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Design of drum type apparatus for processing of bulk materials

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Abstract

The article presents the development and research of drum continuous mixers, most attention is paid to the results of theoretical (using of cybernetic approach) and experimental studies of longitudinal mixing particulate material in rotating drums of continuous action, the influence of internal recycles of material flows, intensifying the process of smoothing the input fluctuations. The authors analyzed the influence of internal recycles material flows, intensifying the process of smoothing the input fluctuations. The results presented in this paper were obtained by the experiments on the smoothing ability determination during which they change the frequency of the drum rotation, the location of the Γ-shaped mixer blades on the drum mixer. The article reported that the studies were conducted on three mixtures which components have different physical and mechanical systems with various dispersed liquid additives and without it.

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Keywords: *drum mixer, bulk material, longitudinal mixing, transfer functions, the L-shaped blade, recycles, smoothing ability;*

1. Introduction

Plants in which the working body is a rotating drum are used in industry and agriculture for the treatment of particulate bulk materials: grinding, mixing, drying, malting and many others.

Apparatus with a rotating drum are more reliable in operation, which is one of the determining factors when choosing the type of technological equipment[7]. Furthermore, the minimal damage of agitated particles occur. For this reason, for example, the highest quality malt is obtained in a drum type malting.

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Longitudinal mixing of particulate material has a marked influence on the performance of the rotating machine by the uneven distribution of the particle velocity and the cross-sectional surface layer of the granular mass[8].

So far, it is given insufficient attention to the study of longitudinal mixing of bulk materials, and in published papers description of the qualitative aspects of the process is prevailed[5].

This paper presents the results of theoretical (using cybernetic approach) and experimental studies of longitudinal mixing bulk material of continuously active rotating drums and analyzes the influence of internal recycles material flows intensifying the process of smoothing of the input fluctuations.

The Factors affecting the intensity of the longitudinal mixing of bulk material in a rotating drum can be divided into 3 groups:

- physical - mechanical properties of the material;
- geometrical parameters of the device (drum diameter D);
- dynamic characteristics (the angular rotation speed ω and the longitudinal linear velocity υ of particulate material).

2. Materials and Methods.

In this paper, we consider the influence of factors of the last two groups. For horizontal machines the dependence of longitudinal mixing efficiency of these quantities D_e can be written as follows:

$$D_e = f(\omega, \upsilon, D, \phi) \tag{1}$$

where D – mixer diameter, m; φ – the degree of a filling mixer.

Using the method of dimensional analysis[10], we represent the equation (1) in the form of the relationship between the dimensionless ratio made up of all of the relevant quantities.

In equation (1), the value of φ is dimensionless. In accordance with the π - theorem in this case there are only two dimensionless ratios composed of dimensional quantities:

$$\frac{D_e}{\upsilon \cdot D} = f\left(\frac{\omega \cdot D}{\upsilon}; \phi\right) \tag{2}$$

Identification of the form of equation (2) is made on the basis of analysis of experimental data when the D values of 0.12 to 0.4 m, and ω - from 1 to 12 s^{-1}. Processing of the experimental data gives the equation relating the basic parameters of the process[4,5]:

$$\frac{D_e}{\upsilon \cdot D} = k \cdot \left(\frac{\upsilon \cdot D}{\omega}\right)^{0,9} \cdot \phi^{0,25} \tag{3}$$

where $K = 0,8 \times 10^{-4}$ – for aluminosilicate catalyst particles, $K = 0.2 \times 10^{-3}$ – for crumb capron resin.

Maximum discrepancy between the experimental and calculated ?data according to equation (3) does not exceed ± 15%. Equation (3) ending is between the following:

$\omega \cdot D / \upsilon = 97 \div 1567$,
$\varphi = 8.8 \div 26.5$ %.

During the experiments in the inlet and outlet of the mixer had a non-uniformity of the particle flux was observed. Due to end effects there is more dependence of the coefficient of geometric shapes D_e of conical devices installed at the inlet and outlet of the unit. The cone was joined to the cylindrical shell with a diameter of 200 mm by means of flanges (fig. 1).

The results showed that the positioning of the inlet cones of the apparatus (b) reduces the coefficient D_e (by 30%). This can be explained by the fact that in this case, the stagnation zone at the entrance is moved into the unit and its size decreases.

