MIXING OF MATERIALS IN ADJACENT FLUIDIZED BEDS

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This paper presents a method of determining the rate of mixing of the solid phase in adjacent fluidized beds. Experimental data are given.

Installations consisting of several adjacent chambers connected hydraulically to one another by openings or overflows in the dividing partitions are widely used in fluidized-bed engineering. In the case of drying of various materials in a fluidized bed such installations ensure ordered movement of the material and largely obviate the overshoot of the unprocessed material into the final product, an unavoidable occurrence in single-chamber operation [1].

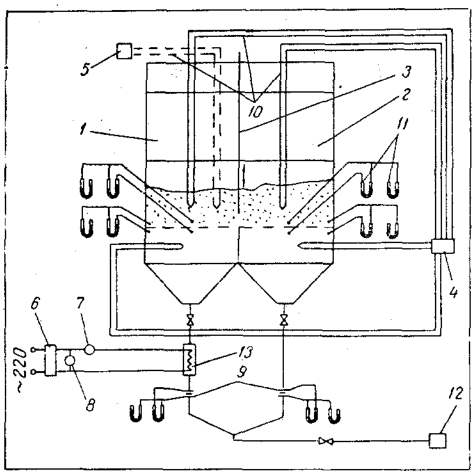

Fig. 1. Diagram of experimental apparatus: 1) Hot chamber; 2) cold chamber; 3) partition; 4) EPP-09 potentiometer; 5) PP potentiometer; 6) laboratory autotransformer; 7) ammeter; 8) voltmeter; 9) measuring diaphragms; 10) thermocouples; 11) manometric tubes; 12) RGN-600 air blower; 13) electric heater.

In the thermal treatment of metal articles [2, 3] in a fluidized bed the use of two-chamber installations ensures the transfer of heat by the material circulating through the opening from one chamber to the other and thus creates in the two chambers zones with different temperatures or gas composition with the liberation of heat (due to combustion of the gas, for instance) in only one of them. Despite the wide use of such installations the laws governing the transfer of the solid phase through the opening in adjacent fluidized beds have hardly been investigated at all. It was shown in [5, 6] that in the absence of a pressure gradient there is a diffusive flux of particles through the opening in the wall separating fluidized beds.

So far the only investigation dealing with the quantitative characteristics of mixing of the material in adjacent fluidized beds is [4]. The investigations were conducted in a small rectangular apparatus with cross-sectional dimension 0.0380 × 0.0760 m and height 0.228 m. The apparatus was divided by a partition with 6.36 × 6.36 mm square holes. One of the chambers was loaded with electrically conductive coke and the other was loaded with a mixture of nonconductive and conductive cokes. The voltage drop between electrodes immersed in the second chamber was measured, and the concentration of particles of nonconductive coke in each chamber was determined from a calibration curve. Using a curve representing the change in the concentration of nonconductive coke with time the researchers determined the mass flow (ω, g/sec) of circulating coke due to horizontal mixing through the openings.

The mode of transport of particles from chamber to chamber is similar to that of horizontal mixing. Bubbles rising above the partition eject particles to the side, and they pass from one chamber to the other.

The rate of mixing can be characterized by the solids flux density (j, kg/m^2·sec), which indicates the amount of solids passing in one direction through one square meter of opening per second. In steady-state conditions without supply or withdrawal of material there will, of course, be an equal flux in the opposite direction.

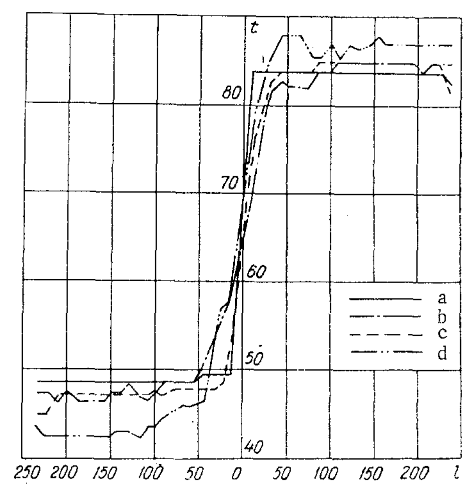

Fig. 2. Temperatures measured at different levels over chamber (t in °C, l in mm): a) for z = 110 mm; b) 20; c) 10; d) 2.5.

