CONDITIONS OF UNIFORM FLUIDIZING IN APPARATUS WITH GAS DISTRIBUTION BY CAPS

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The article contains an analysis of the operation of gas distributing caps. Recommendations are given for sectioning the space under the grid of fluidized bed apparatus.

In many technological processes carried out in fluidized bed apparatus it is necessary to prevent the possibility of stagnant zones forming in the bed. This is usually attained by increasing the resistance of the gas distributing grid. However, if the resistance of the grid is too great, it leads to excessive expenditure of power for compressing the gas. Although the literature [1-3] contains a number of formulas, the problem of selecting the optimum resistance of the gas distributing grid has not been solved. The authors of [1-3] dealt with the case when the gas permeability of the grid over its entire surface is the same (porous or perforated grid with densely spaced holes), and the fluidized material is ideally friable. Then the resistance of the bed at the instant of disturbance of stability is equal to the weight of the column of material per unit area of the grid $\rho_p g H_p$.

With gas distribution by nozzles or caps, the curve $P = f(Q)$ always contains a peculiar peak at the instant of transition of the bed to the fluidized state, even when the material is ideally friable, and the maximum resistance of the bed at that instant exceeds $\rho_p g H_p$ by some value ΔP°_{sz}.

The existence of the peak is due, in the first place, to the increased speeds, and consequently increased resistances of the nonfluidized dense layer around the outlet openings of the caps. This effect manifests itself most lucidly in the spouting bed [4]. The fluidized bed with concentrated gas supply through caps or nozzles may be represented in a simplified manner as a system of spouting beds with gas supply from a common chamber under the grid.

If all the caps and the packing of the particles in the bed were absolutely equal, fluidizing would begin above all N caps simultaneously when the pressure under the grid attains the value P* equal to the sum of $\rho_p g H_p$, ΔP°_{sz}, and the resistance of the caps ΔP°_c at the critical fluidization rate, i.e., at point A in Fig. 1. The pressure under the grid then decreases by ΔP°_{sz} to P_D. However, it is obvious that such a system of spouting beds is hydrodynamically unstable. When the gas flow rate through the bed is increased, the material above one or several $(N - n)$ caps is fluidized, and these caps are found to have the most favorable conditions on account of random deviations. If we take it that the deviations in the operating conditions of the caps are small, we may assume that the flow rate through any of the operating caps is the same and equal to Q_1, and through the nonoperating caps Q_2. Then the overall flow rate of the gas through the bed is equal to:

$$Q = (N - n) Q_1 + nQ_2. \quad (1)$$

The resistance to gas motion through an operating cap consists of the resistances of the cap and of the fluidized bed:

$$P_1 = \frac{1}{2} \rho_g \xi \left(\frac{Q_1}{f}\right)^2 + \rho_p g H_p, \quad (2)$$

and through a nonoperating cap:

$$P_2 = \frac{1}{2} \rho_g \xi \left(\frac{Q_2}{f}\right)^2 + \rho_p g H_p + \Delta P_{sz}. \quad (3)$$

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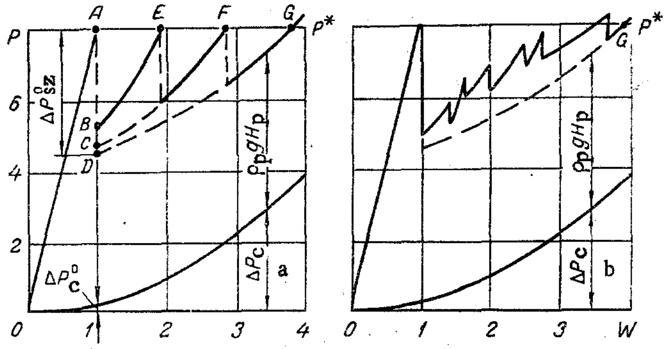

Fig. 1. Dependence of the pressure under the grid on the fluidization number: a) calculated for three caps on the grid; b) experimental with 18 caps. H_p = 0.25 m; P, kPa.

