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PROCESSING OF NONUNIFORM GRANULAR MATERIALS IN OPERATION SEGREGATED FLOWS

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Key words and phrases: mixing; modeling; particulate solids; segregated flows; separation.

Abstract: In the present paper the principle of operating segregated flows and its practical realization are suggested to solve the technological problems in the course of granular material treatment.

Symbols

c – test component concentration, kg·kg^{-1};	L – drum length, m;
c_0 – nominal mixture concentration, kg·kg^{-1};	n – lifting blade number;
D – drum diameter, m;	$S(z)$ – cross section area of a heap in the drum, m^2;
D_{dif} – quasi-diffusion coefficient, m^{2}s^{-1};	z – longitudinal coordinate, m;
F – cross section area of a heap on a blade, m^2;	ρ_b – bulk density, kg·m^{-3};
$I_l(z)$ – function of the test component distribution, kg·s^{-1}·m^{-1};	τ – time, s;
	ω – angular velocity, s^{-1}.

Introduction

The treatment of the nonuniform particulate solids mixtures with high inclination to segregation is a widespread technological problem. First of all, this problem is the consequence of the necessity to provide the distribution homogeneity of particles differing in size or density in the apparatus working volume. The ignorance of this condition leads to the different residence time of nonuniform particles in the apparatus working volume reduces the product quality.

On the other hand, the high segregating components make difficult their mixture production and place exacting technological standards upon the mixing equipment. In consequence of high nonuniformity of the mixture particles their segregated flows arise. These flows are situated in dominate areas of the working volume and differ from each other by structural and kinematical characteristics. Traditionally these flows are destructed by means of several special methods.

In the present paper the principle of operating segregated flows is suggested in order to solve the technological problems during the treatment of nonuniform particulate solids. The basic advantage of this principle consists in its realization possibility for many technological applications. These applications may be as follows:

a) differentiation of technological conditions for different particles by means of operation of their residence time in the apparatus working volume;

b) increasing the mixture quality of particulate solids inclined to segregation due to the intensification of longitudinal and transversal mixing segregated flows;

c) separation process organization of traditionally hard separated mixtures by means of intensification of segregated flows of mixtures.

In the present paper a version of practical realization of the above mentioned principle is discussed.

A version of segregated flow operation in apparatus with rotating drum

The segregated flows especially occur in the course of granular materials treatment when there are steady or cyclic repeated shear flows in apparatus working volumes. That is why the segregated flows are revealed brightly during particulate solids treatment in apparatus having rotating drums. It is well known [1] that the segregated flows formation in a rotating bed of granular materials is very active. The rotating bed process takes place in a rotating drum which has not any nozzles in its working volume.

However our investigation has shown that there are significant segregated flows not only in a nozzleless drum but also in drums provided with peripheral lifting blades (Fig. 1). It is explained by necessity to provide the conditions of blade filling for all the drum length.

In order to carry out this condition it is necessary that the material heap in the lower drum part must be sufficiently big. Then it is evidently that the heap height must be grater than the blade height. In this case a shear gravity flow of particles arises near the free surface of the heap. Because of that the segregated flows of granular materials take place in the upper part of the heap. These flows are characterized by the movement of big or light particles over small or dense ones.

Since the blades are filled at the contact with the above mentioned segregated flow (Fig. 1) then initially the blade takes big or light particles flow from the free surface of the heap. The further filling the blade is fulfilled by small or dense particles from segregated flow depth.

On the other hand as it is shown on Fig. 1 when the blade rises from the heap initially small and dense particles are falling from the blade. When the blade goes down towards the heap big and light particles are falling from the blade.

