The influence of the work space design of the vortex granulator on the nature of the granules movement

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Abstract – Objective – development of an algorithm for determining the optimum configuration of the working space of a vortex granulator, depending on the feed requirements and quality of the finished product. For the first time the numerical and experimental trajectories of granules in a vortex granulator are determined. We analyze the influence of embodiment of the working space of the vortex granulator on the character of the granules therein. The characteristics of the trajectories of the granules in an apparatus of variable working space cross-sectional area is determined and their comparative characteristics are presented in the paper. The obtained results of the research will develop mechanisms to control the movement of granules in the working space of vortex granulation devices.

Key words – vortex granulator, granule, hydrodynamics, trajectory.

I. Introduction

The use of vortex flows in fluidized bed granulation provides for a considerable intensification of the mass-transfer process with resultant increases in the specific productivity of the equipment. The course of the granulation process is significantly influenced by certain hydrodynamic conditions of flow movement of a continious and dispersed phase material. They define the path of the granule in the working space of the machine and the time of its contact with the gas stream. In each case (depending on the properties of the starting material and desired final product) it is necessary to modify both the retention of the granule in the workspace of the vortex granulator and the duration of its stay. Especially important is the selection of stay duration in the preparation of granules with special properties [1].

The design of the vortex granulator has a crucial role in the distribution of the velocity field of the gas flow and the movement of the granules. The required time of granules in a vortex gas flow should be ensured by a combination of the following design parameters:

- configuration of the workspace;
- gas stream swirling characteristics of the unit;
- fractional composition of granulated product.

The purpose of the present work is the development of an algorithm for determining the optimum configuration of the working space of the vortex granulator, depending on the feed requirements and quality of the finished product.

The object of the study – vortex granulators with a variable working space cross-sectional area.

The subject of the study – motion trajectories of the granules in the working space of the vortex granulator.

II. Results of Theoretical Calculations

Theoretical calculations of trajectories were based on mathematical instrument describing the hydrodynamic characteristics of the granules in the working space of the vortex granulator [2] (Eq. 1):

$$\left.\begin{aligned} m\frac{d^2r}{d\tau^2} &= \frac{W_\varphi^2}{r} + \psi\cdot\frac{\pi\cdot\mu_{gs}\cdot d_{gr}}{8\cdot m}\left(V_r - W_r\right),\\ m\frac{d^2\varphi}{d\tau^2} &= -\frac{W_r W_\varphi}{r} + \psi\cdot\frac{\pi\cdot\mu_{gs}\cdot d_{gr}}{8\cdot m}\left(V_\varphi - W_\varphi\right),\\ m\frac{d^2z}{d\tau^2} &= -g + \psi\cdot\frac{\pi\cdot\mu_{gs}\cdot d_{gr}}{8\cdot m}\left(V_z - W_z\right), \end{aligned}\right\} \quad (1)$$

where m – mass of granules, τ - the time; r – the current radius of the working space of the vortex granulator; $dr, d\varphi, dz$ – basic movement gains for the respective axes; V_r, V_j, V_z – radial, circumferential and longitudinal (or perpendicular) components of the velocity of the gas, respectively; W_r, W_φ, W_z – radial, circumferential and longitudinal/perpendicular components of the velocity of the granules, respectively; g – acceleration of gravity; ψ – linear coefficient of the granule's resistance to the gas flow; μ_{gs} - viscosity of the gas stream; d_{gr} – diameter of the granule.

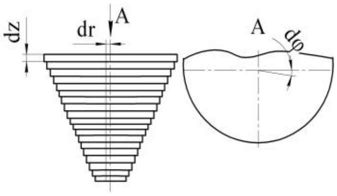

Fig. 1. Design scheme for numerical determination of the trajectory of the granules by the Runge-Kutta method

With the use of the present system of differential equations of motion of the granules in cylindrical coordinates and the numerical solution by the Runge-Kutta method (Fig. 1) the trajectories were obtained according to the structure of the vortex granulator and properties of the granules (Figs. 2 and 3).

