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HYDRODYNAMICS OF A SPOUTING BED WITH AN ACTIVE NEAR-WALL ZONE

P. V. Akulich

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Results of experimental studies of the bed porosity, gas velocity, time of residence, and intensity of agitation in a spouting bed with peripheral admission of the gas are presented. In particular, it is shown that a change in the ratio of the lower and peripheral flow rates of the gas allows one to control the bed structure. The effect of a twist of the lower gas flow on the porosity of the bed is analyzed.

A spouting bed is rather widely used in industry for drying, heat treatment, granulation, etc. [1, 2]. Compared to a fluidized bed, it has a number of special features, and it occupies a certain place in the classification of the regimes of a suspended bed. However, a spouting bed possesses specific drawbacks, among which is, first of all, the small fraction of the active zone. The most active zone of the apparatus – the core of the fountain – has only several percent of the amount of material that is in the near-wall zone, where the intensity of heat and mass transfer processes is much lower. This stimulated the appearance of spouting-bed apparatuses with peripheral admission of the gas [3-5] and with an expanded lower inlet [6]. Studies of conical and rectangular (trough-shaped) apparatuses to which a peripheral flow was supplied in the form of round jets through a perforated grid and slot nozzles are known.

In the present work results of experimental studies of the hydrodynamics of a pyramidal spouting-bed apparatus with peripheral admission of the gas are discussed. Activation of the hydrodynamic regime by peripheral admission of the gas enhances heat and mass transfer, increases the loading of the bed with respect to the gas phase, and stabilizes the regime of treatment of materials susceptible to adhesion to the walls.

A schematic diagram of the experimental setup for hydrodynamic studies is presented in Fig. 1 and consists of the following basic elements: the studied apparatus 1, fan 2, dust catcher 3, air ducts 4 with gates 5, branch pipe for material loading 6, collector of material 7 with pinch 8, and measuring devices. Slot nozzles 9 (see section *A–A*) are positioned in the lower part of the apparatus, which has the form of a truncated tetrahedral pyramid. The phases move in the apparatus in the following manner. The gas is supplied through both lower inlet branch pipe 10 and slot nozzles 9 (a peripheral flow). Here, at the center of the apparatus an ascending gas jet with material particles is formed; these particles are separated in the upper part of the apparatus and enter to the peripheral zone, where, while descending, they interact with the peripheral flow, supplied through four inlets in the form of semiinfinite flat jets.

The air flow rate was measured by Pitot–Prandtl tubes 11 connected to micromanometers 12 at the points shown in the diagram, and the resistance of the bed was measured by differential manometers 13. The required hydrodynamic regime was set by control gates 5. The bed porosity was measured by pickup 14 connected to a high-frequency bridge with a device for digital recording 15.

As an analysis shows, the porosity distribution in an ordinary spouting bed has been studied rather thoroughly [7]. However, the effect of a peripheral gas flow on the porosity of a spouting bed (conical, rectangular, including pyramidal) has not been studied.

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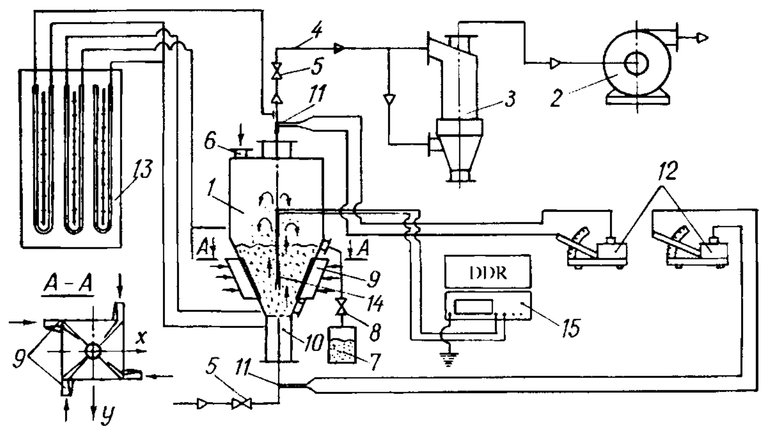


Fig. 1. Schematic diagram of the experimental setup.