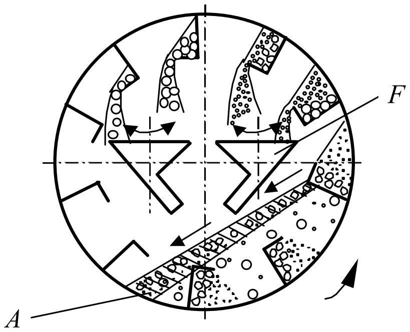

Fig. 1. Schematic of segregated flow formation and their operation in a cross section of a rotating drum apparatus with peripheral blades: *A* – is the area of segregated flows formation; *F* – deflecting elements

Thus the effect of segregated flows arising in the drum heap is extended to the bed of falling particles in the cross section of the drum. Taking into consideration that the apparatus with rotating drums widespread are used for heat and mass transfer as well as for hydromechanical process organization we developed a realization version of the principle of operating the segregated flows of granular materials on the basis of the above discussed physical effect.

This version uses the traditional construction of apparatus which consists of horizontal rotating drum with peripheral lifting blades. Basing on the investigation results in terms of segregated flows in the apparatus of the traditional construction we suggested a device allowing the operation by named flows.

The device operating the segregated flows realizes the principle of the multistage countercurrent flows of nonuniform particles [2] and additionally provides the possibility to change their value and direction along and across of the drum axis. According to this principle the apparatus working volume is divided conventionally into some parts along the drum axis and deflecting elements are placed in pairs in all the parts. The elements are mounted motionless from the rotating drum in its central part (Fig. 1) are made in the form of funnels F having inclined discharge channels.

The incline direction of the channels may be adjusted. Thus the elements of every their pair provide the operation of segregated flows taking place in the falling bed of particles.

The addition of the traditional apparatus by the suggested device allows to set the different treatment time for particles differing in size and density. If the main technological aim is the qualitative mixture production then the residence time of nonuniform components is equalized and longitudinal and transversal mixing segregated flows is organized in the working volume.

Moreover this equipment may be used for separation of particles differing in size and density. In this case the longitudinal countercurrent flows of segregated particles are intensified in the apparatus.

Experimental and analytical research on the efficiency and dynamic characteristics of a multifunctional apparatus

The paper presents the results of experimental and analytical investigations of technological efficiency and dynamic characteristics for multifunctional apparatus at various versions of its technological application.

The basic application versions are the periodic and continuously working mixers also the separator for hard separated materials. Thereby it is noteworthy, that the apparatus construction is rather suitable simultaneously to organize heat-mass transfer processes, because of existence of the falling particles bed in the apparatus working volume.

The experiments on the mixing and separation were carried out with the use of hard mixed and hard separated materials respectively. In order to prepare these materials we have used glass beads and polyethylene granules differing in size and density (see Table 1). The particle sizes were choused to complicate the mixing and separation processes.

Table 1

Characteristics of modeling particulate mixtures

Process	Mixture materials	Fraction size $d \cdot 10^{-3}$, m; and its concentration, $kg \cdot kg^{-1}$	Density ρ, $kg \cdot m^{-3}$
Separation	glass beads	+3,0–3,5; 0,7	2500
	polyethylene granules	+2,5–4,0; 0,3	920
Mixing (periodic)	glass beads	+3,0–3,5; 0,7	2500
	polyethylene granules	+4,0–5,0; 0,3	920
Mixing (continuous)	glass beads	+2,5–3,5; 0,6	2500
	polyethylene granules	+4,0–5,0; 0,4	920

In order to forecast the effect of the segregated flow operation an analytical approach is developed in the paper. This approach is based on an adaptation of the general mass transfer equation for conditions of segregating particulate media.

The dynamics of test component distribution along the drum length z is described in the following way

$$S(z)\frac{\partial(\rho_b c(z,\tau))}{\partial\tau} = -\frac{\partial(c(z,\tau)G(z))}{\partial z} + \\ + D_{dif}\frac{\partial}{\partial z}\left(S(z)\rho_b\frac{\partial c(z,\tau)}{\partial z}\right) + I_l c_0 + S(z)\rho_b\left(I_v^+ + I_v^-\right), \quad (1)$$

where $G(z)$ is the mixture flux in the drum heap along the drum length, kg·s^{-1}; $I_v^-(z) = \omega nF\, c(\tau, z)/(2\pi S(z))$ is the function, describing the exhausting action of the lifting blades; $I_v^+(z)$ is the function modeling the effect of operation of the segregated flows in the falling bed of particles in the drum.

