Journal of Engineering Physics and Thermophysics, Vol. 66, No. 1, 1994

ON THE MECHANISM OF PRESSURE PULSATION IN A BUBBLING FLUIDIZED BED

A. P. Baskakov, A. V. Mudrichenko, and N. F. Filippovskii

UDC 66.096.5

The mechanism of pressure pulsation in fluidized-bed apparatus having a gas-distribution grid of high hydrodynamic resistance or a subgrid chamber with volume much smaller than that of the bed is considered. The results of calculation and measurement of extremal pressures at different levels of the fluidized bed are given.

When finely dispersed particles are fluidized on a gas-distribution grid of small resistance in apparatus where the volume of the subgrid chamber is commensurable with or exceeds by several times the volume of the bed, there originate interrelated self-oscillations of pressure, fluidizing gas flow rate, and of the bed porosity. The mechanism of these self-oscillations was investigated earlier [see, e.g., [1]).

When a bubble leaves the bed surface, a hole is formed on the latter, and the height of the bed decreases locally. Since pressure in the bed propagates with the speed of sound (for a bed of corundum particles with ρ_T = 4030 kg/m^3 this value is of the order of 10 m/sec) [2], the resistance and, consequently, the pressure along the entire height of the bed over the area being "served" by the bubble falls sharply (Fig. 1a). This causes an enhanced filtration of gas from the subgrid chamber. As a result, the pressure in the chamber also falls. After escape of the excess air, its speed falls below the critical one w_{cr}. For this reason, the particles get out of fluization for a while and settle on the grid. The porosity of the bed falls to a value close to the critical one ε_{cr}.

Next, as the gas enters from the supply line, the pressure under the bed and the rate of its aeration quickly recover. But the particles remain stationary. To activate the bed, additional energy is needed to destroy the dense packing of particles, especially near the holes of the gas distributor [3], to overcome the forces binding the particles with the wall, and the inertia forces. Therefore, the pressure under the bed increases above the value

$$P = \rho_{cr} gH_{cr} .$$

After the pressure reaches a certain critical value, the material in the form of a piston starts to rise upward, forming a gas interlayer above the grid. Initially, when the piston velocity is relatively small, the pressure in this interlayer continues to grow.

The boundary between the interlayer and the denser bed above is unstable. The gas cavity begins to form a bubble. In this case, the resistance of the bed and, consequently, the pressure difference on it fall. The bubble rises and, collapsing on the surface, causes the pressure to fall to a minimum. The cycle repeats itself.

This "carrying" mechanism is superimposed by pressure oscillations in the bed caused by the contact of the gauge with a passing bubble, an acoustic wave originating during the formation of the bubble and other reasons. As a result, the oscillations of the gas pressure and gas velocity have a stochastic character, but the fundamental frequency corresponds to the "carrying" mechanism.

As the clear area of the gas distributor or the subgrid chamber volume decrease below a certain critical value, self-oscillations of this type degenerate. In the first case the subgrid chamber turns out to be acoustically separated from the bed; in the second case the accumulating ability of the subgrid volume is insufficient to

Ural State Technical University, Ekaterinburg. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 66, No. 1, pp. 34-37, January, 1994. Original article submitted August 11, 1992.

