0,000342232
a_{50}	0,003375	0,000908275	3,71584	0,000446799
a_{60}	0,0240667	0,000938062	25,6557	$4{,}85562 \cdot 10^{-34}$
a_{12}	-0,00245	0,00128449	-1,90736	0,0612635
a_{15}	0,0003	0,00128449	0,233555	0,816126
a_{16}	-0,0014	0,00128449	-1,08992	0,280105
a_{25}	-0,00175	0,00128449	-1,3624	0,178163
a_{26}	0,00205	0,00128449	1,59596	0,115752
a_{56}	-0,00025	0,00128449	-0,194629	0,846341
a_{11}	-0,01005	0,00133694	-7,51714	$3{,}27308 \cdot 10^{-10}$
a_{22}	-0,0028	0,00133694	-2,09433	0,0404628
a_{55}	-0,00765	0,00133694	-5,722	$3{,}56004 \cdot 10^{-7}$
a_{66}	-0,0117143	0,00158561	-7,38785	$5{,}44414 \cdot 10^{-10}$
Indicator	DF	SS	MS	Fisher's F-statistic
Model	15	61,03	4,06867	123298
Error	60	0,00197991	0,0000329985	1,93

According to the obtained results, the following coefficients were found to be statistically significant at a confidence level of 95 % ($t_{tab} = 2{,}01$) [11]: a_{10}, a_{20}, a_{50}, a_{60}, a_{11}, a_{22}, a_{55}, and a_{66}, since the absolute values of the corresponding Student's t-statistics exceed the tabulated value. This indicates a substantial influence of the respective factors and their quadratic effects on the variation of the homogeneity coefficient. In contrast, the interaction coefficients between the factors (a_{12}, a_{15}, a_{16}, a_{25}, a_{26}, a_{56}) were found to be statistically insignificant, which indicates the absence of a significant interaction effect within the conducted experiment.

Among the estimated model parameters, the intercept $a_{00} = 0{,}918657$ occupies a special position, representing the baseline value of the homogeneity coefficient at zero values of the coded factors, i.e., at the center of the experimental design space. The extremely high value of Student's t-statistic for this coefficient ($t = 546{,}235$) and the practically zero asymptotic significance ($p < 10^{-110}$) indicate its absolute statistical reliability. This confirms that the mean response value at the center point of the design is reliably determined and adequately reflects the actual characteristics of the system.

By excluding the insignificant regression coefficients of equation (1) based on comparison of their absolute values with the tabulated value of Student's t-statistic $t_{tab} = 2{,}01$, a refined relationship describing the dependence of the homogeneity coefficient δ on the investigated factors in decoded form (2) was obtained:

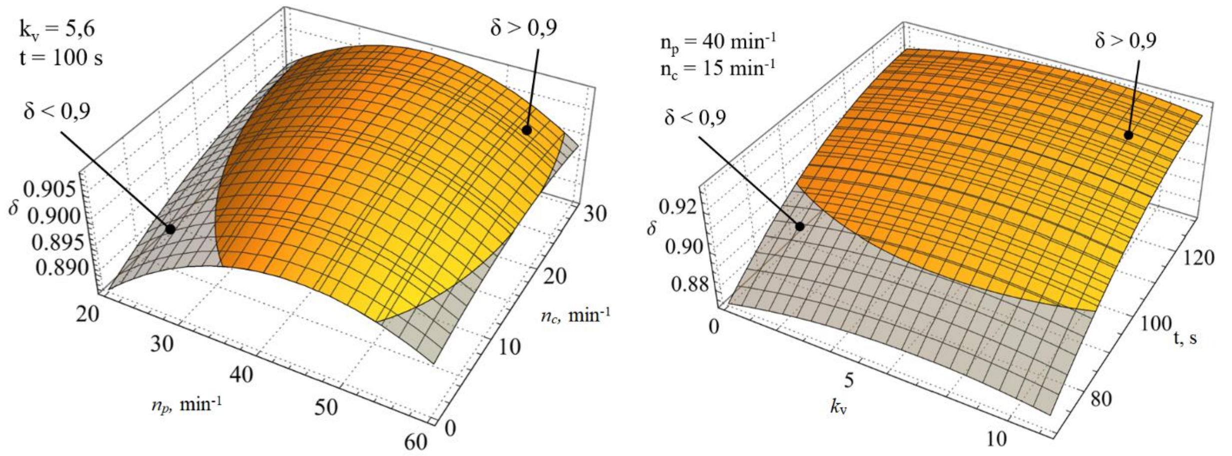
$$\begin{aligned} \delta = {} & 0{,}641051 + 0{,}00333482\, k_v - \\ & - 0{,}000243941\, k_v^2 + 0{,}00093\, n_c - \\ & - 0{,}0000124444\, n_c^2 + 0{,}00225375\, n_p - \\ & - 8{,}16667 \cdot 10^{-6}\, n_c\, n_p - 0{,}000025125\, n_p^2 + \\ & + 0{,}0034054\, t - 0{,}0000130159\, t^2. \end{aligned} \tag{2}$$