The resistance of the stagnant zone ΔP_{sz} increases with increasing filtering rate. At the instant of transition of the bed into the fluidized state the gas flow rate in all stagnant zones attains its critical value (or a value fairly close to it), and ΔP_{sz} attains its maximum value $\Delta P°_{sz}$.

Bearing in mind that the operating and nonoperating caps are connected to a single chamber under the grid, we have:

$$P_1 = P_2 = P. \tag{4}$$

According to the presented Eqs. (1)-(4) an example of the dependence of the pressure in the chamber under the grid on the fluidization number W was plotted in Fig. 1a; W was calculated as the ratio of the total gas flow rate Q into the apparatus to its area and the speed of onset of fluidization w_0. For the sake of simplicity we took a small total number of caps (N = 3). If upon the initial increase of the flow rate the bed breaks down only above one cap, then the pressure under the grid drops to P_B; if it breaks down above two caps (which is less probable), then the pressure drops to P_C, and finally, if the bed breaks down above all three caps, the pressure drops to P_D. As the gas flow rate Q increases, the pressure under the grid increases according to the curves BE, CF, and DG, respectively. If the pressure P^* under the grid is attained successively, the caps in the still nonfluidized stagnant zones (points E, F) are engaged.

From the system of equations (1)-(4) we can obtain an expression enabling us to estimate the speed W_n at which the number of nonoperating caps in the bed does not exceed n:

$$W_n = \frac{n}{N} + \frac{N-n}{N}\sqrt{1+\frac{\Delta P^0_{sz}}{\Delta P^0_c}}. \tag{5}$$

In the example presented in Fig. 1a, $W_1 = W_F$, $W_2 = W_E$, and $W_3 = W_A = 1$. At W_1 the last cap is engaged, and when $W > W_1$, there are no stagnant zones in the bed. With increasing number of caps on the grid, W_1 (other conditions being equal) increases to the speed W_G (point G in Fig. 1):

$$W_G = \sqrt{1+\frac{\Delta P^0_{sz}}{\Delta P^0_c}}, \tag{6}$$

at which full fluidization occurs on the grid, no matter what the number of caps is.*

*Broadening of the fluidized bed in the fluidized zones leads to material being heaped on the stagnant zones and to increased resistance to the gas flow through them. The height of the bed in the fluidized and stagnant zones may be taken to be equal, and broadening of the fluidized bed can be taken according to the relation [5, p. 32] $\varepsilon = \varepsilon_0(W)^{\psi}$, where $\psi = 0.07Ar^{0.031}$. Then, in the case $n/N \to 0$ the value of ΔP^0_{sz} increases, because of the heaping of material, by $\Delta P_p = [(W_G)^{\psi} - 1]\rho_p g H_p$ since at the instant of breakdown of the bed in the stagnant zone the gas flow rate in all fluidized zones is equal to W_G. Substitution of this additional resistance into Eq. (6) considerably complicates the calculation of W_G, and therefore we neglect this magnitude in the first approximation.

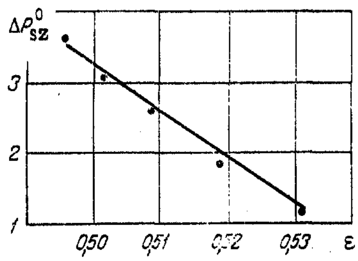

Fig. 2. Dependence of the pressure peak in the bed ΔP^0_{sz}, kPa, on the porosity.

The above considerations were experimentally verified on an installation with a grid 0.6 × 1.2 m, having 18 gas distribution caps spaced 200 mm apart, and used for fluidizing by air of electrocorundum with mean particle diameter of 0.4 mm and a bulk density ρ_p = 1850 kg/m³. The resistance of the grid at the critical fluidization rate was ΔP^0_c = 250 Pa.