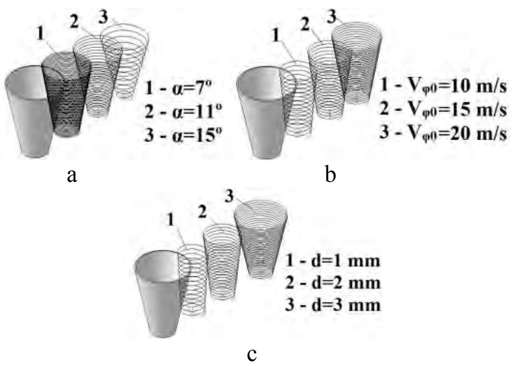

Fig. 2. Comparative characteristics of the motion trajectories of the granules in the vortex granulator for various parameters: a – effect of the cone aperure angles (for Q = 0.63 m^3 / s, d = 3 mm, $V_{\varphi 0}$ = 10 m / s); b – effect of initial swirl of the gas flow (for Q = 0.63 m^3 / s, d = 2 mm, α = 12 °); c – influence of the dimention of the granule (Q = 0.63 m^3 / s, α = 13 °, $V_{\varphi 0}$ = 10 m / s)

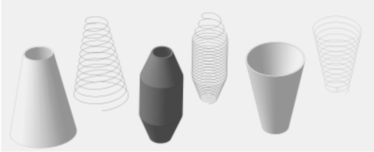

Fig. 3. Comparative characteristics of the motion trajectories of the granule for various configurations of the working space of the vortex granulator.

III. Analysis of the Results

The basic diagram of moving granules is shown in Fig. 4. In accordance with values constituting the full speed of the granules, obtained in paper [3], we get the dependence of the full speed of the granules from the radius of the working space of the vortex granulator (Fig. 5). An analysis of the calculation results showed that as long as granules move from the center of the chamber to the wall, the vector of the full speed changes its direction depending on the predominance of one or another component. Initially, the granule moves from the axis of the machine perpendicular to it due to the predominance of the radial component of its velocity (Fig. 4, point 1). As we approach the half radius of the vortex granulator, the granule starts being sucked into the vortex motion due to the predominance of the circumferential component of its velocity (Fig. 4, point 2). Near the wall of the granulator the granule moves in a helical path with a gradual movement vertically by increasing the impact of the longitudinal component of its velocity (Fig. 4, point 3), its trajectory does not change until it reaches the upper section of the vortex granulator and discharge.

Shown in Fig. 4 trajectory of the granule is characteristic only for the case of the beginning of its movement in the center of the device. In other cases, the closer the place of its entry to the machine, the faster the granule is involved into rotation.

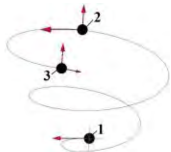

Fig. 4. Estimated nature of the movement of the granule in the vortex granulator

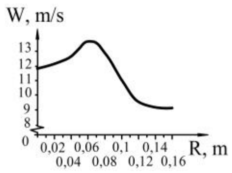

Fig. 5. Change of the full rate of the movement in the working space of the vortex granulator (Q = 0.63 m^3 / s, α = 13 °, z = 0.8 m, $V_{\varphi 0}$ = 10 m / s, d = 3 mm)

In general, spiral trajectories of the granule, depending on its properties and structure of the vortex granulator, differ by number of turns, the pitch between the spirals, and a diameter of the lower and upper bases of the helix. This leads to the fact that the granule extends along a different path in the working space of the vortex granulator, which affects the time of its contact with the gas stream. In particular, an increase of the angle of the cone leads to fewer turns of the helix, an increase of their pitch, a reduction of the path length and residence time of the granule. The increase of the value of the initial swirl of the flow (which is determined by the angle of the blades of the swirler and their number), and the diameter of the granule increases the path length of the granule, as well as its residence time in the granulator by increasing the number of helix convolutions and by a reduction of their pitch.

The results of theoretical calculations are confirmed by a series of experimental studies of the nature of movement of the granules in the working space of the vortex granulator [3]. Movement of granules is an upward spiral with maximum intensity at the vessel wall (Fig. 6).

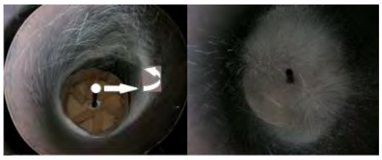

Fig. 6. The experimental trajectory of the granules in the vortex granulator

Conclusion

The flow of the granules in the working space of the vortex granulator is a complex spatial structure, the configuration of which is influenced by the design of the device and by the properties of the granules themselves. The solution of the presented differential equations of motion allows for the prediction of the location of the granule at a given time.

Our studies have determined the peculiarities of the trajectories of granules in an apparatus with a variable working space cross-sectional area and presented their comparative characteristics. The results of the research will allow for the developmet of mechanisms to control the movement of granules in the working space of the vortex of granulation devices.

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