Based on the refined regression equation (2) obtained in decoded coordinates, three-dimensional response surfaces were constructed to characterize the variation of the mixing homogeneity coefficient δ depending on combinations of the main operating parameters: the rotational speed of the paddle shaft n_l and the rotational speed of the container n_p (Fig. 1a), as well as the vibration mode coefficient k_v and the mixing time t (Fig. 1b). The constructed plots clearly illustrate the influence of the corresponding variables on the mixing quality and make it possible to identify regions of effective operating modes at which the specified level of homogeneity is achieved.

The response surface shown in Fig. 1(a) represents the variation of the mixing homogeneity coefficient δ as a function of the rotational speed of the paddle shaft n_l and the rotational speed of the container n_k under fixed values of the vibration mode coefficient $k_v = 5.6$ and the mixing time $t = 100$. The surface exhibits a convex shape with a clearly pronounced maximum in the upper-right region of the plot, indicating the existence of an optimal combination of kinematic parameters at which the highest level of mixture homogeneity is achieved.

With an increase in the rotational speeds of both the paddle shaft and the container, an increase in the value of δ is observed. At the same time, analysis of the surface shape and the coefficients in equation (2) indicates that the rotational speed of the paddle shaft has a greater influence on the result than the rotational speed of the container. This can be explained by the predominance of shear mixing over bulk mixing, since the active motion of the paddles ensures more intensive movement and redistribution of particles within the mixture mass.

The presence of negative quadratic terms in the equation for both variables indicates a saturation effect: upon reaching certain threshold values, further increases in rotational speeds do not result in a significant improvement in homogeneity and may even lead to a slight decrease due to secondary segregation.



а) б)

Fig. 1. Dependence of the homogeneity coefficient δ on the rotational speed of the paddle shaft n_p and the rotational speed of the container n_c (a), and on the vibration mode coefficient k_v and mixing time t (b)

The maximum value of the homogeneity coefficient δ = 0.932 was observed at a paddle shaft rotational speed n_p = 40.9 min⁻¹ and a container rotational speed n_c = 23.9 min⁻¹. In contrast, at minimum rotational speeds (n_p = 20 min⁻¹, n_c = 0 min⁻¹), the homogeneity coefficient decreases to δ = 0.851, which is insufficient from a technological standpoint. The region of the surface where δ > 0.9 represents the zone of rational operating modes, characterized by a combination of medium and high rotational speeds.

Figure 1(b) presents the response surface illustrating the variation of the mixing homogeneity coefficient δ as a function of the vibration mode coefficient k_v and the mixing duration t, under fixed values of the paddle shaft rotational speed n_p = 40 min⁻¹ and the container rotational speed n_c = 15 min⁻¹. The selected fixed values correspond to the optimal region identified in Fig. 1(a) and allow for a more detailed analysis of the influence of the vibration regime and mixing time as secondary factors affecting the process.

The shape of the surface confirms the presence of a pronounced nonlinear dependence of the homogeneity coefficient on both parameters. According to equation (2), the influence of each factor is positive within the investigated range (the corresponding linear coefficients are positive); however, the negative quadratic terms indicate a saturation effect. This is manifested by the flattening of the surface in the upper region of the plot: further increases in k_v or t do not result in a significant improvement in the coefficient δ and, at certain points, may even lead to a slight decrease.

The maximum value of the homogeneity coefficient δ = 0.932 is achieved at k_v = 6.83 and t = 130 s, whereas the minimum value δ = 0.851 is observed at k_v = 0 and t = 70 s. The technologically feasible region corresponds to δ ≥ 0.9, which is attained under a balanced combination of parameters, namely a moderately high level of vibration intensity and sufficient mixing duration, provided that active kinematic influence is ensured.

