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Investigation of the Quality of the Mixture at the First Stage of Operation of a Gravitational Apparatus

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Abstract—The quality of the mixture obtained after the first stage of batch mixing of loose components in the preparation of a finished mixture with a ratio of 1:10 or more is assessed, according to the proposed method of three stages and the results of stochastic simulation of the process of mixing of loose materials in a gravitational apparatus during operation of drums with screw-wound brush elements installed above the trays and with inclined bumpers. The models of the formation of rarefied torches of two types of particles in two cases were employed: (1) after the interaction with the brush elements of the layers of dosage components coming from the drum–tray gap and (2) after the impact of the incoming torches on the bumper. For the first stage of mixing, dependences of the volume and weight fraction of the key component on the reflection angles are simulated with allowance for the physical mechanical properties of the materials and the design and regime parameters of the apparatus, based on the corresponding nonequilibrium differential distribution functions for the number of particles of each component in the angle of scattering from the brush elements (case 1) and the angle of reflection from the bumpers surface (case 2). Using the proposed recurrence relation for dosage materials, the coefficient of inhomogeneity of the mixture at the first stage of mixing particulate components is calculated with the focus on the most significant factors of a quality mixing: the angular speed of drum rotation ω; the degree of deformation of brush elements Δ (the ratio of their length to the height of the drum–tray gap); and the angle of inclination of bumpers to the horizon ψ_1. Analysis of the theoretical and experimental results showed their satisfactory agreement and made it possible to reveal the most rational ranges of variation of the chosen process parameters at the first mixing stage: ω = (45.5–47.2) s^{-1}; Δ = (1.48–1.52); and ψ_1 = (0.87–1.04) rad. These findings can be used in the development of the engineering methodology for calculating new gravity mixers.

Keywords: batch mixing, gravity apparatus, bulk materials, brush elements, bumpers, first stage, inhomogeneity coefficient, stochastic models

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INTRODUCTION

The use of the gravitational method allows one to implement batch mixing of bulk components in a ratio of 1 : 10 or more, which is relevant for many industries, including food, construction, or pharmaceutic industries. The proposed dosing of bulk components 1 and 2 (i = 1, 2) corresponds to three stages of mixing, each of which uses drums with screw-wound brush elements [1, 2] installed above the trays and with inclined bumpers.

RESULTS AND DISCUSSION

Taking the inhomogeneity coefficient of a mixture $V_c^{(1)} = 100\,(\langle[c_2^{(1)}]^2\rangle/\langle c_2^{(1)}\rangle^2 - 1)^{-1/2}$ as a criterion of its quality at stage 1 (upper index), let us model the dependence of the volume and weight fraction $c_2^{(1)}$ for the key component 2 on the angles of reflection γ_{2i} (i = 1, 2), physical mechanical properties of the materials, and the design and regime parameters of the apparatus. Let us also use the nonequilibrium differential distribution functions for the number of particles of each component in the angle of scattering α_i from brush elements $F_i^{(np)}(\alpha_i)$ (case 1) [3, 4] and the angle of reflection γ_{2i} from the bumper surface $U_i^{(np)}(\gamma_{2i}) = f[F_i^{(np)}(\alpha_i)]$ (case 2) [5, 6] within the range $[\gamma_{2i}\,;(\gamma_{2i} + \Delta\gamma_{2i})]$

$$c_2^{(1)}(\gamma_{21}\gamma_{22}) = \{\sum_{i=1}^{n_k}\rho_{Ti}U_i^{(np)}(\gamma_{2i}) + \rho_{T2}\Delta\delta_2^{(1)}\prod_{j=1}^{n_b}U_2^{(np)}(\gamma_{22})\}^{-1}\rho_{T1}U_2^{(np)}(\gamma_{21}), \quad (1)$$

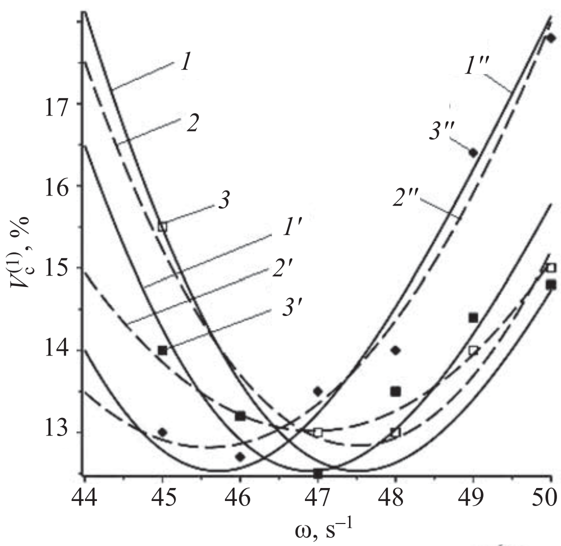

Fig. 1. Dependences $V_c^{(1)}(\omega)$ at different degrees of deformation of brush elements Δ for mixing farina ($i = 1$) and natural sand ($i = 2$) at stage 1 (upper index): (*1, 2, 3*) Δ = 1.45; (*1′, 2′, 3′*) Δ = 1.5; (*1″, 2″, 3″*) Δ = 1.6; (*1, 1′, 1″*) theory; (*2, 2′, 2″*) regression curves; and (*3, 3′, 3″*) experiment; $\psi_1 = 0.953$ rad.

$$\langle c_2^{(1)} \rangle = \{\sum_{i=1}^{2}(\gamma_{2i}+\Delta\gamma_{2i}/2)^{-1} \times \int_{\gamma_{22}}^{\gamma_{22}+\Delta\gamma_{22}/2} d\gamma_{22} \int_{\gamma_{21\min}}^{\gamma_{21}+\Delta\gamma_{21}/2} c_1^{(1)}(\gamma_{21},\gamma_{22})d\gamma_{21}, \quad (2)$$

where $\Delta\delta_2^{(1)} = \delta_2^{(1)} - \delta_1^{(1)}$, according to the recurrent expression $\Delta\delta_2^{(1)} = (n_V + \delta_1^{(1)})/2^{n\tau} - 2\delta_1^{(1)}$ [5] with the number of stages $n_\tau = 3$ at the reference component volume ratio $V_1^{(1)} : V_2^{(1)} = \delta_1^{(1)} : \delta_2^{(1)}$, when $V_1 : V_2 = 1 : n_V$; $\delta_1^{(3)} = 1$; $\delta_2^{(3)} = n_V$ (for example, $n_V = 10$). Analysis of the $V_c^{(1)}(\omega)$ function with account for Eqs. (1) and (2) at different degrees of deformation of brush elements Δ (the ratio of their length to the height of the drum–tray gap) for mixing of two components showed that when the Δ value is varied in the range 1.48–1.52 and the angle of inclination of bumpers to the horizon ψ_1 is varied in the range 0.87–1.04 rad, the minimal values of $V_c^{(1)}$ are reached, when the angle speed of drum rotation ω = (45.5–47.2) s^{-1} (Fig. 1).

CONCLUSIONS

Our present research established that the Δ values lower that 1.5 are inexpedient to choose, because this increases the power consumption of mixing drums. At Δ = 1.45, the ω value should be increased to 47.6 s^{-1} (Fig. 1, curves *1*, *2*, and *3*) for the resulting mixture to have the same quality as at Δ = 1.5 and a lower angle speed ω = 46.8 s^{-1} (Fig. 1, plots *1′*, *2′*, and *3′*). The obtained rational ranges of variation of the main process parameters can be used in the development of the engineering model of a new batch gravity mixer for particulate components.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

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