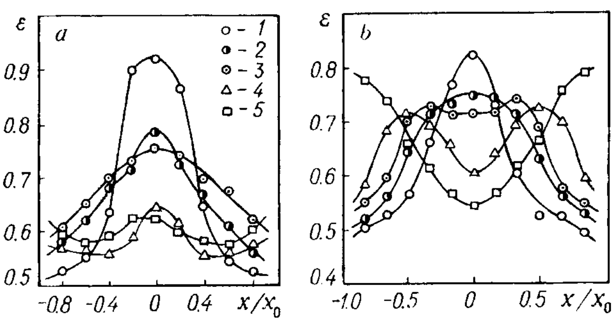


Fig. 2. Horizontal profile of the bed porosity [a) z/H_0 = 0.6; b) 0.8]: 1) K = 0; 2) 0.5; 3) 0.6; 4) 0.7; 5) 0.8.

Experiments were conducted in an apparatus made of acrylic plastic with the following dimensions: separation zone 0.22 × 0.22 m, total height of the apparatus 0.45 m, height of the pyramidal part 0.21 m, angle of slope of the pyramid faces to the vertical 22.5 deg, diameter of the lower inlet section 0.03 m.

The bed porosity was measured by an electric-capacitance method. The local porosity (the average over time) and its peak relative fluctuations were selected as the main quantitative characteristics. Glass beads with a diameter of 1 mm served as the model material.

Plate-type electric capacitors in the form of two and three parallel plates with dimensions of 0.04 × 0.012 m and a distance between the plates of 0.01 m served as the pickup. Large holes were punched in the plates so that the circulation of the solid phase was disturbed to the smallest extent upon introduction of the pickup into the bed. The pickup, removed from the bed, was calibrated before the experiments. The obtained indication corresponded to a bed porosity $\varepsilon = 1.0$. Then the pickup was immersed in the bed, which was precipitated several times after blowings; the average indication of the device from several experiments was taken to correspond to a bed porosity $\varepsilon = 0.4$. The dependence of the electric capacitance of the pickup on the bed porosity was approximated by a straight line.

An R5079 a.c. bridge served as the measuring-recording device. The frequency of the generator was 1000 Hz. The bridge provided automatic measurement of the capacitance with output of the measurement results to the digital panel of an indication unit and an external device for digital recording. The relative error in measuring the capacitance did not exceed 0.03%.

To determine the bed porosity and its relative fluctuation, at each studied point of the bed we recorded N values of the instantaneous porosity. Here, its local value is $\varepsilon = \frac{1}{N}\sum_{i=1}^{N}\varepsilon_i$, and the value of the relative fluctuation is $\delta = \frac{\Delta\varepsilon}{\varepsilon}\cdot 100\%$, where $\Delta\varepsilon = [\frac{1}{N-1}\sum_{i=1}^{N}(\varepsilon_i - \varepsilon)^2]^{1/2}$.

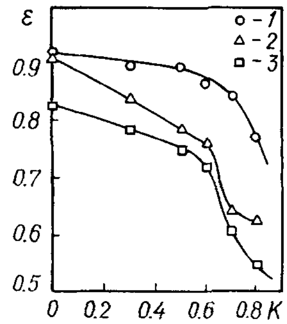


Fig. 3. Dependence of the bed porosity on the axis of the apparatus on the ratio of the flows: 1) z/H_0 = 0.3; 2) 0.6; 3) 0.8.

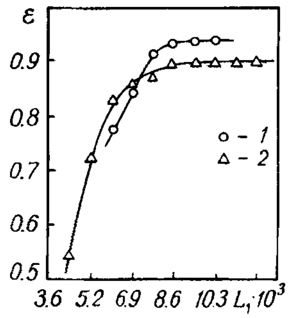
Figure 2 presents horizontal profiles of the bed porosity for various ratios of the flows K. The dependences are obtained for a bed height H_0 = 0.14 m. It is seen from Fig. 2 that the horizontal profile of the bed porosity in this apparatus depends greatly on the ratio of the flows. At K = 0 an ordinary spouting bed is formed, which has a pronounced stationary nonuniformity caused by formation of a rarefied fountain and a compacted peripheral zone. The porosity in the peripheral zone is somewhat higher than the porosity of a motionless bed with loosely packed particles. The profile of the porosity distribution over the cross section of the fountain has a form close to parabolic with a maximum on its axis.

