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ORGANIZATION OF MIXING PROCESS OF GRANULAR MATERIALS WITH PORTION DOSAGE OF SOME COMPONENTS

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Abstract: The earlier suggested method of mixing process organization of segregating particulate solids is developed to improve its dynamics characteristics. The dynamics of a continuous mixing process with portionsdelivery of some components and operation of their segregated flows is studied experimentally and analytically on the basis of a drummer apparatus. It was found out that the efficiency of the suggested method increases sufficiently if a buffer mass of these components is allocated in the head apparatus part.

Symbols

c_j – test component concentration, kg·kg^{-1};
c_{j1} – test component concentration in the buffer mass, kg·kg^{-1};
D_{dif} – quasi-diffusion coefficient, m^2·s^{-1};
$G(z)$, $G_0(z)$ – technological and conventionally reverse mixture fluxes in the drum respectively, kg·s^{-1};
I_B^-, I_{vB}^+, I_{vO}^+ – function modeling the exhausting, delaying and operation actions of the lifting blades, respectively, kg·m^{-3}·s^{-1};
L – drum length, m;
m_{b} – buffer mass, kg;
$S(z)$ – cross section area of a heap in the drum, m^2;
T – dosage period, s;
z – longitudinal coordinate, m;
ρ_{b} – bulk density, kg·m^{-3};
τ, τ_{d} – current and dosage time respectively, s.

The continuous mixture preparation of particulate solids with portions delivery of some components is rather complicated technological problem. This problem arises, for example, when precision micro dosage needs for some components having high inclination to segregation.

In our previous paper [1] we suggested the method of the continuous mixing process organization by means of the segregated flow operation. The method consists in the impulse influences on the segregated flow, concentrating the portions delivery components, to the opposite direction of the technological flux. This influence leads to the component concentration increase in the charging mixer part. As a result, this action provides the buffer mass increase of the component having high dosage non-uniformity, in the apparatus and improves selectively its smooth ability relatively to this component.

In the work [1] the suggest method was realized on the basis of apparatus having rotating drum with peripheral lifting blades. It was found out, that there are significant segregated flows in the bed of particles falling from the blades. Mainly this bed consists of small and dense particles in the drum area under rising blades and large or light particles-under sinking blades [2].

The control over the segregated flows in this apparatus is carried out by means of selective impulse influence on these falling particle flows transversally to their direction. Due to this operation the suitable hydrodynamical conditions may be served in the apparatus for effective treatment of particulate solids by mixing and separation methods in the course of hydro mechanical and heat-mass transfer process organization [3].

In the work [1] an experimental and analytical research on the flow structure characteristics in the drummer apparatus with peripheral lifting blades was performed. The mathematical model allowing to forecast the structure characteristics of the operated segregated flows during the suggested method realization was developed.

The dynamics equation of the longitudinal distribution of test component $c_j(z, \tau)$ was described [2] in the following way

$$S(z)\rho_b(z)\frac{\partial c_j(z,\tau)}{\partial \tau} = -\frac{\partial\big(c_j(z,\tau)(G(z)-G_0(z))\big)}{\partial z} + D_{\text{dif}}\frac{\partial}{\partial z}\left(\rho_b(z)S(z)\frac{\partial c_j(z,\tau)}{\partial z}\right) + S(z)\big(I_B^- + I_{vB}^+ + I_{vO}^+\big). \tag{1}$$

This equation was integrated numerically at the boundary and initial conditions, which were formulated as follows:

$$\begin{cases} \partial c_j / \partial z = 0, \ z = 0, L; \\ c_j(0,\tau) = c_{j1}, \ \text{at} \ kT < \tau \le kT + \tau_d; \\ c_j(0,\tau) = 0, \ \text{at} \ kT + \tau_d < \tau \le (k+1)T; \end{cases} \tag{2}$$

$$c_j(z,0) = 0, \tag{3}$$

where $k = 0, 1, 2, 3, \ldots, \infty$ is the component dose number.

The investigation was carried out on the basis of the experimental unit [3] having the rotating drum with peripheral lifting blades which shaped as Γ-form. The nozzle is mounted motionless from the rotating drum thus central part to operate the segregated flows of falling particles. The nozzle was performed as a longitudinal row of deflecting elements. The elements were made in the form of funnels having inclined discharge channels directed opposite to the technological flux. The control over the impulse influence on the segregated flows had been realizing by means of a transversal movement of the nozzle and the inclination angle changing of an inclined plate mounted above the funnels.