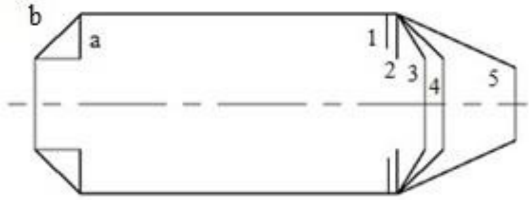

Fig. 1. Form input and output cones

The Cone of number 3, 4 installed at the outlet of the device creating a strong local mixing and ,thereby, significantly increases the coefficient D_e. For the cones with an apex angle is less than 350 (№ 5), and for the length greater than the diameter of the apparatus, the value of D_e is increased 2 fold. This is because in the output of the cone there is considerable turbulence and a portion of the effluent is discarded inside of the unit (it recycles).

Based on these data, we developed the original design of the drum continuous mixer (DCM)[1,6] with cone inserts (fig. 2), which allow you to recycle material flows.

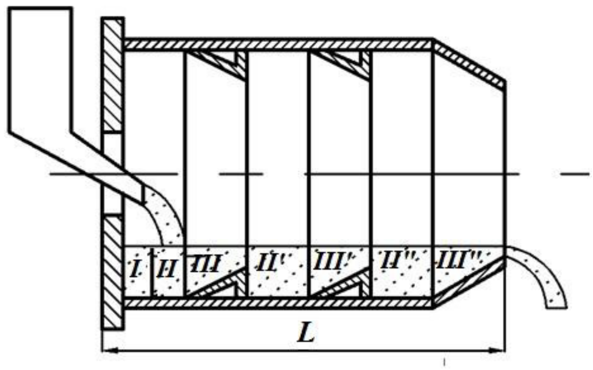

Fig. 2. Drum mixer with cone inserts

According to the nature of motion of the particulate material in the mixer, its volume can be divided into three zones:

- Stagnant which presence is due to the fact that in real devices the input of the material is at L > 0 and it is distributed;
- Diffusive mixing;
- Diffusive mixing with recirculation. In the latter, due to the conical insertion a portion of the material is recirculated in a closed circuit.

Zone II ', II ", III', III" are similar II and III. According to the defined hydrodynamics of the flow the following diagram of the process can be presented in the following way (fig. 3).

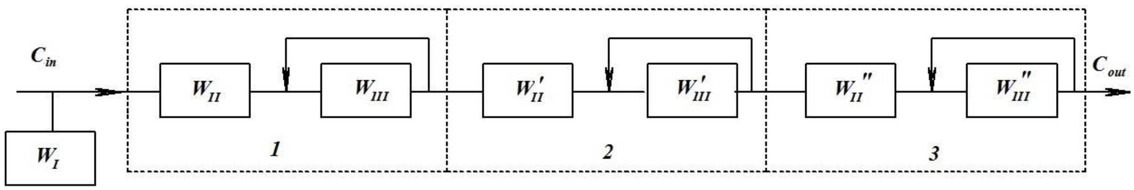

Fig. 3. Block diagram of the process in a drum with a conical DCM inserts

In accordance with this block diagram the transfer function (TF) of the mixer can be written as follows:

$$W_p = W_I \cdot W_1 \cdot W_2 \cdot W_3 \tag{4}$$

where W_I – TF of stagnant zone; $W_{1\text{-}3}$ – TF of circuits composed of diffusive mixing zones with recirculation.

Since the circuits are structured in the same way, they will be equal to TF:

$$W_1 = W_2 = W_3 = W_{II} \cdot W_{III} \tag{5}$$

where W_{II} – TF of diffusive mixing zones; W_{III} – TF of diffusive mixing zones with recycling.

It is known that the concentration change of the labeled substance in the flow area, contacting with the stagnant zone, is described by equation[6]:

$$C_{in}(t) = C_{out}(t) + B_{01} \cdot \left(\frac{\partial c}{\partial x}\right)_b \tag{6}$$

where $C_{in}(t)$ – input concentration of the labeled substance in the flow; $C_{out}(t)$ – output concentration of the labeled substance with respect to the stagnation zone;

$B_{01} = \upsilon \cdot L / D_1$ – Bodeshteyn criterion (analogue of Peclet criterion);

D_I – coefficient of longitudinal mixing in the stagnant zone (diffusion is considered to be a major mechanism of mixing in this zone);

L – length of the stagnant zone;

$(\partial c/\partial x)_b$ – the labeled substance concentration gradient at the boundary of zones.

