GAS DISTRIBUTION IN A PACKED BED

V. V. Chukin and R. F. Kuznetsov

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The authors give experimental and theoretical results obtained in studying the effects of the bed filtration rate, bed height, and the piece diameter on the distribution of gas streams in a close-packed bed.

The development of heat- and mass-transfer processes in a packed bed is largely determined by the uniformity of the gas stream in the piece bed. However, at present, the factors responsible for gas motion in the bed have not been studied sufficiently. Problems such as the effect of bed height and filtration rate on velocity-field uniformity are also as yet unsolved.

Results of experimental studies and some theoretical comments concerning these problems are given below.

Device and study techniques. The studies were performed on a cold shaft furnace (Fig. 1). The model is of cylindrical cross section, 120 mm in diameter, 1500 mm high, and utilizes one-way air draft. The bed height is read off from point B (Fig. 1). The shaft below point B is first filled with the piece material under study.

Figure 1 shows the gas distribution over the cross sections; this distribution was measured with a disk attachment placed directly on the bed. The attachment has 33 pulse tubes for measuring the total head above the bed; this makes it possible to plot the velocity field over the entire cross section of the shaft. Such pulses over the bed make it possible to measure without disturbing the structure of the packed bed. The absolute value of the effective cross section (27.5%) of the disk attachment is assumed to be close to the area of the gaps in the bed. In our experiment, the spacing in the bed was 22–23% according to the data in [1] and 25% according to the data of [2]. The fact that the effective cross section of the attachment and bed spacing is the same makes it possible to eliminate redistribution of the gas flows ahead of the disk attachment.

After the disk attachment was installed in the model, the space between the tube and the edge of the attachment was sealed with plasticine to prevent intensification in peripheral gas flow. Later, however, this was done away with since control experiments established that the gas-velocity fields resulting from a disk attachment with a sealed and unsealed space are the same.

The gas-velocity distribution in the bed was checked by using pressurized tubes placed directly in the bed according to a standard technique [3]. The velocity fields as measured by the disk attachment and by the pressurized tubes coincide to within 5–6%.

The experimental data were processed as follows:

1) the mean arithmetic total head over the cross section (P_{av}) was calculated from the data obtained from individual measurements of the total head at individual points;

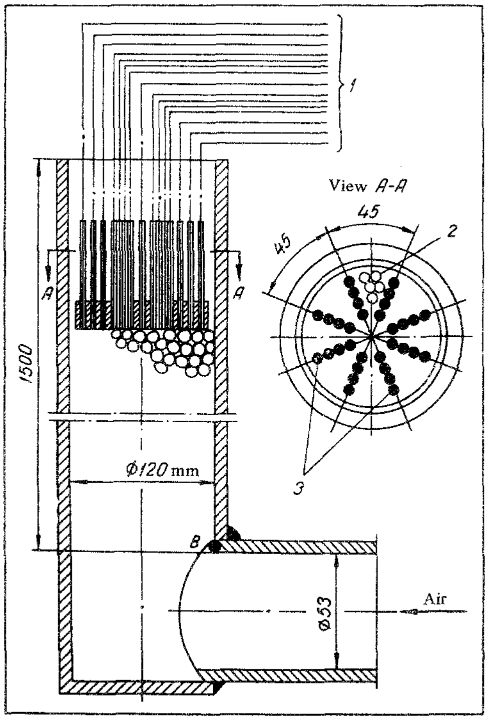

Fig. 1. Diagram of device and basic dimensions of model: 1) pulse lines; 2) 442 apertures with d = 3 mm over entire surface of disk; 3) 33 apertures corresponding to pulse points.

2) from the value of P_{av}, gas flow nonuniformity at each point in the bed was determined:

$$H_i = \frac{P_i \pm P_{av}}{P_{av}};$$

3) the mean arithmetic nonuniformity (H_{av}) in gas flow over the cross section of the model shaft was calculated.

Experiments were performed with peas (d = 4.6–6.0 mm) and steel spheres (d = 12.6–12.9 mm). The ratio of the shaft diameter to the mean weighted diameter of the piece for these materials was, respectively, 24 and 10 while the ratio of the shaft height to the mean weighted piece diameter was, respectively, 300 and 120.

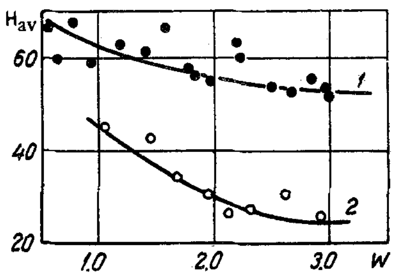

Fig. 2. Effects of bed-filtration rate on gas distribution within the bed (W, m/sec; H_{av}, %): 1) bed height equal to the piece diameter; 2) bed height equal to three times the piece diameter.