1062-0125/94/6601-0030$12.50

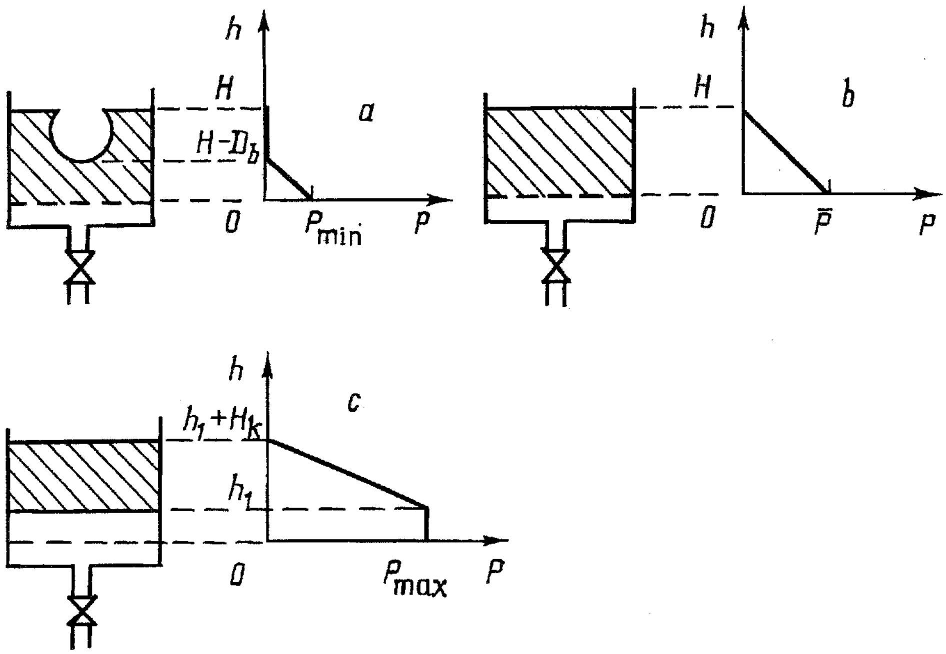

Fig. 1. Mechanism of pressure oscillations in a bubbling bed: a) time corresponding to minimal pressure in the bed; b) to mean pressure; c) to maximal pressure.

accumulate the needed quantity of gas during its compression. However, the pressure oscillations do not disappear. They become less regular, their frequency increases, and the amplitude becomes smaller.

Under these conditions the part played by the subgrid chamber goes over to the gas interlayer originating at regular intervals on the gas distributor. Qualitatively the mechanism of oscillations remains the same as in the mode of self-oscillations described above. As before, we may isolate the fundamental frequency, even though the spectrum of frequencies expands appreciably.

Due to the large hydraulic resistance of the grid, the velocity of the gas emerging from it is virtually constant over the grid cross-section and in time. As a result, a region is formed above the grid in which the particles are in a state close to homogeneous fluidization. It is precisely this region which fulfills the function of a gas accumulator in the process of pressure oscillations. Gas bubbles form above it and produce a zone of inhomogeneous fluidization in the upper part of the bed. The gas interlayer above the grid is formed with a frequency equal to the carrying frequency of the pressure oscillations.

The pressure in the bed pulsates about a certain mean value. It is logical to suppose that this value corresponds to the hydrostatic pressure at a given level of the bed

$$\overline{P}\,(h) = \rho g\,(H - h) = \rho_{\text{cr}}\, gH_{\text{cr}} \left(1 - \frac{h}{H} \right). \tag{1}$$

For simplification we will assume that the bubble has a spherical shape and that the greatest pressure drop occurs at the time when the front part of the bubble touches the bed surface. Then the distribution of minimum pressures along the bed height will be described by the formula

$$P_{\text{min}} = \overline{P} - \rho g D_{\text{b}} = \rho_{\text{cr}}\, gH_{\text{cr}} \left(1 - \frac{D_b}{H} - \frac{h}{H} \right). \tag{2}$$