The mixing process in the diffusion zone can be described by equation of one-dimensional diffusion of moving stream[3].

$$\frac{\partial c}{\partial t} = D_2 \cdot \frac{\partial^2 c}{\partial x^2} - \upsilon \cdot \frac{\partial c}{\partial x} \tag{7}$$

where C – current concentration of the indicator in the mixture; D_I – coefficient of longitudinal mixing in this zone; υ – flow velocity in the zone;

x – coordinate;

t – time.

The following TF of these zones were found by Laplace transformation of solutions of equations (6) and (7) a step change $C_{in}(t)$:

$$W_I = 1 \pm B_{01} \cdot \sqrt{\frac{S}{D_1}} \tag{8}$$

$$W_{II} = \frac{1}{2} \cdot e^{-(x_2 - \upsilon \cdot t) \cdot \sqrt{\frac{S}{D_2}}} \tag{9}$$

where S – complex variable.
TF of the third zone is defined as for component applied feedback:

$$W_{III} = \frac{W_{III}}{1 + \beta - \beta \cdot \overline{W_{III}} \cdot W_{III}} \tag{10}$$

$$\overline{W_{III}} = e^{-(x_3 - \upsilon \cdot t) \cdot \sqrt{\frac{S}{D_3}}} \tag{11}$$

where W_{III}, $\overline{W_{III}}$ – TF of direct and recirculation channels of the third zone; β – degree of recycle.

As can be seen from equations (8) and (11) TF of mixer depends on a large number of parameters and it is mainly determined by physical-mechanical properties of the mixed materials, the geometry of the apparatus and its mode of operation. In the first approximation we approximate the mixing process by only two zones (congestive mixing and diffusion). In this case, the transfer function of DCM will be:

$$W_p = W_I \cdot W_{II} = \left(1 - B_{01} \cdot \sqrt{\frac{S}{D_1}} \right) \cdot \frac{1}{2} \cdot e^{-(x_2 - \upsilon \cdot t) \cdot \sqrt{\frac{S}{D_2}}} \tag{12}$$

Solving the equation (12) in the real variable t, in a step input indicator, we obtain the following relationship:

$$C_{out}(t) = \frac{C_{in}(t)}{2} \cdot \left[1 - \text{erf}\left(\frac{x_2 - \upsilon \cdot t}{2\sqrt{D_2 \cdot t}} \right) - \frac{Bo_1}{2\sqrt{D_1 \cdot \pi \cdot t}} \cdot e\left(-\frac{x^2}{4 D_1 \cdot t} \right) \right] \tag{13}$$

The change in concentration of the indicator on the output from the mixer according to time can be determined by replacing the expression (13) $x = L$, :

$$C_{out}(t) = \frac{C_{in}(t)}{2} \cdot \left[1 - \text{erf}\left(\frac{L - \upsilon \cdot t}{2\sqrt{D_2 \cdot t}} \right) - \frac{Bo_1}{2\sqrt{D_1 \cdot \pi \cdot t}} \cdot e\left(-\frac{L^2}{4 D_1 \cdot t} \right) \right] \tag{14}$$

The longitudinal mixing coefficient is considered to be constant over the length of the apparatus. We introduce the dimensionless time θ, and reduce the equation (14) to the dimensionless form:

$$\frac{C_{out}(t)}{C_{in}(t)} = \frac{1}{2} \cdot \left[1 - \text{erf}\left(\frac{1 - \theta}{2\sqrt{B_{02} \cdot \theta}} \right) - \frac{B_{01}}{2\sqrt{D_1 \cdot \pi \cdot t_a \cdot \theta}} \cdot e\left(-\frac{B_{01} \cdot \theta}{4} \right) \right] \tag{15}$$

where $t_a = V/\upsilon$ – the average residence time; V – volume of material in the mixer; υ – volumetric efficiency of mixer; B_{02} – analogue Peclet number for the diffusion zone. Criteria values B_{01}, B_{02} and D coefficient are experimentally determined by the residence time distribution functions for this mixer.

Equation (15) has been tested empirically. Sand with a particle size of 0,1 ÷ 0,8 mm was used as the base material. The design of the experimental setup and data processing distribution curves were similar to those described earlier. Rectangular pulse duration of 30 s was applied as disturbing effect. The mass of the injected indicator was 200 g. Steel filings with a particle size similar to the main material was the indicator. Removing response curves was produced with analyzer.

3. Results and Discussions

The results of the experimental transition functions processing showed that TF of mixer sufficiently reflects the dynamics of the process. Particular good agreement between the experimental and theoretical transfer functions was observed at small longitudinal mixing coefficients. Error of such kind of approximation is less than 5%, on a plot of $\theta < 1.25$. The largest deviation was observed at $1.25 < \theta < 2.5$. This indicates that equation (15) describes TF of apparatus quite well. To determine TF more accurately it is necessary to take into account the effect conical inserts, which we had previously neglected.

