Hydrodynamics of jet-pulsating mode of fluidization

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Abstract. An analysis of the conditions for the implementation of inhomogeneous jet-pulsating fluidization (IJPF) in self-oscilating mode without the use of any mechanical devices during the process of granulation of organic-mineral fertilizers are presented. The results of experimental studies confirm the efficiency of the use of IJPF in increasing the intensity of diffusion-controlled processes.

Keywords: fluidization, granulation, hydrodynamics, jet-pulsating, self-oscillating mode, diffusion-controlled process, gas distributing device.

Introduction

Increasing the efficiency of heat and mass transfer processes in the presence of a phase transition is the main task for the creation of modern innovative technologies. The use of fluidization technology for dehydration and granulation of liquid systems allows to increase the coefficient of use of thermal energy above 50%.

When implementing such processes, it is necessary to remove more than 50%(wt.) of the solvent, usually water, from the liquid phase entering the apparatus, so it is important to create conditions for active movement of granular solid material between zones of irrigation and intensive heat and mass exchange. In addition, with homogeneous fluidization, it is not possible to signif-icantly increase the intensity of diffusion-controlled processes and provide sufficient driving force of the process along the height of the fluidized bed.

Recently, to solve these problems, many researchers use pulsating injection of heated coolant by using a mechanical device [1].An obvious disadvantage of this method is the cessation of the injection of the liquefying agent to the apparatus and the transition of the granular material from a suspended to a stationary state, which, in the case of using a high-temperature coolant, will lead to the melting of granules and the cessation of operation of the apparatus.

For a better distribution of working liquid phase, the authors [2-4] proposed the introduction of liquid heterogeneous system during granulation into the middle of the fluidized bed using a mechanical disperser.

Presentation of the main material

The physical model for the implementation of inhomogeneous jet-pulsating fluidization (IJPF) consists in the pulsed transformation of the kinetic energy of jets of the liquefying agent into the locally concentrated potential energy of a gas bubble with subsequent transformation into the kinetic energy of the dynamic removal of a cluster of granular material beyond the initial bed of solids with an asymmetric movement in the upper bed space. This leads to an instantaneous local uneven distribution of the granular material in the fluidized bed, which causes a dynamic avalanche-like movement of the granular material (pseudo-liquid) into the formed cavity in the initial volume of the bed, Fig. 1.

The technical idea is that the camera of the apparatus with dimensions $A \times B$, which has the shape of a parallelepiped, is divided by conditional vertical planes into three zones (*I*, *II* and *III*),

Fig. 1. A slit-type gas distributing device (GDD) is installed in the lower part of the granulator chamber. Gas jets are injected into the apparatus: slit at point p – horizontally and slit at point k – vertically. The slit at point k is located higher in relation to the slit at point p by the value Δ, Fig. 1(a), which makes it possible to actively form a gas jet. It was experimentally established [1-3] that the breakdown height z_f of the formed gas jet is 1/3 of the height of the initial bed of solid granular material H_0. Therefore, roughly, the velocity of the gas in the slit at point k can be determined from the expression:

$$z_f\left(1-\varepsilon_0\right)\rho_s g = \frac{W_{slits}{}^2\rho_s}{2}. \quad (1)$$