Equation (1) was integrated numerically at the boundary conditions

$$\left.\frac{\partial c}{\partial z}\right|_{z=0,L} = 0 \quad (2)$$

and initial conditions:

$$c(z,0) = c_0 \text{ for separation process,} \quad (3)$$

$$c(z,0) = \begin{cases} 1, 0 < z < 0.42L \\ 0, 0.42L < z < L \end{cases} \text{ for periodic mixing process.}$$

Because of the mixing process is carried out by means of the counterbalanced longitudinal impulses along the drum axis for all the segregated flows the mixing modeling may be fulfilled on the basis of the mathematical description of the separation process (1) – (3), when the transversal segregation fluxes are neglected.

The mixture non homogeneity was estimated by means of the variation coefficient determination. This coefficient is calculated as the ration of the standard concentration deviation of the test component to its mean concentration in the mixture expressed as the percentage.

The investigation results for different technological application versions of apparatus are presented on Figs. 2–5. Thereat Figs. 2 and 4 show the mixing and

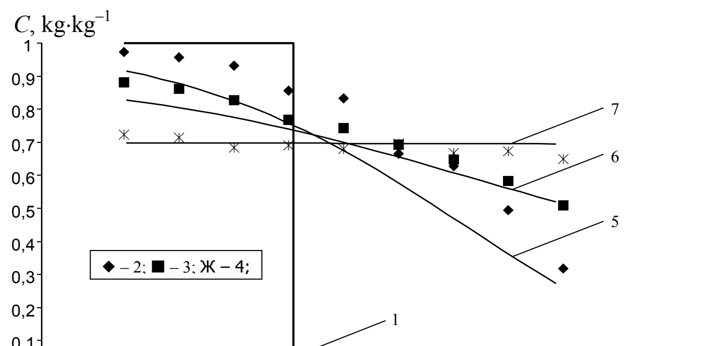

Fig. 2. Experimental dynamics of the test component distribution along the apparatus length *z*/*D* in the course of the periodic mixture preparing:
1 – 0 s; *2*, *5* – 24 s; *3*, *6* – 72 s; *4*, *7* – 360 s (*1–4* – experimental; *1*, *5–7* – calculated)

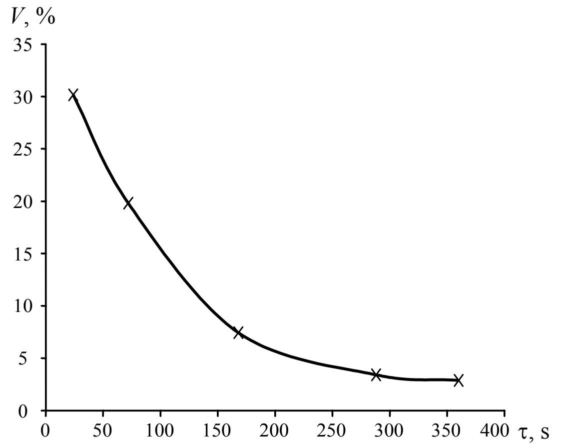

Fig. 3. Variation coefficient evaluation (experimental) in the course of the periodic mixture preparing high segregating particles