Fig. 4 shows the experimental (solid line) and theoretical curves of the transition process with the following parameters:

$\upsilon = 8.85 \cdot 10^{-6}$ m^3/s; $\omega = 7.35$ s^{-1}; $L = 0.65$ m.
$\upsilon = 8.85 \times 10^{-6}$ m^3/s; $n = 7.16$ s^{-1}

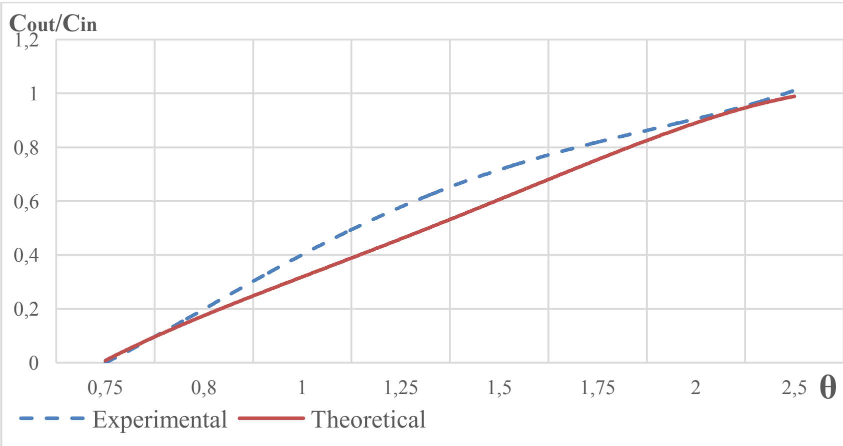

Fig.4. The distribution function of residence time in the drum with tapered inserts DCM

In the development of the idea of creation internal recycles material flows along the entire length of the drum, we proposed to use DCM original device - L-shaped blades (fig. 5), which are mounted on the shaft inside the drum and rotate with it.

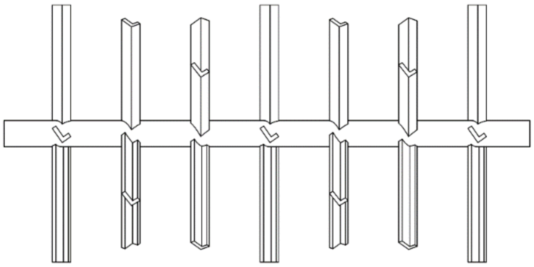

Fig.5. L-shaped blade of drum DCM

Moving to the exit of the apparatus, the primary components systematically fall on the blades of the device and these blades divert some of the flow in the opposite direction. Thus, each blade of device creates its local recycling, but in general the intensification of the mixing process occurs and the ability of smoothing DCM improves. In the improved design of DCM L - shaped blades are made as turning blades relative to each other at 360^0 and they set in a spiral or staggered order[9] that allows you to adjust the residence time of the particles mixed material inside the rotating drum.

To determine the ability of the smoothing[4] the experiments were carried out with a help of the new drum mixer. During these experiments the frequency of rotation of the drum (0.17; 0.42; 0.67 min^{-1}) and the location of the L-shaped blades of mixer (chess and spiral order) were changed. Investigations were carried out with a use of three mixtures the components of which had different physical characteristics (semolina - sugar, flour - salt, flour - milk powder).

Experiments were carried out as follows: the main component was transported as a continuous flow in a new design drum mixer. Indicator in an amount of 8-10% of the original DCM was almost instantly (no more than 2 s.) carried in the working chamber of the apparatus. Then sampling (30-50 g.) at its output was begun. According to the investigations the integral functions of residence time distribution were obtained at different speeds of drum rotation during a spiral arrangement of L-shaped blades. The integral functions of residence time distribution are shown in Fig.6.

