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ANALYTIC DETERMINATION OF THE ENERGY CAPACITY OF THE MIXING FORMATION IN THE STEP-TYPE MIXER

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Abstract

The analysis of mixing devices for the preparation of dry mixtures and technological lines used for this determines the process of formation of mixtures as the interaction of metering and mixing devices. One of the effective options for mixing is step mixing. As a result of the analysis of the process, we clarified the operational sequence of actions for stepwise mixing of material, taking into account the activities of not only the mixer, but already taking into account the entire mixing unit, i.e. during the interaction of the mixer and the multicomponent batcher. The components of the energy intensity of mixture formation are clarified. The operational sequence diagram for the stepwise preparation of dry mixes is analytically determined. It made it possible to establish the dependences of the total work on the preparation of the mixture, carried out by the mixing unit as part of a multicomponent batcher and mixer, mixer performance, the duration of individual cycles and the entire cycle of the mixer.

***Key words**: mixing devices, mixture formation, multicomponent batcher.*

INTRODUCTION

The economic efficiency of animal husbandry requires high productivity of farm animals. To solve this problem animals are provided with the necessary nutrients. For this purpose, an animal feeding ration is developed taking into account their species, age and productivity. According to the recipe given to the animal feed, feed mixtures should be prepared in such a way. For the preparation of mixtures, mixers of different designs and with different working parts are used. For liquids, it is possible to use circulation mixers (Habchi et al., 2018; Soni et al., 2019; Yaraghi et al., 2018). However, they are problematic for bulk mixtures used in the concentrated type of animal feeding. Drum mixers with a rotating container prepare bulk mixtures with low energy consumption, however, it is difficult to evenly distribute all components throughout the entire volume of the cooked (Teryushkov et al., 2019; Li et al., 2017). Mixers with a working auger require more energy, but a better mix is possible (Emeljanova et al., 2018; Celik et al., 2019). Paddle mixers spend a little more energy they are able to prepare a uniform mixture (Ebrahimi et al., 2018; Chupshev et al., 2019). The reduction of energy consumption for the preparation of the mixture is realized by improving the design of the mixer, as well as improving the process (Fomina et al., 2016). For example, using stepwise mixing in an increasing volume of material being mixed.

To determine the energy intensity of mixing by a batch mixer of a step type with 4 mixing stages E (J/kg) it was proposed to use the formula (Chupshev et al., 2018):

$$E = \frac{\sum A_{j,i}}{M} = \frac{\sum_i [P_{j,i} \cdot Txx_j + P_{j,i} \cdot Tz_j/2 + P_{j,i} \cdot Tx_j + P_{j,i} \cdot Tc_i + P_{j,i} \cdot Tv_j/2]}{M}$$

$A_{j,i}$ – work spent on performing j-x operations in the i-x capacity, J; M is the mass of the prepared portion of the mixture, kg; Txx_j - idle movement time of the working body (j = 1), s; Tz_j, Tv_j - the duration of the loading of components (j = 2) and unloading of the finished mixture in the i capacity (j = 5), s; Tx_j, Tc_i - the duration of idle mixing (before applying the controlled component, /j=3/) and working mixing (j = 4), s; $P_{j,I}$ is the power required to drive the working body in the i capacity during the j operation, W.

In the technology of operation of stepwise batch mixers was proposed, which reduces energy costs by preparing the mixture at the preliminary stages of mixing to a uniformity of 80%, and only at the last stage (k) of mixing is the main mixing ensured that the quality of the mixture is maintained according to technological (zootechnical) requirements - 90 or 95% (Konovalov et al., 2015).

Therefore, studies were carried out to reduce the number of mixer capacities and to determine the energy intensity of stepwise mixing in the minimum number of capacities.

The purpose of the research is to justify the expression of the energy intensity of stepwise mixing with a minimum number of capacities of the mixing device with the definition of the expressions necessary for calculation.

MATERIALS AND METHODS

The research methodology provided an analytical justification for expressing the energy intensity of stepwise mixing with a minimum number of mixing containers based on known theoretical expressions, as well as the establishment of missing functions. Parameters that could not be found analytically were determined experimentally. For this, 4 mixer tanks were used with the corresponding proportional to the working bodies. The influence of the duration of mixing of the components (from 0.5 to 15 minutes) was studied with a change in the proportion of the laid control component from 1 to 10%. The number of samples weighing 100 g with each measurement - 20 pcs with three iterations.