The experimental dependence of the pressure under the grid on the fluidization rate (Fig. 1b) differs from the calculated value chiefly because the caps coming into operation destroy by jets and pulsations the stagnant zones above the adjacent caps. The neighboring caps may therefore be engaged at a pressure lower than the first peak P*. Conversely, because of greater compaction of the material near some caps, these caps come into operation last at a pressure exceeding P*. Moreover, a cap itself, having six openings, operates like a kind of gas distributing grid, and different openings in one cap may come into operation at different times. However, the fluidizing rate is close to the value calculated by formulas (5) and (6).

The value of the pressure peak P* at the initial instant of fluidization of the bed, and correspondingly the value

$$\Delta P^0_{sz} = P^* - \rho_p g H_p - \Delta P^0_c \tag{7}$$

depend on the design of the grid and on the state of the material. In particular, in fluidizing freshly packed, settled, or vibration-compacted material in an apparatus 0.3 × 0.6 m with two caps, the value of ΔP^0_{sz} naturally increased with increasing compaction of the material (decreasing porosity) (Fig. 2). According to literature data [6, 7] and our own observations with a transparent model, when the gas flows out into a dense layer, a cavern forms at the opening. The larger the cavern is, the smaller is the resistance of the bed ΔP_{sz}. When the bed as a whole remains motionless, the size of the cavern is determined by the possibility of additional compaction of the particles around the opening, i.e., by the original porosity of the bed.

In the large apparatus the air flow rate through each of the 18 caps was measured with the aid of a minicomputer with an interrogation frequency of 130 Hz. This made it possible to check the number of operating and "nonoperating" caps at any instant. The value of ΔP^0_{sz} was calculated by formula (7) upon engagement of each cap (or several caps simultaneously). In different experiments conducted under practically equal conditions, different values of ΔP^0_{sz} were obtained, probably because when the material is packed into the apparatus, the packing of the particles near the caps depends on many random factors. The smallest values of ΔP^0_{sz}, and consequently also of W_n were obtained upon repeated fluidization of the material which did not have time to settle and become compacted. The ratio between W_n and ΔP_{sz} corresponded to the dependence (5) (Fig. 3).

During the process of decreasing rate after full fluidization it is difficult to determine ΔP^0_{sz} because often several caps are engaged simultaneously, but the rate at which the formation of stagnant zones begins is always much lower than the rate (W_1) at which the last cap is engaged.

To suppress stagnant zones in kilns and other large industrial fluidized bed apparatuses, the space under the grid is divided into a number of sections. From the point of view of the model of transition of the bed into the fluidized state examined above, sectioning in itself has hardly any effect at all on the destruction of the stagnant zones. In industrial apparatuses a sufficiently large number of caps is situated in each section, and therefore

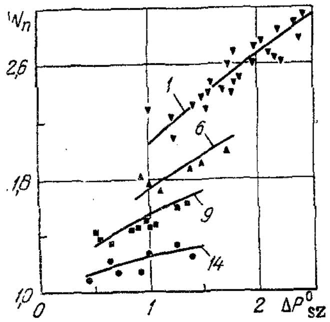

Fig. 3

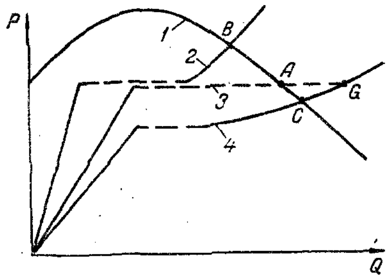

Fig. 4

Fig. 3. Experimental dependence (dots) and dependence calculated by formula (5) of the fluidization number W_n, at which one of the n (numbers next to the curves) nonoperating caps is engaged on the resistance of the stagnant zone ΔP°_{sz}, H_p = 0.25 m.