The modeling granular materials were selected taking into consideration their particle size and density to complicate the mixing process organization. Therefore, the polypropylene granules of fraction (+ 3.0 – 4.0)$\cdot 10^{-3}$ m, were used as the mixture basis and the clayite (expanded clay) granules of fraction (+ 4.0 – 5.0)$\cdot 10^{-3}$ m were applied as the portion dosed component. The bulk density of the above mentioned materials was equal to 605 kg$\cdot$m^{-3} and 515 kg$\cdot$m^{-3} respectively.

The mathematical model adequacy and the suggested method efficiency were checked experimentally by the indicator method. The indicator method is realized at simultaneous input of indicators both of the mixture components to estimate more accurately the impulse influence on the selective smooth ability and longitudinal mixing of apparatus.

During the experiment the nozzle with deflecting elements was removed into the drum area situated under the sinking blades. This area is characterized by the higher concentration of the portions delivery component that allowed us to provide the reverse

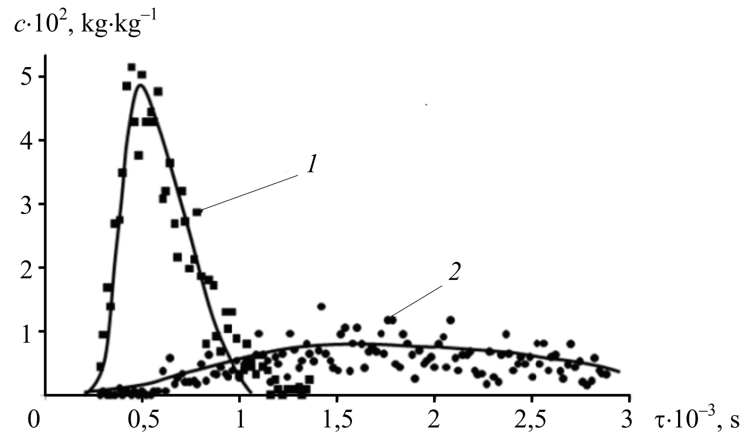

Fig. 1. RTD of the polypropylene (*1*) and clayite (*2*) granules in the apparatus operating the segregated flows at the reverse impulse influence on the flow area, enriched by clayite granules:
point – experimental; lines – calculated

impulse influence on the technological flux of this component. The indicators were putting into the apparatus during the steady state of the technological flux. All the experiments were repeated three times to increase their accuracy and to verity the statistical uniformity of experimental and calculated results.

The investigation results, shown on Fig. 1, reveals the adequacy of the experimental and calculated functions of the residence time distribution (**RTD**).

The analysis of the flow structure characteristics of the mixture components (Fig. 1) allowed us to conclude that the reverse impulse influence on the segregated flow, enriched by the tested component, leads to the selective increase of the smooth function and the mixing intensity relatively to this component. Moreover these results testify indirectly to the high efficiency of the suggested mixing method.

The developed mathematical model after its adequacy checking was used for a computational dynamics modeling the continuous mixing process for the polypropylene and clayite granules, when the mixture microcomponent (clayite granules) was dosed portions by a weight method. The mixing process organization had been conformed to the suggested method.

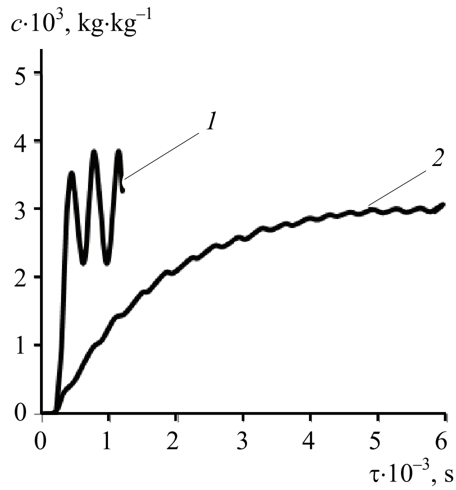

Fig. 2. Process dynamics modeling the binary mixture formation with the portions dosing one of the components:
1 – without any segregated flow control;
2 – with the segregated flow operation

Fig. 2 shows the computational modeling results of the mixture formation dynamics, when the mixing process goes to its steady state, for the different variants of process organization:

– without any segregated flow operation (curve *1*);

– with the reverse impulse influence on the segregated flow, enriched by the micro component (curve *2*).

The portion dosage modeling was carried out at the dosing period $T = 350$ s, and the dose supply duration $\tau_d = 3$ s.