As the ratio of the flows increases, the porosity in the fountain decreases greatly (Fig. 3). This is caused, first, by an increase in the kinetic energy of the flat near-wall jets and thus in the radial forces acting on the particles and in their circulation in the jet flares. As a consequence, the number of particles injected into the fountain zone in a pulsed manner increases and the average time of existence of voids in it decreases, i.e., the porosity decreases. Second, the flow rate of the lower gas flow decreases (provided the total flow rate is kept constant), and consequently, its kinetic energy decreases. We note that the porosity reduction in the fountain becomes more substantial on approaching the upper boundary of the bed and at larger K. The bed porosity in the peripheral zone increases, more so at the walls of the apparatus.

The shape of the horizontal porosity profile in the lower cross sections of the bed ($z/H_0 < 0.3$) is close to parabolic and depends weakly on the ratio of the flows; it only shifts to the region of reduced values. As K increases, the profile of the porosity distribution in the middle and upper cross sections of the bed is strongly deformed, and then it straightens, i.e., the bed structure becomes more uniform. Thus, the "bell-shaped" profile with a high crest is deformed to a flatter profile. And only in the upper cross sections of the bed, when K = 0.8, has the profile a minimum on the axis of the apparatus; this means compaction in the central zone and a considerable porosity increase ($\varepsilon \approx 0.8$) in the peripheral zone.

Porosity fluctuations increase in both the fountain and the peripheral zone. This is due to enhancement of the fluctuating motion of the material particles along the apparatus walls caused by an increase in the flow rate of the peripheral gas flow.

We also studied the effect of twisting (by a blade swirler with a slope angle of the elements of 45 deg) of the lower gas flow on the bed porosity in the apparatus for different ratios of flows. It follows from an analysis of the dependences obtained that twisting of the lower gas flow at K = 0 leads to a certain porosity increase in the fountain in the lower cross sections of the bed. This is caused by the fact that under the effect of a centrifugal force particles are thrown from the fountain to the peripheral zone, where they are packed. An increase in the gas flow rate decreases the effect of the twist, and ε becomes higher than 0.95. However, due to intense filtration of the twisted gas flow to the peripheral zone, the porosity in the fountain quickly decreases over height, and in the middle and upper cross sections it reaches values that are smaller than in the case of an untwisted gas flow (Fig. 4). It is noteworthy that still the diameter of the fountain core decreases (Fig. 5).



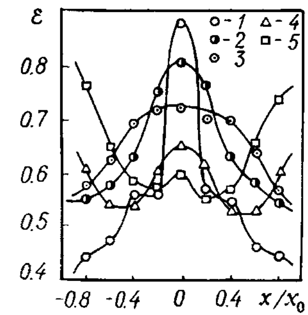


Fig. 4. Dependence of the bed porosity on the axis of the apparatus on the gas flow rate for $K = 0$, $z/H_0 = 0.6$: 1) untwisted gas flow; 2) twisted flow. L_1, m^3/sec.

Fig. 5. Horizontal profile of the bed porosity in the cross section $z/H_0 = 0.6$ for a twisted lower gas flow: 1) $K = 0$; 2) 0.5; 3) 0.6; 4) 0.7; 5) 0.8.

Introduction of a peripheral gas flow reduces the porosity in the fountain in much the same way as in the case of a nontwisted lower flow, whereas in the peripheral zone a more substantial increase in the bed porosity over its entire height is observed (Fig. 5).

The distribution of the velocity of the gas phase in the apparatus along the coordinates was obtained by the method of laser Doppler anemometry (LDA). The method is based on measuring the Doppler frequency shift caused by the scattering of light by moving particles (scattering centers), which is proportional to the velocity of their motion. In the experiments, an aerosol of glycerin produced by a compressor and introduced into the apparatus with the primary gas flow was used as the scattering centers.

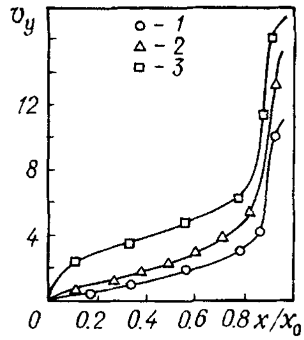
The studies were conducted in an apparatus made of acrylic plastic with the following dimensions: total height 0.4 m, height of the pyramidal part 0.18 m, separation zone 0.18 × 0.18 m, diameter of the lower inlet section 0.03 m, height of the nozzles 0.07 m, width in their lower cross section 2 mm and in the upper cross section 1.5 mm. Before measurements, the apparatus was brought to the desired mode of operation, i.e., the required values of the parameters (total flow rate of the gas and ratio of the flows) were established. This was achieved using control gates and Pitot–Prandtl pneumatic-measuring tubes connected to micromanometers. The measurements were performed by a DISA laser anemometer (Denmark), the design of which implements a differential scheme of LDA. An He-Ne gas laser was used as the radiation source.