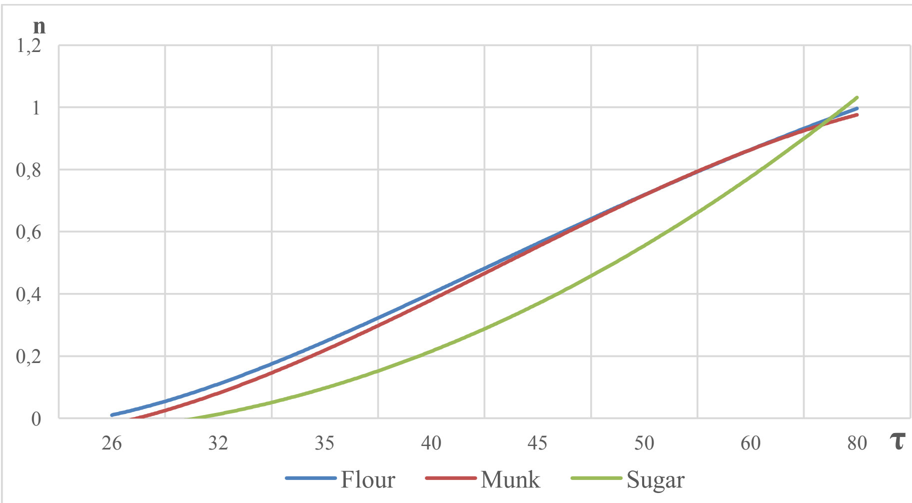

Fig. 6. Integral curves obtained at different speeds of drum rotation for semolina-sugar mixture

The values of the time constants T_1 and T_2^2 included in the transfer function of the mixer were identified by graphical method in accordance with integral curves (fig. 6). They are shown in Tables 1 and Table 2.

Table 1. Time constant values in blade spiral order

Material	n, s^{-1}	Values of time constants appearing in the transfer functions		
		T_1	T_2^2	τ
Flour	0.17	52.5	641.7	79.37
	0.42	37.5	345.31	28.125
	0.67	36.87	317.85	21.87
Semolina	0.17	10	22.26	58
	0.42	16.6	46.25	37.2
	0.67	18	60.75	27
Sugar	0.17	34.85	336.31	56.3
	0.42	39.1	381.39	27.2
	0.67	32.72	250.82	30

Table 2. - The values of time constants blade staggered order

Material	n, s^{-1}	The values of time constants appearing in the transfer functions		
		T_1	T_2^2	τ
Flour	0.17	30.625	234.375	61.875
	0.42	32.4	257.6	24.3
	0.67	63.6	997.5	20
Semolina	0.17	25.4	108.2	50.27
	0.42	25.4	90.62	28.10
	0.67	15.93	52.71	21.87
Sugar	0.17	36.75	327.11	47.56
	0.42	34.54	257.80	30.9
	0.67	42.27	444.18	32.72

From Table 1 and Table 2 we can previously conclude that the more the values of T_1 and T_2^2 are, the greater the smoothing ability of the mixer is.

TF of mixer was taken as the second link with delay intervals[3]:

$$W(S)=\frac{Kc\cdot\exp^{-\tau s}}{T_2^2 S+T_1 S+1} \tag{16}$$

where T_1 и T_2^2 – time constant of DCM; Kc – transfer coefficient of mixer; τ - delay time.

We substitute the numerical values in T_1 and T_2 in (16) and define the TF for sugar- semolina mixture with n=0.17 s^{-1}:

$$W(S)=\frac{1\cdot\exp^{-58s}}{22{,}26S+10S+1} \tag{17}$$

Smoothing capacity of the drum mixer was assessed with a help of frequency analysis[2], which allows you to assess the degree of smoothing on virtually any frequency of dosing. The results are shown in Table 3 and Table 4.

Table 3. Smoothing capacity of the drum mixer with L-shaped blades in spiral order

Smoothing capacity, S			
n. s^{-1}	semolina-sugar	flour-salt	flour-powder milk
0.17	280020	394700	343000
0.42	580200	238000	231000
0.67	760400	219600	216000

Table 4. Smoothing capacity of the drum mixer at the location of the L-shaped blades in quincunx

Smoothing capacity, S			
n. s^{-1}	semolina-sugar	flour-salt	flour-powder milk
0.17	137400	161400	93300
0.42	115100	177400	102000
0.67	670100	310400	247000

4. Conclusions

The data obtained show that the smoothing ability for materials with various physical and mechanical properties is different. It is impossible to tell definitely that *S* increases or decreases with an increase of speed, since there is a different frequency for various mixtures.

The layout of L-shaped blades, the angle of rotation of each other, and the frequency of rotation of the drum should be chosen depending on the physical and mechanical properties of materials to produce a mixture of specified quality.

In conclusion, it should be noted that to produce a loose material mixture of specified quality with a ratio of blending components from 1/10 to 1/50 it is reasonable to use a new type of drum mixer in which there is ability to regulate the storage unit due to the possibility of installing L-shaped blades in spiral or staggered order.

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