A previous review analysis made it possible to establish a list of the required calculated indicators. Using literary sources, we define the necessary expressions.

The duration of the loading of components (s) in the capacity of the mixer is determined:

$$T_Z = {M_{i,n}}/{Q_n},$$

Q_k – productivity of the nth dosing device, kg/s; $M_{i,k}$ is the mass of the *n*th component loaded into the *i* capacity, kg.

$$M_n = M \cdot d_{k_n},$$

d_{kn} – the proportion of the *n*th component according to the recipe of the mixture (Konovalov et al., 2015).

The discharge time of the mixture can be determined on the basis of data. If the mass of the mixture components *M* (kg) is loaded in the mixer with a diameter of *D* (m), then the height of the feed in the mixer will be *H* (m). In this case, the coordinate of the position of the center of gravity of the X_C of the radial elementary sector at the time *t* of rotation of some mixer blade rotating on the shaft 4 around the vertical axis of the vertical cylindrical tank 2, relative to the beginning of the discharge hole 1 on its side surface (at which *t*=0), m, will be determined relative to the axis of rotation:

$$X_C = C_1 \cdot e^{\lambda_1 \cdot to} + C_2 \cdot e^{\lambda_2 \cdot to} + \frac{g \cdot f_1 \cdot H}{\omega^2 \cdot S_l},$$

g – acceleration of gravity, m/s^2; *f* is the coefficient of friction; ω - angular speed of rotation of the mixer, rad/s; S_l is the height of the discharge opening, m (Konovalov et. al., 2014).

When unloading materials, the sector shifts in the radial direction have no time to be filled up. Radial sectors constitute in total the entire surface of the bottom of the mixing tank.

The radial velocity of the center of gravity of the radial sector will be a function of the rotation time of the blade (Figure 1) (respectively, the location of the blade relative to the beginning of the discharge hole), m/s (Konovalov et. al., 2014):

$$\vartheta = \dot{X}_C = C_1 \cdot \lambda_1 \cdot e^{\lambda_1 \cdot t} + C_2 \cdot \lambda_2 \cdot e^{\lambda_2 \cdot t},$$

The supply of material through the discharge opening in the form of a rectangular slit is determined, kg/s

$$Q = Q_V \cdot \rho = (S_l \cdot S_O \cdot \vartheta_{cp}) \cdot \rho$$

$$\text{or} \quad Q = S_l \cdot S_O \cdot \rho \cdot \frac{\sum_i \vartheta_i}{N_i},$$

S_O – discharge hole width, m; ϑ_{cp} - average speed of material exit from the mixer through the discharge hole in the radial direction, m/s; ϑ_i is the speed of material exit from the mixer in the radial direction on the *i* section, m/s; N_i - the number of i-x sections of the discharge opening, pcs; ρ is the density of the heap of material in the mixing tank during operation of the mixer, kg/m^3.

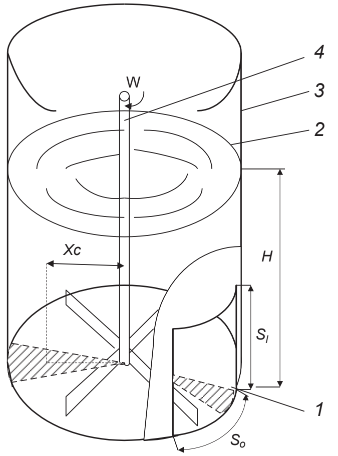

Figure 1. Layout of dimensions when unloading materials from the mixer tank: 1 - discharge hole; 2 - top layer of material; 3 - mixer capacity; 4 - rotating shaft with a mixer

During unloading, for an infinitely short time ΔT, the feed mass M_I (kg) and the mixture volume V_I (m3) are unloaded from the mixer:

$$M_I=\Delta T\cdot Q. \qquad V_I=M_I/\rho$$

Power when the stirrer is moving in the *i* capacity with a diameter of D_i is written, W:

$$P_i = \mathrm{K}_1\cdot\sigma_i\cdot \mathrm{Z}\cdot\left(\frac{D_i}{2}\right)^3\cdot\sin(\alpha)\cdot\omega/6$$