The obtained results (Fig. 2) reveals that the suggested mixing method allows to increase the mixture quality with the variation coefficient decrease more than 40 times. However, the mixture quality increase is achieved at the essential rise of the non steady state period.

The unfavorable process dynamics is explained by the high period duration of the buffer mass accumulation of the portions delivery component in the apparatus working volume. This conclusion is confirmed by investigation results of the dynamics distribution of the tested component $c_j(z, t)$ along the drum length (Fig. 3). The investigation, carried out by the method of computational modeling on the basis of eq. (1) – (2), shows that a gradual accumulation increase of the test component takes place in the apparatus when the mixing process goes to its steady state. Thereby, the mean component concentration in the apparatus working volume exceeds its nominal concentration in the mixture more than twice when the steady state takes shape (Fig. 3).

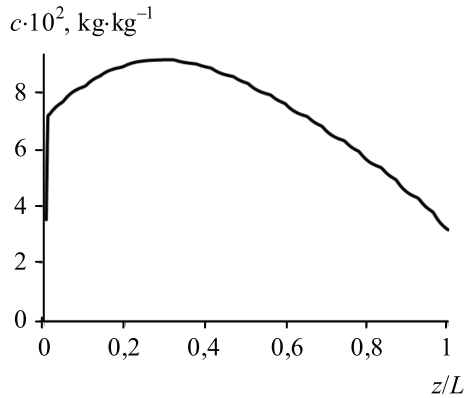

Fig. 3. Modeling results of the concentration distribution of the portions delivery component (clayite granules) along the drum length in the mixing process steady state

In order to improve the dynamics characteristics of the suggested method of the mixing process organization its modernization was carried out. This modernization consists in the buffer mass placing of the portion component in advance in the head apparatus part to accelerate the steady state coming. The buffer mass m_b may be determined on the basis of the modeling results of the test component distribution along the drum length at the mixing process steady state (Fig. 3) as follows

$$m_{\text{b}} = \int_0^L S(z)\rho_{\text{b}}(z)c_j(z)dz.$$

The obtained mass of the component in the apparatus is allocated in some way in its head part. According to this approach the special initial conditions must be provided for eq. (1) and during the mixing process organization respectively.

A practically more important variant of the process initial conditions may be carried out by means of an uniform distribution of the buffer mass in the apparatus head part. These initial conditions may be formulated for eq. (1) in the following way:

$$\begin{cases} c_j(z,0) = c_{j0}, \text{ at } 0 < z < z_1; \\ c_j(z,0) = 0, \text{ at } z_1 < z; \end{cases} \quad (4)$$

where z_1 is the buffer allocation boundary.

The modeling results of the mixing process dynamics for different variants of the buffer mass distribution in the apparatus volume had been allowed us to found out that the most rational buffer allocation is its uniform distribution in the first quarter of the drum length (z_1 = 0,25L).

Fig. 4 displays the computational dynamics of mixing process of the modeling materials for different variants of its organization.

The comparison of the investigation results, displayed on Fig. 4, shows that the suggested modernization method allows almost ten times decrease in the non steady state period and approximates for this indictor to the process variant without any operation of segregated flows.

As an example of practical realization of the mixing method suggested organizing continuous technological processes by the portion dosage of some components may be carried out in the production of combined food products and specifically in the muesli production. The typical muesli components are the cereal flakes dry fruits, candied fruits and nuts. The mixture of these components has the high inclination to segregation. This circumstance with taking into account small doses of some components and technical problems of their continuous dosage causes the portion dose preparation.

In the present paper the technological possibilities of the suggested method is investigated when it is used to organize a continuous mixing process of the muesli preparation on the basis of cereal flakes consisting of oats, wheat, barley, rye and maize flakes. The mixture of these components is segregated in a great extent because of big size and small density of maize flakes. By the way the mixture flakes without maize flakes is very resistant against segregation.

The investigation was carried out by the mathematical modeling method on the basis of eq. (1). The exhausting coefficient, reflecting the exhausting effect of the lifting blades for the tested component, had been determined by the experimental method described in [1].

Fig. 5 shows the modeling results of the mixture formation dynamics for the non steady state period for the variants of process organization: without any operation of segregated flows (curve *1*) and with the reverse impulse influence on the segregated flow, concentrating the portions delivery component (maize flakes) (curve *2*). The portions delivery was modeled for the dosage period $T = 350$ s, and the dose supply duration $\tau_d = 3$ s.