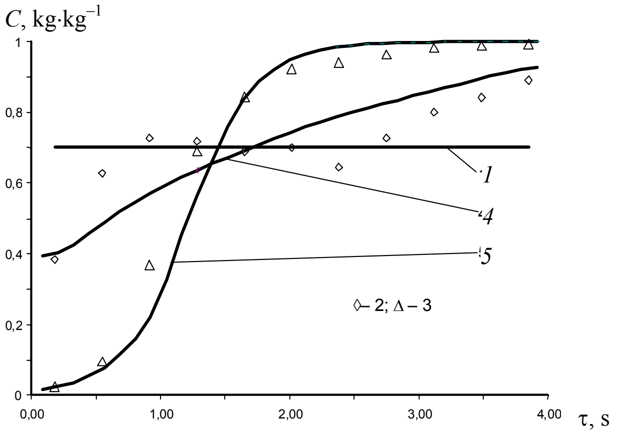

Fig. 4. Dynamics of concentration distribution along the drum length *z*/*D* during continuous granular mixture separation (Table 1) at the initial condition:
1 – 0 s; *2*, *4* – 24 s; *3*, *5* – 360 s (*2*, *3* – experimental; *1*, *4*, *5* – calculated)

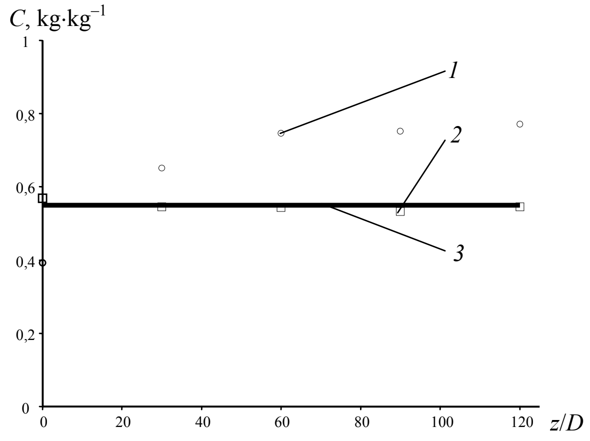

Fig. 5. Dynamic of the product concentration evaluation (experimental) in the course of the continuous mixture preparing:
1 – without operating segregated flows; *2* – with operating segregated flows; *3* – is the mixture concentration (nominal)

separation dynamics respectively, as the comparison of experimental and calculated data. The authors explain particularly the observed deviation of these data from each other by technical difficulties arising during mixture concentration measuring along the drum length for high segregating materials.

Conclusions

The principle of operation of segregated flows is suggested in order to solve the technological problems during the treatment of nonuniform particulate solids. The basic advantage of this principle consists in its realization possibility for many technological applications. These application versions are determined as follows:

a) differentiation of technological conditions for different particles by means of operation of their residence time in the apparatus working volume;

b) increasing the mixture quality of particulate solids inclined to segregation due to the intensification of longitudinal and transversal mixing segregated flows;

c) separation process organization of traditionally hard separated mixtures by means of intensification of segregated flows of mixtures.

Variant of practical realization of the above mentioned principle on the bases of a rotary apparatus, having rotating drum with peripheral lifting blades is suggested.

The results of experimental and analytical investigations of technological efficiency and dynamic characteristics for multifunctional apparatus at its basic application versions are presented. These basic versions are the periodic and continuously working mixers also the separator for hard separated mixes.

In order to forecast the effect of the segregated flows operation an analytical approach is developed.

The investigation results reveal that the suggested apparatus is rather effective especially when it is important to process the high segregating materials without sieves and separating gas-liquid flows.

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Обработка неоднородных зернистых материалов при управлении сегрегированными потоками

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Ключевые слова и фразы: зернистая смесь; моделирование; сегрегированные потоки; сепарация; смешение.

Аннотация: Для решения технологических проблем в ходе обработки зернистых материалов предлагается принцип управления сегрегированными потоками и его практическое исполнение.

Bearbeitung der ungleichartigen Kornstoffe bei der Steuerung von den segregierten Ströme

Zusammenfassung: Für die Lösung der technologischen Probleme im Laufe der Bearbeitung der Kornstoffe wird das Prinzip der Steuerung von den segregierten Ströme und seine praktische Erfüllung vorgeschlagen.

Traitement des matériaux hétérogènes granulés lors de la commande des flux de ségrégation

Résumé: Pour la solution des problèmes technologiques lors du traitement des matériaux granulés est proposé un principe de la commande des flux de ségrégation ainsi que sa réalisation pratique.