K_I is the coefficient of proportionality of the width of the blade and the diameter of the tank; Z - the number of blades, pcs; α - angle of attack when installing the blades, rad; σ - stresses in the mixture during blade motion at K_I = D/6:

$$\sigma = 10125{,}86\cdot \mathrm{M}\cdot \mathrm{D}^{-4}\cdot \mathrm{n}^{-0{,}185863}\cdot \mathrm{Z}^{-0{,}606518}\cdot\sin(\alpha)^{-0{,}653631}\cdot \mathrm{L}^{0{,}962341}$$

L – blade length, m.
The mixing time of the components in general will be determined with

$$T_C = -\frac{1}{k}\ln\frac{(1\text{-}\Theta_K)}{(1\text{-}\Theta_H)}$$

k – empirical mixing intensity factor for a particular mixer); Θ_H, Θ_K - initial and final uniformity of the mixture, 0.01% (Chupshev et al., 2018).
According to a number of researchers, mixers have a limitation on the use of the minimum proportion of the control component (Konovalov et al., 2013). The number of mixing steps is determined from the condition:

$$k \geq \log_{(1/d_{kz})}(1/d_{k_{min}})$$

d*kz* - minimum proportion of the control component, less than which the mixer does not ensure the quality of the prepared mixture; $d_{k_{min}}$ is the fraction of the smaller component in the mixture.

RESULTS AND DISCUSSIONS

Analysis of the design of the mixer for step mixing indicates the need to simplify its design in the direction of reducing the number of tanks and increasing the efficiency of their use.
In the conditions of agricultural production in Russia, half of the feed is produced at the feed mill, and half - in the conditions of farms from their own fodder and purchased additives. Either premix (1-2% by weight of feed, i.e. $d_{k_{min1}} = 0.01$ - the proportion of the smaller component 1% in the mixture), or protein-vitamin supplements (10-20% by weight of feed, i.e. $d_{k_{min2}} = 0.1$).
As a result of experimental studies of the influence of the fraction of the controlled component D_k and the duration of mixing T, the calculated values of the coefficient of variation of the content of the control component in the samples are established. The expressions of the non-uniformity of the mixture ν are obtained for the corresponding volume of the mixing tank V_o (Figure 2):- при V_o= 0,5 liters:

$\nu_{0.5}$=–1.469+4.53/Dk+4.18/T–1.26/Dk·T+1,1·(1–1.8/Dk·T); R=0.921;

V_o= 2,5 liters:
$\nu_{2.5}$=0.185+5.38/Dk+3.124/T–0.98/Dk·T+0,85·(1+3.08/Dk·T); R=0.92846;

V_o= 9 liters:
ν_9=0.029+6.14/Dk+2.87/T–1.22/Dk·T+0.64·(1+3.48/Dk·T); R=0.95359;

V_o= 30 liters:
ν_{30}=2.336+4.19/Dk+0.356/T–

3.146/Dk·T+1.69·(1+4.95/Dk·T); R=0.963
R – values of the Pearson correlation coefficient.

When the proportion of the controlled component is more than 1.5%, the mixing time is sufficient T = 1.5 ... 2.0 minutes, while achieving a coefficient of variation of 5 ... 9% (Figure 3). Better mixing quality with lower mixing chamber volumes. When the proportion of the controlled component is 0.5 and 1.0% after T = 15 minutes of mixing, the quality of the mixture for containers is achieved, respectively: V_o = 30 l - ν = 14.1 and 5.9%; V_o = 9 l - ν = 13.8 and 5.0%; V_o = 2.5 l - ν = 11.0, and 5.5% at T = 10 and 5 min; V_o = 0.5 L - ν = 8.6 and 4.8% at T = 4.5 and 1.6 min.