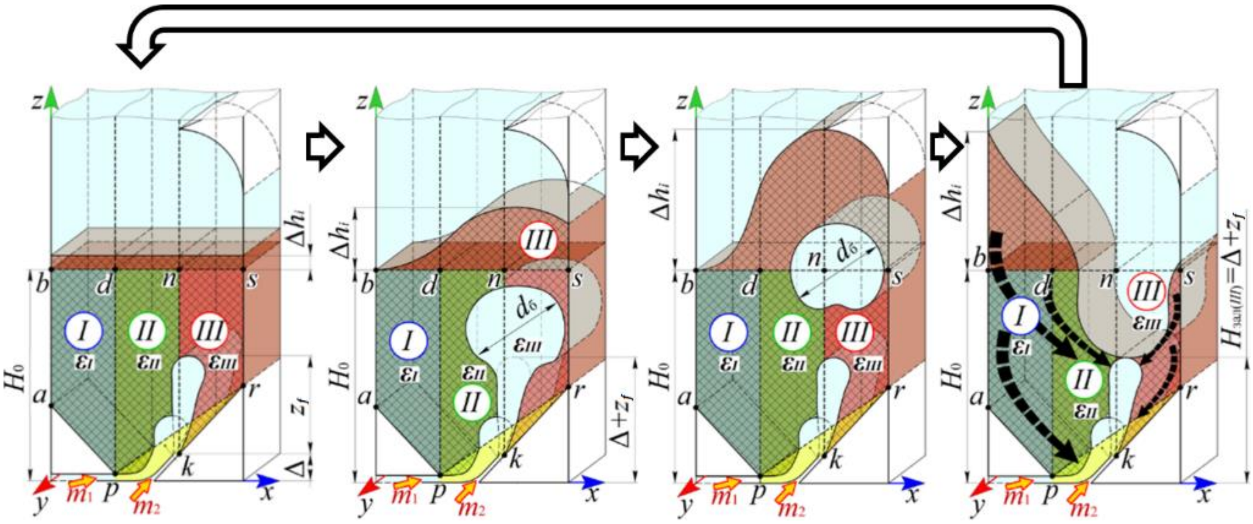


Fig.1. The physical model of inhomogeneous jet-pulsating fluidization (IJPF) in the self-oscillating mode.

So, at the gas velocity in the gas distributing device (GDD) slits W_{slits}=36.6 m/s, the calculated height of the breakdown height of the gas jet accordingly to the experimentally determined gas jet breakdown height (z_f=0.085±0.005 m [1]):

$$z_f = 0.287H_0. \quad (2)$$

The merging of the jets at point k causes the formation of a gas bubble at the top of the gas jet, Fig. 1 (b). At the same time, the gas bubble has a cylindrical shape with a horizontal axis of symmetry, and the diameter of the bubble at which its movement in the vertical direction begins is determined from the conditions:

$$\Delta P_{lift} = \Delta P_{hydrost.} = H_0\left(1-\varepsilon_0\right)\rho_s g. \quad (3)$$

For the case of flat slits through which gas jets are supplied, the diameter of the formed bubble at the top of the gas jet, which has a cylindrical shape, is calculated by the equation [4]:

$$d_{bubble} = \frac{H_0 - z_f - \Delta}{1+\pi/4}. \quad (4)$$

For the case when H_0=0.32 m, the critical calculated diameter (breakaway diameter) of the bubble d_{bubble}=0.114 m=0.356H_0.

Therefore, the time during which gas jets combine to form a gas bubble, which is affected by the lifting force and causes the start of vertical movement, is considered induction. At the same time, the hydraulic resistance of the bed of solids reaches a maximum and can be calculated using the expression:

$$\Delta P_{\max} = \Delta P_{hydrost.(0)} + \Delta P_{\Delta H_0} + \Delta P_{bubble} = \left(H_{bed} + d_{bubble}\right)\left(1-\varepsilon_0\right)\rho_s g \qquad (5)$$

$$\Delta P_{\Delta H_0} = \left(H_{bed} - H_0\right)\left(1-\varepsilon_0\right)\rho_s g \qquad (6)$$

$$\Delta P_{bubble} = d_{bubble}\left(1-\varepsilon_0\right)\rho_s g \qquad (7)$$

where H_{bed} – the current value of the total height of bed of solids is defined as:

$$H_{bed} = \frac{H_0\left(1-\varepsilon_0\right)}{\left(1-\varepsilon_{\tau_1}\right)}, \qquad (8)$$

where $\varepsilon_{\tau 1}$ – average porosity of the bed of solids at the time of gas bubble separation ($\varepsilon_{\tau 1}=\varepsilon_0+\Delta\varepsilon_{bubble}$), $\Delta\varepsilon_{bubble}$ – an increase in the average porosity of the bed of solids due to the formation of a gas bubble with a critical diameter ($\Delta\varepsilon_b=V_{bubble}/V_{bed}$).

At the same time, the gas bubble has a corresponding lifting force:

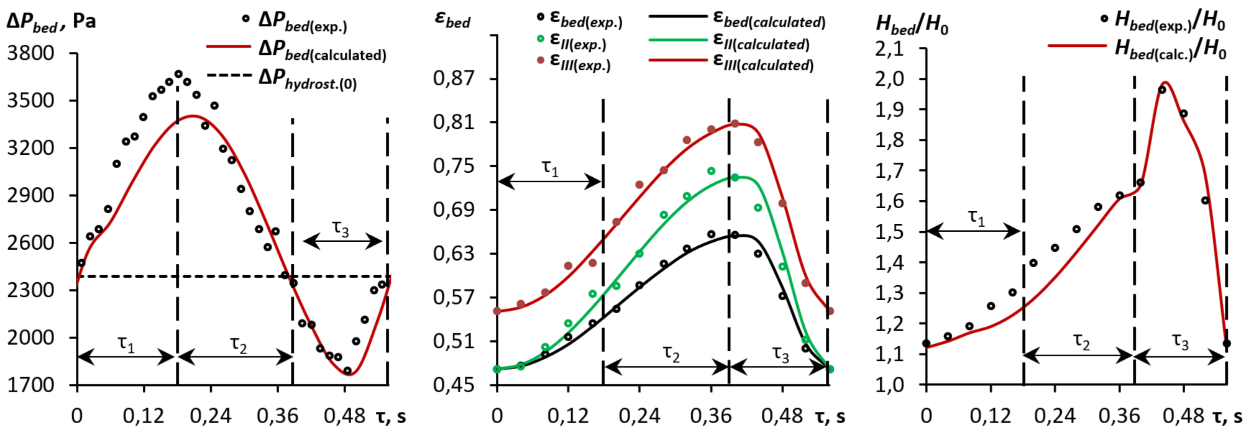
$$O = \left(1-\varepsilon_0\right)\rho_s g \frac{\pi d_{bubble}^2}{4} B. \ (1) \qquad (9)$$

