EXPERIMENTAL STUDY OF THE HEAT TRANSFER PATTERN IN A DILUTED FLUIDIZATION BED

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An experiment was performed to establish a relation between the heightwise distribution of porosity and the heat-transfer coefficient in a diluted fluidization bed.

According to the hypothesis in [1], the concentration of particles decreases along the height of a monodisperse fluidization bed with a wide layer expansion and an adequate gas distribution. It has also been established in [1] that the total pressure in a diluted fluidization bed decreases exponentially as

$$P_h = P_0 \exp(-Fh). \tag{1}$$

Assuming that the concentration of particles varies along the height according to the same law as the pressure does, we have

$$\frac{\varepsilon_h}{\varepsilon_0} = \exp(-Fh). \tag{2}$$

Without quantitative data on the porosity variation along the height [2-4], little progress can be made in the study of heat transfer in a fluidization bed and it is not possible to determine the heat transfer coefficients with sufficient accuracy. For this reason, an important aim of further studies in the area is to

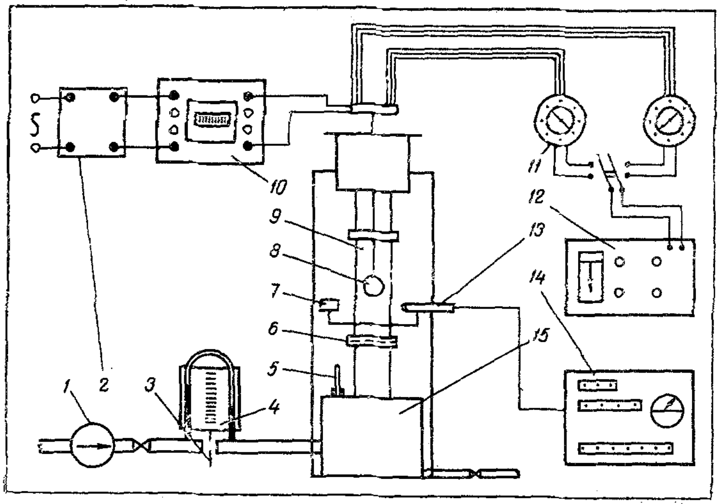

Fig. 1. Schematic diagram of the test apparatus: 1) air blower; 2) model RNO-250-2 transformer; 3) metering diaphragm; 4) differential manometer; 5) thermometer; 6) distributor grid; 7) γ-radiation source; 8) thermal probe; 9) cylindrical reactor; 10) measuring block; 11) switch; 12) model PP-63 potentiometer; 13) model HST-6 ionization chamber; 14) model PST-100 radioscope; 15) damping chamber.

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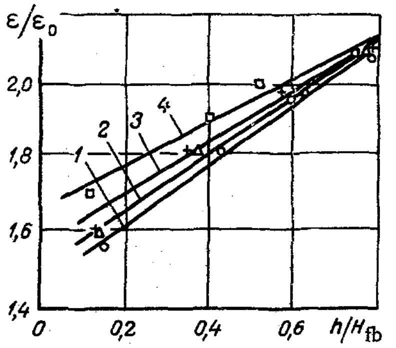

Fig. 2

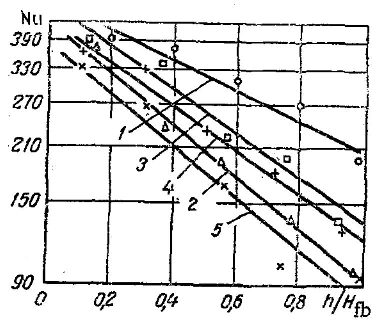

Fig. 3

Fig. 2. Relation $\varepsilon/\varepsilon_0 = f(h/H_{fb})$ for corundum d = 0.36 mm: 1) w_f = 1.34 m/sec; 2) 1.52 m/sec; 3) 1.76 m/sec; 4) 2.03 m/sec.

Fig. 3. Relation $Nu = f(h/H_{fb})$ for corundum d = 0.36 mm: 1) w_f = 1.02; 2) 1.55 m/sec; 3) 1.76 m/sec; 4) 2.19 m/sec; 5) 2.34 m/sec.

determine the local porosities along the bed height as a function of various physical parameters characterizing such a bed, namely: of the flow velocity, of the particle diameter, of the material density, etc.

In order to study the local porosity and the heat transfer in a monodisperse fluidization bed with a wide layer expansion, the authors have performed tests with the apparatus shown schematically in Fig. 1. The bed with a gaseous fluidizing agent was produced in a cylindrical reactor, inside diameter 150 mm and height 800 mm, made of acrylic glass so as to make it possible to visually observe the bed expansion and behavior. To this reactor was attached a millimeter scale for reading the height of both the loose solid material and of the fluidized material, and for ensuring the proper height of installed thermal probes. In order to maintain the bed and to uniformly distribute the fluidizing agent, a grid of stainless steel 2 mm thick was placed inside the reactor. This grid had 1993 holes 0.65 mm in diameter and a 3.73% active section area. The apparatus operated as follows. Atmospheric air was injected through a receiving chamber (for cooling the air and for damping the pressure pulsations) into the reactor, from where through the fluidization bed it was exhausted back into the atmosphere. The air flow rate was regulated by a valve in the high-pressure line and was measured with a differential manometer mounted on a metering diaphragm. Following earlier recommendations [5], this diaphragm was tared out with water.