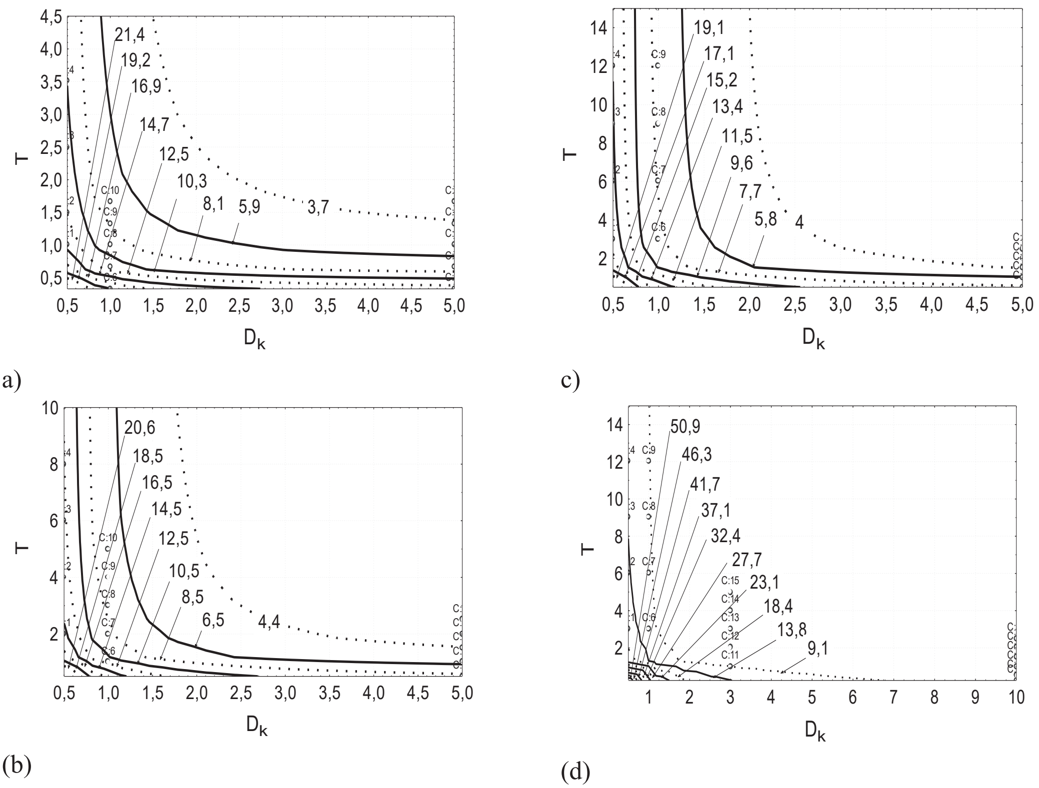

Figure 2. Effect of the duration of the mixed T (min) and accounting for the controlled component $_{Dk}$ (%) in the volume of the mixing tank V_o on the uneven mixture ν (%):
(a) - at V_o = 0.5 L.; (b) - at V_o = 2.5 l; (c) - at V_o = 9 l; (d) - at V_o = 30 l

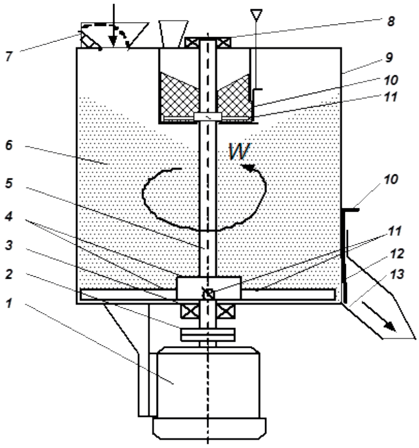

Figure 3. Scheme of a two-staged dry materials mixer: 1– electric motor; 2– coupling; 3– lower bearing support; bunker operational stock of components; 4 - paddle mixer; 5– shaft; 6– mixed material; 7– loading neck; 8– upper bearing support; 9– mixing chamber (capacity); 10– gate; 11– blades; 12– discharge hole; 13– unloading tray