The first series of experiments described below was carried out on an experimental apparatus (Fig. 1) consisting of a chamber of rectangular section (0.5 ×

$\times$ 0.092 m) and height 1 m, divided into two halves by a movable vertical wooden partition 3.5 mm thick. Air heated in an electric heater ($t = 90°–100°$ C) was blown into the bottom of one half of the chamber, and cold air ($t = 20°–30°$ C) was blown into the other. From the heat-balance equation in steady-state operation we found the value of

$$G_s = \frac{[Q'_{ha} - Q''_{ha} - Q_{par} - Q^{I}_{loss}]}{C_s (t_h - t_c)} \qquad (1)$$

with which the required quantity j is connected by the relationship

$$j = G_s / F_{sl}. \qquad (2)$$

In the treatment of the experimental data we neglected the transfer of heat through the opening by the gas in view of the absence of a pressure gradient and the insignificant bulk specific heat of the gas.

The loss of heat to the surroundings was assumed to be proportional to the difference in temperature between the half of the chamber and the surroundings. This perfectly logical assumption enables us to estimate the heat loss to the surroundings from the following formulas:

$$Q^{I}_{loss} = Q^{exp}_{loss}(t_h - t_0)/(t_h + t_c - 2t_0), \qquad (3)$$

$$Q^{II}_{loss} = Q^{exp}_{loss}(t_c - t_0)/(t_h + t_c - 2t_0). \qquad (4)$$

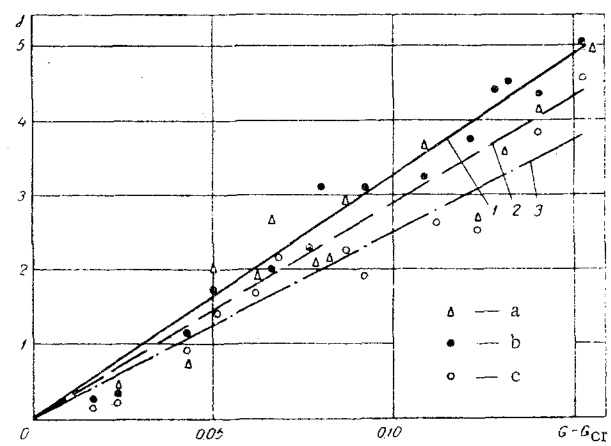

Fig. 3. Plot of solids flux density j(kg/m^2·sec) against superficial mass rate $G - G_{cr}$ (kg/m^2·sec) and height of opening H_{op} (mm): 1) and a) H_{op} = 30; 2 and b) H_{op} = 110; 3 and c) H_{op} = 70.

Although the apparatus was thoroughly insulated, the loss to the surroundings at low air flow rates reached 20%. For the heat transfer through the partition we introduced a heat transfer coefficient k_0, which was assumed constant over the height of the bed and was determined in the case of a completely shut partition from the formula

$$k_0 = Q^0_{par}/H^0_{par}(t_h - t_c). \qquad (5)$$

The heat transfer through the partially open partition was then found from

$$Q_{par} = k_0 H_{par} b (t_h - t_c). \qquad (6)$$

Thus the experiment reduced to measurement of the air flow and the temperatures of the bed and the hot and cold air at the entrance to the bed. As the entrance temperatures of the air we took the temperatures of the hot and cold air under the screen. To determine the temperature t which could be regarded as that of the bed we measured the temperature distribution in the two chambers in different operating conditions with a movable thermocouple.

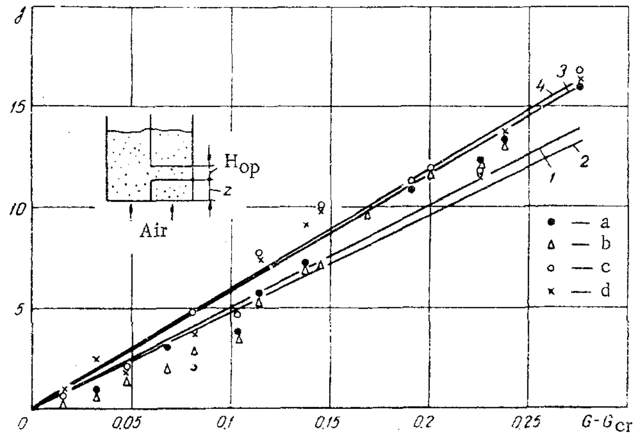

Fig. 4. Plot of solids flux density j(kg/m^2·sec) against superficial mass rate $G - G_{cr}$ (kg/m^2·sec) and height z (mm) of opening above screen; 1 and a) z = 0; 2 and b) z = 30; 3 and c) z = 60; 4 and d) z = 90.

The temperature profile illustrated in Fig. 2 shows that the temperatures measured in the bed by an unshielded thermocouple were rapidly evened out over the section and over the height. This fact is indicative of the thorough mixing in the beds. Hence, as the bed temperature we took the temperature indicated by an unshielded thermocouple mounted at a distance from the screen equal to half the height of the bed at rest and in the center of the half of the chamber.