In the case when the bubble has a cylindrical shape, the accumulated potential energy will be determined as:

$$\Delta P_O = \frac{O}{f_{bubble}} = \left(1-\varepsilon_0\right)\rho_s g \frac{\pi d_{bubble}}{4}, \qquad (10)$$

where $f_{bubble}=dB$ – the surface of a cylindrical gas bubble within the horizontal plane.

The results of experimental studies of IJF hydrodynamics for a bed of solid granular material with an equivalent particle diameter d_e = 4.0 mm [1, 5] at the initial height of the stationary bed H_0=0.32m (z_f/H_0=0.33), the specific surface area of the bed $a=6(1-\varepsilon_0)/d_e$=900 m^2/m^3, bed of solids mass M_{bed}=7.83 kg, which corresponds to the hydrostatic pressure of the stationary bed $\Delta P_{hydrost.(0)}$=2389 Pa, Fig. 2 (a).



a) $\Delta P=f(\tau)$ b) $\varepsilon=f(\tau)$ c) $H_{bed}/H_0=f(\tau)$

Fig. 2. Dynamics of changes in the main parameters of hydrodynamics when using IJPF with a minimal risk of formation of stagnant zones on the GDD surface.

Therefore, when the average porosity changes from $\varepsilon_{bed(1)}$=0.475 to $\varepsilon_{bed(critical)}$=0.575, Fig. 2(b), ($\Delta\varepsilon_{bed(critical)}$=0.1 or 21% of the initial porosity $\varepsilon_{bed(1)}$) at $0 \leq \tau \leq 0.18$s, the induction period of potential energy accumulation ends and the size of the gas bubble reaches critical values. At the same time, the hydraulic resistance of the bed of solids reaches a maximum of 3650 Pa, which is 1.5 times higher than the hydrostatic pressure of the stationary bed of solids, Fig. 2 (a). At the end of the first stage, H_{bed}/H_0=1.35, Fig. 2 (c). The heterogeneity of the porosity can be observed already at the beginning of the cycle in zone *III*, Fig. 2 (b), $\varepsilon_{III(0)}$=0.55 versus $\varepsilon_{II(0)}$=0.475.

At the second stage, at $0.18 \leq \tau \leq 0.39$ s, there is an intensive removal of granular material beyond the initial bed of solids in zones *II* and *III*, which is confirmed by an increase in porosity in zone *III* to 0.81 and in zone *II* to 0.73, Fig. 2 (b). Removal of material from these zones takes place until the excess height in zone *II* equals the height of the gas jet breakdown height z_f. In total, more than half of the granular material was removed from zone *III*, which is $0.135M_{bed}$ (the mass of the initial bed of solids), and from zone *II* – $0.108M_{bed}$, i.e., in general, at the second stage, $0.243M_{bed}$ was removed outside the bed of solids. At the end of the second stage, the hydraulic resistance of the fluidized bed returned to the initial one, Fig. 2 (a), the porosity in zones *II* and *III* reached a maximum, Fig. 2 (b), as well as the total height of the fluidized bed, Fig. 2 (c). It is in this time interval (stage 3) – $0.39 \leq \tau \leq 0.56$s that an avalanche-like movement of granular material from zone *I* occurs due to an almost 2-fold increase in the height of the fluidized bed, Fig. 2 (c). The process is cyclic τ_{cycle}=0.56 s, frequency, respectively – f=1.785 Hz.

Works [1, 4, 5] show that the use of IJPF in the process of production of granulated organic-mineral fertilizers with an equivalent diameter of granules of 2.5÷4.0 mm by dewatering 50%(wt.) of the aqueous composite liquid phase achieved the specific load of the surface of the fluidized bed by moisture, which accounts for 1°C of driving force, exceeds by 1.55 times the similar indicator in the bubbling mode.

Conclusion

The proposed method of creating inhomogeneous jet-pulsating mode of fluidization (IJPF) allows for volume circulation of solid granular material in the apparatus, which improves interphase exchange and also significantly intensifies diffusion-controlled processes.

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