An analysis of the graphs (taking into account real experimental values) shows that when the proportion of the controlled component is more than 1.5-2.0% and the mixture is uneven 10%, the mixing time is T = 1.5-2 min, for ν≤5% - T = 2-5 min. In small containers (2.5 L or less) mixing can be reduced to T = 0.5 ... 1.0 min. When the proportion of the controlled component is 1% and ν≤10%, the mixing time is not less than: for V_o = 0.5 L - 1.0 min; for V_o = 2.5 l - 1.5 min; for V_o = 9.0 l - 2.5 min; for V_o = 30 l - 3.0 min. When the proportion of the controlled component is 1% and ν≤5%, the mixing time is not less than: for V_o = 0.5 L - 1.6 min; for V_o = 2.5 l - 5.0 min; for V_o = 9.0 l - 12.0 min; for V_o = 30 liters - 15 min. If the proportion of the control component is 8%, the mixing time is about 10 minutes (ν≤5%; and 2.2 minutes - ν≤10%). Increasing the mixing time is not economically feasible, therefore, the maximum minimum proportion of the control component, less than which the mixer does not ensure the quality of the prepared mixture: $d_{kz} = 0.08$.

The required number of mixing steps is defined as the logarithm $\left(\frac{1}{d_{kz}}\right) = \frac{1}{0.08} = 12.5$ on the basis of $\left(\frac{1}{d_{k_{min1}}}\right) = \frac{1}{0.01} = 100$, and on the basis of $(1/d_{k_{min2}}) = \frac{1}{0.10} = 10$.

The required number of mixing steps for the proposed type of working body: for preparation from premix - 2 cycles ($k_1 = 1.823{\sim}2$); for the preparation of protein and vitamin supplements - 1 cycle ($k_2 = 0.912{\sim}1$).

Accordingly, the volume of capacities will vary about 10 times.

Thus the minimum number of containers of the mixing unit for the preparation of premix-based mixtures, or when making drugs, consists of two containers of the mixer. The last option is presented in Figure 4. The order of operations: loading the initial components of the mixture in containers; mixing components.

The energy costs of preparing the mixture with two capacitive mixer (J/kg) are determined:

$$E = \frac{[A_1 + A_2]}{\Sigma M_s},$$

$$A_1 = \frac{Tz_s \cdot (P_1 + P`_2)}{2} + \cdot\, Tc_1 \cdot (P_1 + P`_2) + Tc_2 \cdot (Px_1 + P_2);$$

$$A_2 = Tv_2 \cdot \frac{(Px_1 + P_2)}{2} + Txx_j \cdot (Px_1 + Px_2),$$

$A_1 + A_2$- work spent on all operations in containers, J; ΣM_s - total mass of components of the prepared portion of the mixture, kg; Tz_s, Tv_s - duration of loading of all s-th components and unloading of the finished mixture from the 2nd tank, s; Tc_1, Tc_2 - the duration of mixing of the components in the first (1 - small) and (2 - large) capacity, s; T_{xx} - idle movement of the working body, s; Px_1, Px_2 – power required to drive the working body in the absence of mixture components, W; P_1, P_2 - power required to drive the corresponding working body when loading all components of the mixture according to the technological process, W; $P`_2$ - power required to drive a large working body when loading all components of the mixture, provided that there are no components from the small capacity of the mixer, W.

CONCLUSIONS

The analysis of mixing devices for the preparation of dry mixtures and technological lines used for this determines the process of formation of mixtures as the interaction of metering and mixing devices. One of the effective options for mixing is step mixing. As a result of the analysis of the process, we clarified the operational sequence of actions for stepwise mixing of material, taking into account the activities of not only the mixer, but already taking into account the entire mixing unit, i.e. during the interaction of the mixer and the multicomponent batcher. The components of the energy intensity of mixture formation are clarified. The operational sequence diagram for the stepwise preparation of dry mixes is analytically determined. It made it possible to establish the dependences of the total work on the preparation of the mixture, carried out by the mixing unit as part of a multicomponent batcher and mixer, mixer performance, the duration of individual cycles and the entire cycle of the mixer.

The required number of mixing steps for the proposed type of working body: for preparation from premix - 2 cycles; for the preparation of a mixture of protein-vitamin supplements - 1 cycle. Mixer tank volumes vary about 10 times.

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TECHNOLOGIES OF THE AGRO FOOD PRODUCTS PROCESSING