Thus, Figures 1(a) and 1(b), considered together, provide a comprehensive representation of the influence of the main operating variables on mixing homogeneity, allowing the identification of technologically justified ranges for their variation and creating the basis for further process optimization with consideration of energy and productivity criteria.

The obtained graphical dependencies (Fig. 1a, b) make it possible to visually assess the influence of the main operating parameters on mixing homogeneity; however, for precise determination of the conditions required to achieve a specified level of homogeneity, it is necessary to use an analytical expression. For this purpose, the time parameter t was analytically isolated from equation (2) by fixing the value of the homogeneity coefficient at δ = 0.9 (3). This made it possible to obtain an equation describing the dependence of the mixing duration $t_{0.9}$ (4) on the rotational speed of the paddle shaft n_l, the rotational speed of the container n_k, and the vibration mode coefficient k_v:

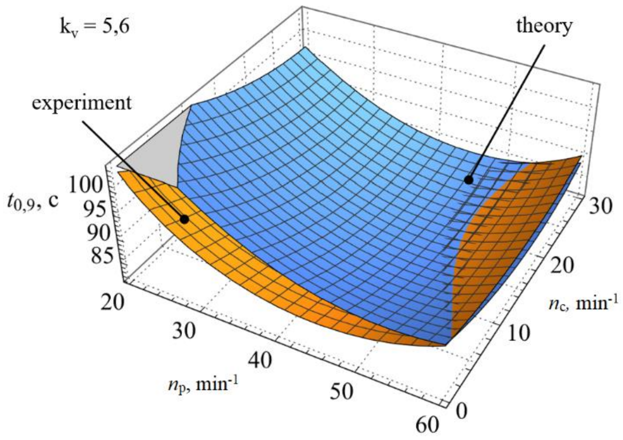
$$\delta(n_p,\ n_c,\ k_v) = 0,9 \rightarrow \qquad (3)$$

$$t_{0,9} = 0,00609756\ (21454 - 0,119523 \times \times (-5,23724 \cdot 10^9 + 4,82375 \cdot 10^8\ k_v - - 3,52856 \cdot 10^7\ k_v^2 + 1,34523 \cdot 10^8\ n_c - 1,80006 \cdot 10^6\ n_c^2 + 3,26 \cdot 10^8\ n_p - - 1,18129 \cdot 10^6\ n_c\ n_p - 3,63428 \cdot 10^6\ n_p^2)^{0,5}). \qquad (4)$$

Dependence (4) has a complex multifactor structure with quadratic and interaction terms, which corresponds to a second-order model. It accounts for both the individual effects of each parameter and their interactions, in particular the influence of the cross-product term $n_c n_p$. This makes it possible to describe the effect of changes in mixing conditions even with small deviations from the baseline values.

Figures 2(a) and 2(b) present a graphical comparison of the dependence of the time required to achieve the specified mixture homogeneity, $t_{0,9}$, constructed based on the experimental model (4), with the corresponding theoretical dependence. Both surfaces make it possible to analyze the agreement between the experimental data and the analytical description of the process.

Figure 2(a) illustrates the spatial dependence of $t_{0.9}$ on the rotational speed of the paddle shaft n_l and the rotational speed of the container n_k at a fixed vibration mode coefficient $k_v = 5.6$. The surface exhibits a pronounced convex shape with a minimum in the central region, corresponding to the optimal combination of parameters at which the mixing time is minimal. An increase or decrease in any of the parameters beyond the rational range leads to an increase in $t_{0,9}$, which is associated with a loss of mixing efficiency due to either excessive or insufficient mechanical action.



а) б)

Fig. 2. Dependence of the time required to achieve the specified homogeneity $t_{0,9}$ on the rotational speed of the paddle shaft n_p and the rotational speed of the container n_c (a), and on the vibration mode coefficient k_v and the rotational speed of the container n_c (b)

Figure 2 (b) shows the dependence of $t_{0.9}$ on the container rotational speed n_k and the vibration mode coefficient k_v at a fixed paddle shaft rotational speed $n_p = 40$ min^{-1}. Similar to the previous case, the surface is characterized by the presence of a minimum region and a saturation effect at the extreme values of the parameters. An increase in k_v combined with moderate values of n_c contributes to a reduction in mixing time, whereas excessive vibration intensity or insufficient rotational motion of the container may lead to a decrease in mixing efficiency.