In the treatment of the data we found the mean value for slit heights H_{sl} = 30, 70, and 110 mm in relation to the superficial mass fluidizing velocity. The particle material in all cases was fine corundum ($d_p = 120\mu$) and the fluidizing agent was air.

Figure 3 shows the relationship $j = f(G - G_{cr})$ for the range G/G_{cr} = 1–3.5. The bulk specific heat C_s of the solid phase was taken as 1.14 kJ/kg·deg. More accurate data gave C_s = 0.83 kJ/kg·deg. With this latter figure the data were represented reasonably accurately by the straight lines

$$j = A(G - G_{cr}), \qquad (7)$$

where A = 47, 34, and 42 for slit heights 30, 70, and 110 mm, respectively. The height of the bed at rest in all the experiments was 110 mm.

All the straight lines pass through a point where, according to the experimental data, there is no mixing. The rate at this point is 0.061 kg/m^2·sec, which is 10% below the stability limit calculated from Todes' formula [7] for a bed voidage ε_{cr} = 0.532. This discrepancy can be attributed to the nonsphericity of the particles and some variation in ε_{cr}.

$$\mathrm{Re}_{cr} = \mathrm{Ar} \Bigg/ \left(150 \frac{1-\varepsilon_{cr}}{\varepsilon_{cr}^3} + \sqrt{\frac{1.75}{\varepsilon_{cr}^3}\mathrm{Ar}}\right), \qquad (8)$$

where

$$\mathrm{Ar} = \frac{g d_p^3}{\nu^2} \frac{\rho_s - \rho_f}{\rho_f}; \quad \mathrm{Re}_{cr} = \frac{W_{cr} d_p}{\nu}.$$

The second series of experiments was conducted on an experimental apparatus which differed from the first only in the cross-sectional dimensions (0.3 × × 0.11 m) and in having improved heat insulation to reduce the heat loss. The method of determining j was the same as before. We investigated the value of j in relation to the superficial mass air flow $G-G_{cr}$ and the height z of the slit above the screen. The dimensions of the slit were the same as before (0.11 × 0.03 m). The experiments were conducted with corundum (d_p = = 120 μ) and the bed height at rest was H = 120 mm.

The experimental data are shown in Fig. 4. They are satisfactorily described by relationship (7), where the coefficient A is considerably higher than in the first experiments and is equal to 72, 66, 80, and 81 for distances of 0, 30, 60, and 90 mm, respectively, between the lower edge of the slit and the screen.

The value of j was determined also in [4]. The data were treated in the form of a relationship $j = k(W - W_{cr})$, where the coefficient k is called the circulation flux density and has dimensions kg/m³. The numerical values obtained in [4] agree satisfactorily with our data of the second series. However, the dimensions of the openings in Lochiel and Sutherland's experimental apparatus [4] were very small (6.36 × × 6.36 mm), and these authors found that on slightly altering the size of the holes the value of j was inversely proportional to the area of the opening raised to the power 0.29:

$$j \backsim F_{sl}^{-0.29}. \qquad (9)$$

The slit area in our apparatuses was 83 times greater than in [4]. If the above relationship holds, this should reduce the value of j by a factor of almost four. The disagreement between the experimental data and relationship (9) casts doubt on the applicability of this relationship in experimental conditions differing from those in [4].

NOTATION

j is the solids flux density, kg/m²·sec; G_s is the mass of solids passing through opening in one direction, kg/sec; Q'_{ha}, Q''_{ha} is the heat brought into chamber by heated air and carried out of it, W; Q_{par}, Q''_{par} is the heat transferred from hot to cold chamber through partially opened and completely closed partition, respectively, W; H_{par}, H^0_{par} is the height of partition involved in heat transfer with partition partially opened and completely closed, respectively, m; Q^{exp}_{loss} is the experimentally determined heat loss, W; Q^{I}_{loss}, Q^{II}_{loss} are the losses of hot and cold chambers to surroundings, W; t_c is the temperature of cold bed, °C; t_h is the temperature of hot bed, °C; t_c is the ambient temperature, °C; k_0 is the coefficient of heat transfer through partition, W/m², °C; G is the mass flow rate of fluidizing agent, kg/m²·sec; G_{cr} is the minimum fluidizing mass flow rate, kg/m²·sec; d_p is the particle diameter, m; b is the slit width, m; F_{sl} is the area of slit, m²; z is the height of slit above screen; ε_{cr} is the bed voidage at minimum fluidization; g is the gravitational constant, m/sec²; ν is the kinematic viscosity, m²/sec; ρ_s, ρ_f is the density of solids and fluid, respectively, kg/m³; W_{cr} is the minimum fluidizing velocity, m/sec; W is the fluidizing velocity, m/sec; Re_{cr} is the Reynolds number at minimum fluidization; Ar is the Archimedes number.

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