Fig. 4. Analysis of the expediency of dividing the space under the grid into sections.

the speed of complete fluidization in each section, like in unsectioned apparatuses, is practically close to W_G. However, sectioning is useful if it makes it possible for a time (for the destruction of the stagnant zones) to increase the pressure and the flow rate in one of the sections by changing the flow rates in the others.

We will examine the case of a centrifugal blower operating in an apparatus with a chamber under the grid divided into two sections. Figure 4 presents the characteristic of the blower (curve 1) and the dependence of the pressure in the chamber under the grid on the air flow rate when only one section operates (2) and when both sections operate jointly (curve 3, obtained by doubling the flow rates corresponding to curve 2). For the sake of lucidity, coinciding parts of the curves are represented by two lines. The dashed straight lines correspond to the line AEFG in Fig. 1a, i.e., to the section of the characteristic of the "net" (fluidized bed + grid) on which stagnant zones may occur. When both sections are started simultaneously, the system operates in a regime bounded by point A. In this regime it is impossible to eliminate completely the formation of stagnant zones. If all the gas is supplied to one of the sections, the pressure and flow rate produced by the blower will be sufficient for the complete fluidization of the bed in this section (point B). In reality, when one of the sections is disengaged and the total flow rate therefore decreases, the pressure under the grid also increases on account of the diminished resistance of the supply lines common to both sections. When complete fluidization has successively been attained in both sections, we may go over to their parallel operation (point C). Then there will not be any stagnant zones any more because after the preceding complete fluidization, the value of ΔP°_{sz} turns out to be much smaller (the dependence of the pressure on the flow rate corresponds to curve 4) than with settled, and even freshly packed material. An even more reliable procedure after previous fluidization on the first section is not to engage it fully but to lower the flow rate, leaving the material in a weakly fluidized state when stagnant zones have not formed yet. After having effected complete fluidization in the second section, we may go over to the operating regime. This prevents compaction of the material in the nonfluidized zone on account of vibration of the apparatus and heaping of material from the fluidized zone on it.

We point out that it is inadvisable to have many sections because, firstly, this complicates the design, and secondly, surge may occur with centrifugal blowers when the flow rate is reduced to a value far below the nominal one.

NOTATION

f, cross-sectional area of the cap, m^2; g, acceleration of gravity, m/sec^2; H_p, height of the packed bed, m; N, number of caps in the grid; n, number of "nonoperating" caps; P, pressure, kPa; P*, pressure under the grid at the instant of destruction of the stagnant zone, kPa; Q, Q_1, Q_2, air flow rate for the entire installation, through the operation and "nonoperating" caps, respectively, m^3/sec; W, fluidization number; W_n, fluidization number with n "nonoperating" caps; W_G, total fluidization number; ΔP_c, resistance of the cap, kPa; ΔP_c°, resistance of the cap at critical flow rate, kPa; ΔP_{sz}, resistance of the stagnant zone, kPa; ΔP_{sz}°, maximum resistance of the stagnant zone at the instant of its destruction, kPa; ξ, resistance coefficient of the cap; ρ_g, ρ_p, density of the gas and of the packed layer, respectively, kg/m³; ε, porosity of the bed.

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ALTERNATIVE METHOD OF DESCRIBING THE KINETICS OF CRYSTALLIZATION

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We present a comparative analysis of a macrokinetic type equation and the Avrami–Kolmogorov equation for describing the crystallization of polymers. We show that the macrokinetic equation agrees with experiment over the whole range of the degrees of transformations.

A standard method of describing the isothermal kinetics of crystallization based on the Avrami–Kolmogorov equation

$$\alpha(t) = 1 - \exp(-Kt^n) \tag{1}$$

has been available in the scientific literature for a long time. However, this equation is difficult to use to solve practical problems which are complicated by heat transfer, since there is no sufficiently simple generalization of Eq. (1) for a nonisothermal process. This forces us to turn to other methods of describing $\alpha(t)$ quantitatively. We solve this problem by employing the so-called macrokinetic approach, which is widely used to solve problems of

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