The comparison of the investigation results, shown on Fig. 5, for the two versions of the mixing process organization reveals that the suggested method allows to decrease the concentration variation almost by hundred times practically without any variance of the non steady state period.

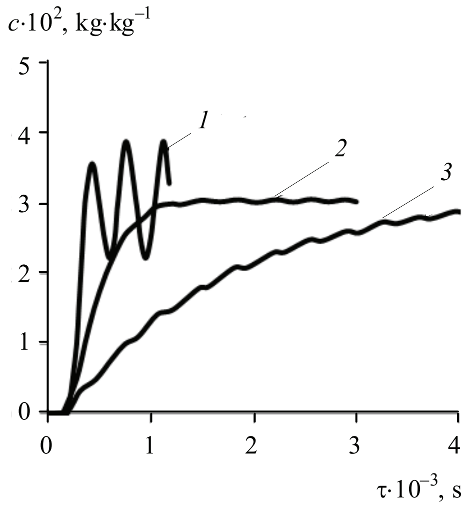

Fig. 4. Dynamics of the continuous mixing process of polypropylene and clayite granules by portion microdosage of clayite granules (T = 350 s, τ_d = 3 s) without any operation (*1*) and with operation (*2*), (*3*) of segregated flows:
2 – with the buffer mass of the portions delivery component; *3* – without any component buffer mass

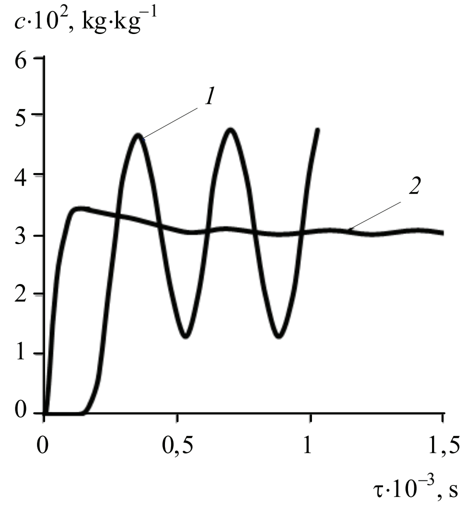

Fig. 5. Process dynamics modeling the cereal flakes mixture formation with the portions deliveryof maize flakes for the versions:
1 – with the reverse impulse influence on the segregated flow, concentrating the portions delivery component;
2 – without any segregated flow control

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Организация процесса смешения зернистых материалов при порционном дозировании отдельных компонентов

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Ключевые слова и фразы: моделирование; сегрегация потоков; смешивание; управление.

Аннотация: Рассмотрено дальнейшее усовершенствование предложенного ранее способа смешения сыпучих материалов с высокой склонностью к сегрегации путем улучшения его динамических характеристик. Проведено экспериментальное и аналитическое исследование динамики процесса смешения зернистых материалов с порционной подачей отдельных компонентов при управлении их сегрегированными потоками на базе барабанного аппарата. Установлено, что существенному увеличению эффективности метода способствует размещение буферной массы названных компонентов в головной части аппарата.

Organisation des Prozesses des Vermischens der körnigen Stoffe bei dem Portionsdosieren der einzelnen Komponente

Zusammenfassung: Es wird die weitere Vervollkommnung der früher vorgeschlagenen Methode des Vermischens der körnigen Stoffe mit der hohen Neigung zur Segregation durch die Verbesserung ihrer dynamischen Charakteristiken durchgeführt. Es ist die experimentelle und analytische Untersuchung des Prozeses des Vermischens der körnigen Stoffe mit der Portionszubringung der einzelnen Komponente bei der Steuerung von den segregierten Strömen auf Grund des Trommelapparates durchgeführt. Es ist festgestellt, dass zu der wesentlichen Steigerung der Effektivität der Methode die Anordnung der Puffermasse der genannten Komponente im Kopfteil des Apparates beiträgt.

Organisation du processus du mélange des matériaux granulés lors du dosage de portion de certains composants

Résumé: Est exécuté le perfectionnement ultérieur du moyen proposé avant en ce qui concerne le mélange des matériaux granulés avec une grande sensibilité envers la ségrégation par la voie de l'amélioration de ses caractéristiques dynamiques. Est réalisée une étude expérimentale et analytique de la dynamique du processus du mélange des matériaux granulés lors du dosage de portion de certains composants lors de la commande de leurs courants de ségrégation à la base de l'appareil de tambour. Est établi que le placement de la masse de tampon des composants nommés dans une partie de tête de l'appareil contribue à une sensible augmentation de l'efficacité de la méthode.

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