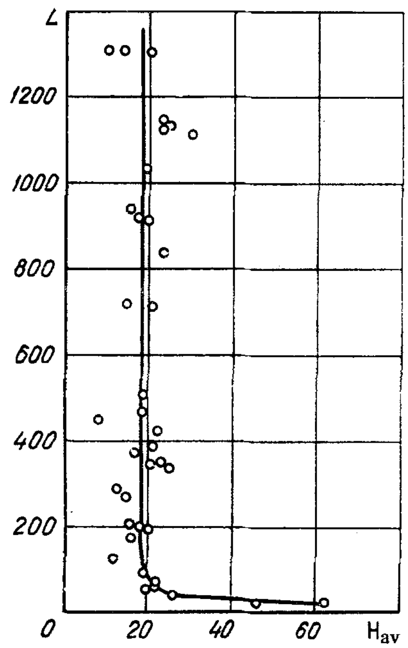

Fig. 3. Effect of bed height on gas distribution within the bed. Pea material is used with d = 4.6–6.0 mm (L, mm; H_{av}, %).

Fifty experiments in all were performed. Each type of experiment was repeated three to four times; the results coincided to within 6%.

Effect of bed-filtration rate on gas distribution. Experiments showed that with an increase in the bed filtration rate there is a decrease in the nonuniformity of gas flow in the shaft of the model (Fig. 2). For example, an increase from 1 to 3 m/sec in gas velocity (calculated for the free section of the shaft) reduced the average nonuniformity in the gas flow in the bed by 10% for a bed height equal to the piece diameter and by 20% for a bed height equal to 3 times the piece diameter. A similar effect also occurred at other levels in the shaft of the model. Similar experimental results were obtained in [4] with the above technique for graphite spheres 8–10 mm in diameter and a bed height equal to ten times the piece diameter.

Thus, even in a bed with material of uniform dimensions, an increase in W leads to an equalization of the velocity field in the bed. In a bed of polydisperse material this effect is considerably stronger [3].

Studies have shown [5] that in actual shaft units, segregation of the material is unavoidable due to imperfections in contemporary charging devices, i.e., pieces of various diameters (arbitrarily taken as d_1 and d_2) are placed at different sections of the furnace.

The resistance of the bed material (lumps or spheres) is written in general form as

$$\Delta P = \xi \frac{\gamma W^2}{2g\varphi^2 d} L. \quad (1)$$

The value of ΔP at a given bed height is the same for materials of different diameters. Now, allowing for the fact that the porosity of the spherical materials is independent of their diameter [2] (i.e., $\varphi_1 = \varphi_2$), we can write

$$\xi_1 \frac{W_1^2}{d_1} = \xi_2 \frac{W_2^2}{d_2}, \quad (2)$$

i.e., in this case the gas-flow distribution is determined from the piece diameter and from the resistance coefficient of each bed fraction:

$$\frac{W_1}{W_2} = \left(\frac{\xi_2}{\xi_1}\right)^{1/2} \left(\frac{d_1}{d_2}\right)^{1/2}. \quad (3)$$

With a change in the bed-filtration rate there is a redistribution in the gas flows over the furnace cross section only because of a change in the ratio ξ_2/ξ_1, since the ratio d_1/d_2 is constant.

It is commonly known [1, 3, 6–19] that with an increase in Re the bed resistance coefficient ξ attenuates in accordance with the equation [7]

$$\xi = \frac{A}{\mathrm{Re}^n} + B = \frac{A}{\left(\frac{Wd}{\nu}\right)^n} + B. \quad (4)$$

It is clear from an analysis of Eqs. (3) and (4) that in actual shaft furnaces the difference $\xi_1 - \xi_2$ decreases as the bed-filtration rate increases; this increase in turn results in a decrease in the ratio $(W_1^2 - W_2^2)/W_2^2$ which characterizes the nonuniformity in the cross sectional flow distribution (this is also confirmed by experimental data).

Effect of bed height on gas distribution. The gas-velocity distribution in a bed of piece material (with the pieces exhibiting various diameters) is described by Eq. (3). The quantities ξ and d on the right-hand side of this equation are independent of the bed height. We can thus conclude that, after the gas jet finishes expanding into the bed, an increase or a decrease in bed height will not affect the gas-flow distribution within it.

In fact, experimental data show (Fig. 3) that stabilization in the gas-flow distribution over the bed cross section begins even at a height of ~15 mm. A further increase in bed height to 1400 mm does not result in any significant equalization of the velocity field in the bed. Nonuniformity in gas flow remains almost constant at any height.

Thus, the bed height determines the gas distribution within the bed only in the section where the gas jet is expanding into the bed; however, it does not have any great effect on the gas distribution in the layer as a whole. Therefore the bed height should not be increased to obtain uniform gas flow.

NOTATION

P is the total gas head in the bed; H is the nonuniformity of the gas flow in the bed; ΔP is the bed resistance; ξ is the resistance coefficient of the bed; γ is the specific density of the gas stream; W is the gas velocity at the free section; φ is the bed porosity; d is the piece diameter; L is the bed height; g is the gravitational acceleration; ν is the gas flow viscosity; A and n are empirical coefficients.

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Institute of Metallurgical Thermal Engineering, Sverdlovsk