Updating the Matrix Approach to Creating a Parametric Balance of Technological Process

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Abstract. Currently, the feed industry uses a large number of different types of feed mixers. The preparation of feed mixtures with different ingredients, with frequently changing compositions, must comply with such condition as uniformity. Basically, any prepared multicomponent mass should be distributed uniformly throughout the volume of each recipe element. The mixtures homogeneity can be achieved by using various equipment, which, unfortunately, is not always efficient and cost-effective. The selection of a technological line from equipment that provides a low-cost production cycle is a very time-consuming task, since the use of an experimental base of changing types of mixing machines implies unforeseen economic expenditures. Often when starting a certain production cycle of dry or wet mixtures, a preliminary forecast of the process effectiveness which can be achieved by creating a mathematical model of mixing is needed. All kinds of technological units designs, their geometric components classification, physico-mechanical and rheological indicators, operating-kinematic characteristics of the process can be used in the mathematical model. Having studied the mixing process we came to the conclusion that a high degree of mixing uniformity can be obtained with the same geometric particle sizes. But such a phenomenon is quite rare. Thus, an ideal mixture can be obtained by forcibly selecting process parameters. The effectiveness of this process can be based on a matrix approach. The process matrix will contain the dominant most significant indicators which have interconnections in the intermatrix space that create a certain parametric balance. It is advisable to divide the mathematical interpretation of the homogeneous feed mixtures creating process into several stages:
- the first stage includes loading into the software model of the characteristics displaying the specific features of the process in question;
- the second stage includes empirical patterns description;
- the third stage creates an opportunity for searching for optimal tasks solutions.

When studying the graphical dependences of the influence of process parameters on the output of quality energy indicators, the optimal solutions region is determined, each point of which allows to effectively carry out the mixing process in a screw-blade mixer.
1. Introduction
Due to the existing circumstances, the degradation of the industrial production of bulk feed mixtures there is a switch to small farms which are more mobile. Accordingly, they need the most cost effective equipment package including less energy-intensive next generation mixers capable of carrying a multifunctional load depending on changing demands.

Mixing in this type of mixers is more efficient only due to the possibility to control the process duration while changing the formulation and most accurately metering the components. Thus, they are widely used in the feed industry as well as on livestock farms.

For this, it is necessary to theoretically justify the modes and simulate the mixing process, to predict the mixers’ structural elements destruction assessing the operational risk.

2. Theoretical part
To determine the optimal mode of mixing mathematical methods which are a set of dependencies between the characteristics of the process being studied which allow us to draw certain conclusions and predict the development and the result of the process as a whole are used in the process under consideration.

In the study of the process taking place in screw-blade mixers, we use the decomposition method, which is based on the matrix approach and which allows to develop the structure of a mathematical model (Fig. 1).

![Diagram of mixture preparation process](image)

Figure 1. Parametric matrix of mixture preparation process.

According to the parametric matrix, to describe the mixture preparation process it is necessary to select the most significant parameters that determine the positive outcome of the process. Physico-mechanical and rheological indicators include:

- bulk density ($\rho_n$) of the test mixture
  $$\rho_n=0.26\rho_1+0.12\rho_2+0.1\rho_3+0.27\rho_4+0.1\rho_5+0.15\rho_6$$
  (2.1)

  where $\rho_1$, $\rho_2$, $\rho_3$, $\rho_5$, $\rho_6$ – bulk density of barley, oats, wheat, corn, rape; $\rho_4$ – bulk density of the combined component, including $\rho_{\text{m}}, \rho_{\text{mk}}, \rho_{\text{c}}, \rho_{\text{pr}}$ – bulk density of meal, molasses, monocalcium phosphate, salt, premix;
- humidity ($W$)
  $$W = \frac{m_b - m_c}{m_b}$$
  (2.2)

  where $m_b$ and $m_c$ - wet weight and dry weight;
- rigidity ($Y$)
\[ Y = \frac{\sum_{i=1}^{n} Y_i}{n} \quad (2.3) \]

where \( Y_i \) – the result of determining the stiffness index of the granular mixture in the \( i \)-th sample, \( n \) - is the number of samples;

\[ \tau = \tau_1 = \frac{Q_{spol}}{F} \quad (2.4) \]

where \( F \) - shift (G);