The bubble diameter can be calculated from Kobayashi's formula [4] in which all of the quantities are expressed in the CGS system

$$D_{\text{b}} = 1.4 \rho_{\text{T}}\, dWh\,. \tag{3}$$

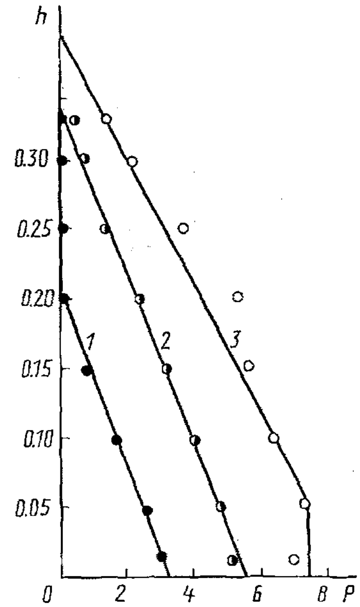

Fig. 2. Distribution of the minimal (1), mean (2), and maximal (3) pressure along the height of a fluidized bed. Fluidization velocity $w = 0.36$ m/sec; bed volume $V_{bed} = 85 \cdot 10^{-3}$ m^3; volume of the subgrid character $V_{sub} = 1.41 \cdot 10^{-3}$ m^3; coefficient of hydrodynamic resistance of the grid $\xi = 55.76$; fluidized particles are corundum ($\rho_T = 4030$ kg/m^3). h, m; P, kPa.

Making the necessary cancellations and introducing the coefficients for the conversion from the CGS to the SI system, we obtain

$$P_{min} = \rho_{cr} g H_{cr} \left(\frac{w_{cr} - 0.07\rho_T dw}{w_{cr} + 0.07\rho_T dw} - \frac{h}{H} \right). \tag{4}$$

The line of change in the minimum pressure along the height of the apparatus lies below the graph of the mean pressure and parallel to it, whereas beginning from the height $h = H - D_b$ the minimal pressure becomes constant and equal to the pressure above the bed (Fig. 1a). To Eq. (4) there corresponds line 1 in Fig. 2.

As noted above, the growth of pressure above the grid after the minimum ultimately causes the rise of particles in the form of a piston (Fig. 1c). The maximum pressure is attained at the time when the piston continues its acceleration due to the aeration with a speed exceeding w_{cr}. Therefore, the maximum pressure line in Figs. 1c and 2 is not parallel to the lines of the mean and minimal pressures.

If no fine bubbles were left in the volume of the bed from the previous cycle, then by the time the pressure attains its maximum value the upper boundary of the bed will occur at a height $h_l + H_{cr}$ from the gas-distribution grid. At the bottom of the apparatus where a gas interlayer of height h_l is formed, the maximum pressure remains constant along the height.

The above-described mechanism explains many specific features of the bubbling fluidized bed, in particular the constancy of the standard deviation of pressure along the bed height from the grid to the level $h = H = D_b$ [2] despite the decrease in the mean pressure, the formation of bubbles not on the grid itself but at a certain height from it [5], the finite size of the bubbles forming at the bottom of the bed, and the synchronism of the pressure oscillations along the bed height [5].

NOTATION

d, diameter of particles of finely dispersed material; D_b, diameter of bubble; g, free fall acceleration; h, height of point above gas distribution grid; H, height of bed (H_{cr}, at the limit of fluidization); $\overline{P}$, P_{max}, P_{min}, mean, maximal, and minimal pressure in bed, respectively; w, w_{cr}, fluidization velocity, velocity of the start of fluidization; W, dimensionless number of fluidization; ε, bed porosity (ε_{cr}, at the limit of fluidization); ρ, bed density (ρ_{cr}, at the limit of fluidization); ρ_T density of finely dispersed material.

REFERENCES

1. V. A. Borodulya, Yu. A. Buevich, and V. V. Zav'yalov, Inzh.-Fiz. Zh., **30**, No. 3, 425-430 (1976).
2. R. Roy, J. F. Davidson, and V. G. Tuponogov, Chem. Eng. Sci., **45**, No. 11, 3233-3245 (1990).
3. V. G. Ainshtein and A. P. Baskakov (editors), Fluidization [in Russian], Moscow (1991).
4. A. P. Baskakov (editor), Heat and Mass Transfer in a Fluidized Bed [in Russian], Moscow (1978).
5. L. T. Fan et al., AIChE J., **27**, No. 3, 388-396 (1981).