The fine-grain solid material in our experiment were three fractions of corundum particles: 0.36 mm, 0.60 mm, and 1.6 mm diameter. For each fraction we built up a stationary bed to a height of 90 mm. The local porosity was measured by γ-ray radioscopy of the diluted fluidization bed. The attenuation of the narrow collimated beam of γ-rays by a layer of absorbing material is exponential:

$$I = I_0 \exp\left(-\sum_i \mu_{x_i} x_i\right).$$

After a few transformations, Eq. (3) can be rewritten more conveniently as

$$\ln \frac{N - N_g}{N_1 - N_g} = -[\mu_S (1 - \varepsilon) + \mu_A(\varepsilon)] D_0. \qquad (4)$$

As the source of γ-radiation we used the radioactive cobalt-60 isotope with a half-life of 5.27 yrs and an emission energy of 1.17-1.33 MeV. The intensity of the γ-radiation was measured with gas-filled counters having types HTS-6 steel cathodes. The advantage of this procedure was that, with the entire instrumentation immersed in the bed, the bed structure remained undistorted during the measurements.

The local porosity was measured at four different filtration rates in each fine-grain fraction, from 40 mm above the gas distributor grid up.

For studying the heat transfer between an inner surface and the diluted bed with a gaseous fluidizing agent, we used in our tests a ball-shaped thermal probe 55 mm in diameter. This copper probe was made up of two hemispheres with six equally spaced hot thermocouple junctions soldered to one of them around the semiperimeter parallel to the oncoming air stream. In order to eliminate the possibility of short circuits through the heater and to avoid stray induced emfs, the thermocouples were insulated with Teflon

TABLE 1. Values of C and K at Various w_f and H_{fb}

d, mm	ε_0	w_f, mm	H_{fb}, mm	C	K
0,360	0,4645	1,34	270	1,45	0,48
		1,52	300	1,50	0,44
		1,76	320	1,63	0,35
		2,03	380	1,54	0,42
0,600	0,3911	1,76	300	1,66	0,53
		1,96	320	1,72	0,49
		2,15	330	1,83	0,43
		2,32	340	1,77	0,48
1,600	0,4187	3,04	280	1,63	0,48
		3,40	300	1,79	0,38
		3,69	350	1,73	0,41
		3,99	400	1,85	0,35

TABLE 2. Values of A and B at Various w_f and H_{fb}

d, mm	w_f, m/sec	H_{fb}, mm	A	B
0,360	1,02	200	522,17	—0,93
	1,55	270	448,54	—1,55
	1,76	300	506,23	—1,36
	2,19	350	452,60	—1,30
	2,34	380	388,00	—1,50
0,600	1,66	290	547,30	—1,96
	2,03	300	548,40	—1,86
	2,26	350	483,96	—1,81
	2,48	400	511,83	—2,06
	2,68	420	409,12	—1,68
	2,87	450	413,23	—1,60
1,600	3,10	240	351,78	—1,26
	3,51	280	448,09	—1,42
	3,92	300	331,62	—1,11
	4,26	350	385,68	—1,20
	4,61	400	357,81	—1,42

coating and their lead wires pulled through a shielding sleeve. The heater elements for the thermal probe were wound with size 0.5 mm (diameter) Nichrome wire.

The heat transfer tests were performed with the same corundum fractions in which the local porosity was measured. In each fraction we established 5-6 different filtration rates and the thermal probe was held at five different heights in the diluted fluidization bed.

An analysis of the particle distribution along the height of a diluted fluidization bed has shown that the relative porosity is a function of the relative height. Test data describing this relation are shown in Fig. 2. An evaluation of the test data by the method of least squares has yielded the following relation between the relative porosity and the relative height in a diluted bed:

$$\frac{\varepsilon}{\varepsilon_0} = C \exp\left(K \frac{h}{H_{fb}}\right), \qquad (5)$$

where C and K are constants for a given particle size and a given filtration rate.

In Table 1 we show the data, already evaluated, for each of the fine-grain fractions used in our experiment. These results indicate that coefficient K for any given corundum fraction decreases as the filtration rate increases, while coefficient C increases with the size of particles in a particular fraction.

An evaluation of data pertaining to the internal heat transfer in a diluted fluidization bed indicates that the heat-transfer coefficient is an exponential function of the relative bed height, namely:

$$\mathrm{Nu} = A \exp\left(B \frac{h}{H_{fb}}\right), \qquad (6)$$

with $\mathrm{Nu} = \alpha d_p/\lambda_f$ and A, B being constants for a given fraction a given filtration rate.

Test data pertaining to monodisperse particles of the 0.36 mm fraction are shown in Fig. 3. Test data pertaining to the internal heat transfer in a diluted fluidization bed are shown, already evaluated, in Table 2.

Results of this study could be useful for the hydraulic and thermal design of apparatus with diluted fluidization beds.

NOTATION

P_0, P_h are the pressure at the distributor grid level and at height h respectively;
H_0, H_{fb} are the height of the loose solid and of the fluidized bed respectively;
h is the height coordinate;

I_0, I	are the intensity of incident radiation and of radiation which has passed through the material respectively;
x_i	is the thickness of the i-th layer of absorbing material;
μ_{x_i}, μ_S, μ_A	are the linear γ-radiation attenuation factor: overall, in the fluidizing agent, and in air respectively;
N_g, N_1, N	are the number of pulses per unit time: due to background noise, during irradiation of the reactor containing a fluidization bed, and during irradiation of the empty reactor respectively;
α	is the mean heat-transfer coefficient for a ball immersed in a fluidization bed;
λ_f	is the thermal conductivity of the fluidizing agent;
D_0, d_p, d	are the diameter of the empty reactor, of the copper ball, and of a corundum particle respectively;
F	is the constant coefficient;
ε_0	is the porosity of a loose bed;
ε	is the porosity at any given instant;
$Nu = \alpha d_p/\lambda_f$	is the Nusselt number.

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