Structural and technological indicators include:
- mixing chamber working volume, \( \left( V_{cm} \right) \)
- working chamber filling factor \( \left( \frac{V_{cm}}{V_{n}} \right) \)

\[ K_z = \frac{V_{cm}}{V_{max}} \quad (2.5) \]

where \( V_{cm} \) – working volume of the mixing chamber, \( K_z \) – chamber loading factor, \( V_{n} \) – nozzle volume including the sum of volumes \( V_i \), \( V_{hn} \), \( V_{ct} \) - i.e. respectively, volumes of the blade, screw, rods;

\[ V_{max} \]

Structural and technological indicators include:
- angle of blades rotation (\( \varphi \));
- rotation velocity (\( \nu \));
- mixing time (T) c.

The complex of regime-kinematic indicators are:
- angle of blades rotation (\( \varphi \));
- rotation velocity (\( \nu \));
- mixing time (T) c.

The energy intensity of the process can be calculated as follows:

\[ E = \frac{N}{m} \cdot \left( L_h \cdot g \cdot \rho_n \cdot \left( \frac{K_{V_{cm,c}}}{T} + \frac{\pi D^2 n \cdot \nu \cdot S_o}{4} \right) + 8 \cdot \varepsilon \cdot \pi^4 \cdot \rho_n \cdot \nu^3 \cdot [a \cdot \sum_{i=1}^{n} H_i + \left( L^2 - l^2 \right)] \cdot \left( \sum_{i=1}^{n} r_i + R \right)^3 \right) \cdot \left( \Delta c \right) \]  

\[ \sum_{i=1}^{n} \left( c_i - c \right)^2 \right] \), (Dj/kg)  

(2.8)

According to the parametric matrix structure, the quality of loose and wet feed mixtures is expressed by homogeneity degree \( M \), determined by the formula:

\[ M = 100 \left( 1 - \frac{1}{\Delta c} \sqrt[2]{\sum_{i=1}^{n} \left( c_i - c \right)^2} \right) \]  

(2.9)

where \( n \) – number of samples taken, \( c_i \) – the amount of the control component in the \( i \)-th sample (component mass, g, or its concentration, %).

3. Results of experimental studies

Figure 2 shows the obtained dependences of energy intensity on mixing time. Empirical, graphical constructions demonstrate the advisability of conducting the mixing process in a certain range of indicators that respond to the mixture stiffness, its moisture, as well as design features associated with the rotation of the blades of the mixing apparatus.
The most significant mixer operating mode indicators are the rotation frequency of its blades and the angle of rotation of the blades relative to each other. These indicators directly affect the quality of the prepared mixture. The dependences of the degree of homogeneity of the mixture $M\%$ on the rotation frequency $\nu$ at blades rotation angle $\phi = 345^\circ$ shown in Fig. 3, indicate an increase in the quality of the mixture with an increase in the frequency of rotation of the blades. The quality growth is visible to a certain value, after which the process stabilizes and the expediency of its continuation is lost because uniformity practically does not change and further process management leads to an increase in energy costs.

Checking the adequacy of the developed matrix of the technological process is carried out in a traditional way, e.g., using the Fisher criterion.

$$M=28233.37V_{ek} - 7.186765(E-02)\phi - 3.357468(E-02)\rho_n - 1.736908W - 5.265113K - 5.588221(E-05)G + 69.81744K + 7.479701v + 0.1926816t - 1226092V + 2.094389(E-04)\phi^2 + 4.741984(E-12)G^2\rho_n + 145.6274V_{ek}K - 4.579373(E-08)t^3 - 39.24084$$

Figure 2. The dependence of energy intensity on mixing time.

Figure 3. Dependence of the homogeneity degree of the mixture $M$ on the rotation frequency $\nu$ at blades rotation angle $\phi = 345^\circ$. 

Ob/с
4. Conclusions
As a result of using the proposed dependences of the output quality-energy parameters on the physicomechanical, rheological, structural-technological and regime-kinematic parameters, the necessary process mode that meets the requirements of the finished product, which allows to reduce its energy consumption is selected.

Based on the results of the experimental data, the optimal solutions domain is determined, each point of which allows to efficiently carry out the mixing process in a screw-blade mixer.

Thus, the proposed matrix approach allows one to adequately describe the mixing process in screw-blade mixers as well as determines the effect of the selected process parameters on the output quality-energy parameters.

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