The correlation coefficient between the results is 0.87, which, according to the Chaddock [11, 13] scale, indicates a high degree of relationship between them. This confirms the correctness of the regression model construction and its consistency with the fundamental analytical dependence.

In view of the above, it can be stated that the results presented in Figures 2(a) and 2(b) confirm the effectiveness of the applied modeling approach, demonstrate the reliability of the obtained equations for describing the process of achieving the specified homogeneity, and provide a basis for further optimization of mixing parameters.

Conclusions. As a result of the conducted experimental studies, quantitative patterns describing the influence of the operating parameters of a vibratory mixer on the homogeneity coefficient of a feed mixture were established. A statistically justified second-order regression model was developed, which adequately describes the mixing process and can be used for engineering calculations and prediction of mixture quality.

It was determined that the rotational speed of the paddle shaft has the greatest influence on homogeneity formation, which is explained by the predominance of the shear mixing mechanism over bulk material movement. The container rotational speed and the vibration mode coefficient have an additional but significant influence on process efficiency.

Rational operating modes of the mixer were identified, under which the homogeneity coefficient reaches δ = 0.932 at a paddle shaft rotational speed of 40.9 min^{-1} and a container rotational speed of 23.9 min^{-1}. At minimum parameter values, the homogeneity decreases to δ = 0.851, which is insufficient from a technological standpoint. An effective operating region was established within which the technologically required homogeneity level δ ≥ 0.9 is ensured.

An analytical dependence of the mixing duration $t_{0.9}$ required to achieve the specified homogeneity level on the main operating parameters of the mixer was obtained. This makes it possible to determine the rational duration of the mixing cycle and creates the basis for the development of process control algorithms.

Comparison of experimental and calculated data showed a high level of agreement (correlation coefficient 0.87), confirming the adequacy of the developed mathematical model and the possibility of its application for optimization of vibratory feed mixing parameters with consideration of technological and energy criteria.

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ВИЗНАЧЕННЯ ЗАЛЕЖНОСТІ КОЕФІЦІЄНТА ОДНОРІДНОСТІ КОРМОВОЇ СУМІШІ ВІД РЕЖИМНИХ ПАРАМЕТРІВ ВІБРАЦІЙНОГО ЗМІШУВАЧА

У статті досліджено вплив режимних параметрів вібраційного змішувача на формування однорідності кормової суміші та встановлено кількісні закономірності зміни *коефіцієнта однорідності залежно від кінематичних і вібраційних характеристик процесу. Актуальність роботи зумовлена необхідністю забезпечення високої якості кормових сумішей за мінімальних витрат часу та енергії, оскільки однорідність компонентного складу безпосередньо впливає на ефективність годівлі та економічні показники виробництва продукції тваринництва. Метою дослідження є встановлення статистично обґрунтованої багатофакторної залежності коефіцієнта однорідності від режимних параметрів вібраційного змішувача та визначення раціональних режимів його роботи.*

Експериментальні дослідження проведено з використанням методу повнофакторного експерименту з варіюванням частоти обертання лопатевого валу, частоти обертання контейнера, коефіцієнта режиму вібрації та тривалості змішування. На основі обробки експериментальних даних побудовано регресійну модель другого порядку, що описує зміну коефіцієнта однорідності суміші. Статистичну значущість параметрів моделі оцінено за критерієм Стьюдента, а її адекватність – за критерієм Фішера при довірчій імовірності 0,95.

За результатами моделювання визначено раціональні режими роботи змішувача, при яких коефіцієнт однорідності досягає значення $\delta = 0,932$ при частоті обертання лопатевого валу 40,9 хв$^{-1}$ і частоті обертання контейнера 23,9 хв$^{-1}$. Мінімальне значення показника $\delta = 0,851$ спостерігається при низьких значеннях режимних параметрів. Встановлено область ефективних режимів, у межах якої забезпечується технологічно достатній рівень однорідності $\delta \geq 0,9$. Отримано аналітичну залежність тривалості змішування $t_{0,9}$, необхідної для досягнення заданого рівня однорідності, що дозволяє прогнозувати параметри процесу та здійснювати його оптимізацію. Коефіцієнт кореляції між експериментальними та розрахунковими даними становить 0,87, що підтверджує адекватність розробленої математичної моделі.

Ключові слова: *вібраційний змішувач, кормова суміш, однорідність, режимні параметри, математичне моделювання, оптимізація.*

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