Velocity profiles of the gas phase along the coordinates were found from the experiments. An analysis of the dependences obtained showed that the ratio of the flows exerts a substantial effect on the distribution of the vertical component v_z and the component v_y of the gas velocity. At $K = 0.5$ in the middle cross section of the bed ($z = 0.07$ m), the profile of the velocity v_z has a Gaussian shape with a high crest. An increase in K to 0.8 leads to a considerable decrease in the velocity on the axis of the apparatus and an increase in the peripheral zone, with the velocity maximum shifting from the axis of the apparatus (the graph is not given). This is caused by enhancement of twisting of the gas flow in the apparatus.

The dependence of the component of the gas velocity v_y on the coordinate x in the central zone of the apparatus is close to linear. A sharp velocity increase that is enhanced with increase in K is observed in the near-wall zone of the apparatus (Fig. 6). This gas distribution leads to weakened interaction of the treated material with the walls of the apparatus, which is very important in treatment of materials succeptible to adhesion to the chamber surfaces. Moreover, this facilitates enhancement of circulation of material particles along the apparatus walls, which leads to activation of the hydrodynamics.

The time of residence of the particles in the bed and the intensity of agitation of them for different regime parameters were determined by recording curves of the response to the pulsed input of a tracer.

It follows from an analysis of the results obtained that with increase in the flow rate of the material G (other regime-design parameters being constant), the average time of residence of the material particles in the



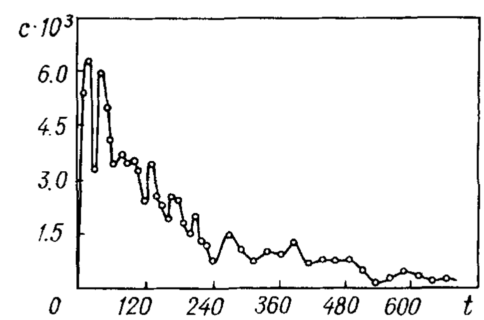


Fig. 6. Dependence of the gas velocity component v_y (m/sec) on the coordinate x/x_0 for different ratios of the flows: 1) K = 0.5; 2) 0.65; 3) 0.8.

Fig. 7. Curve of the response for $K = 0.6$; $G = 3 \cdot 10^{-3}$ kg/sec; $L = 1.94 \cdot 10^{-2}$ m^3/sec. t, sec.

apparatus decreases. This is caused by a reduction in the time of "washing" of the particles from the bed of the material. A typical curve of the response is shown in Fig. 7.

To evaluate quantitatively the intensity of agitation, the number of cells of ideal agitation $n = 1/\sigma_0^2$, where $\sigma_0^2 = \sigma^2/\bar{t}^2$ is the dimensionless dispersion, was determined in a first approximation within the framework of the cell model. The quantity n was calculated for different hydrodynamic and design parameters of the apparatus. It follows from an analysis of the results obtained that this apparatus is characterized by intense agitation of the disperse phase n = 1.2–2.0. The introduction of a peripheral gas flow decreases somewhat the number of cells of ideal agitation, which indicates an increase in the intensity of the latter.

In closing we note that this distribution of the gas in the apparatus allows one to control the bed structure, activate the hydrodynamic mode, and weaken somewhat the contact of the treated material with the walls.

NOTATION

c, dimensionless concentration of the tracer; G, flow rate of the material through the apparatus, kg/sec; H_0, initial height of the bed, m; K, ratio of the peripheral flow rate to the total flow rate of the gas through the apparatus, $K = L_2/L$, $L = L_1 + L_2$; L_1, L_2, flow rate of the lower and peripheral gas flows, respectively, m^3/sec; x, y, z, coordinates; x_0, distance from the axis of the apparatus to the wall in the x direction, m; t, time, sec; ε, bed porosity.

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