INFLUENCE OF AERODYNAMICS OF A CIRCULATION FLUIDIZED BED
ON INTENSITY OF EXTERNAL HEAT TRANSFER

A. P. Baskakov, V. K. Maskaev, I. V. Ivanov,
and A. G. Usol'tsev

UDC 621.1:66.02

The authors present results of an experimental investigation of external heat transfer over the height of a circulation fluidized bed.

External heat transfer in a circulation fluidized bed has been studied experimentally on an equipment closed with respect to the disperse material, and open with respect to the gas. Its basic element, an experimental channel of height 10 m and diameter 0.25 m, has pressure taps and also transparent windows for visual observation [1]. As disperse material we used the ash of Estonian shale from the bottom of cyclones of electric power stations with an average particle diameter of 78 μm (the fractional composition is shown in Table 1).

The true density and the bulk density of the ash were 2856 and 1167 kg/m^3, respectively. As the fluidizing agent air at temperature 25-45°C arrived under the grid with speed w = 2-10 m/sec as computed in the empty channel section. The solid material in amount up to 7.7 ton/hr [which corresponded to a specific charge G_s of up to 44 kg/(m^2·sec)] was supplied to the channel with the aid of a screw conveyor of diameter 144 mm, mounted at a height of 175 mm from the gas distribution grating. In the experiments we used gratings of two types: a perforated type (active cross section f = 10%) for fluidizing air speed w from 5.3 to 10.1 m/sec, and a hooded type (f = 1%) for speeds w = 2.4 to 4.3 m/sec, which allowed us to decrease considerably the speed at which "pile-up" set in.

The external heat transfer between the bed and the channel wall was studied by the steady-state method with the aid of an electrical calorimeter of height 0.1 m and internal diameter (0.25 m) the same as the experimental channel, set up at heights 0.43; 1.07; 1.91; 3.95; 6.43 m from the level of the gas distribution grating.

The mean surface heat transfer coefficient α between the bed and the calorimeter wall was computed from the thermal power, accounting for loss from the external surface of the thermal insulation and leakage through the ends, after the experiment reached steady temperature conditions, and the power supplied. The convective—conductive heat transfer coefficient α_K was calculated as

$$\alpha_K = \alpha - \alpha_r, \tag{1}$$

where α_r = 6 W/(m^2·K) is the computed radiative heat transfer coefficient.

To check the correctness of the method we determined the heat transfer coefficient for the flow without dust. If the length l of the calorimeter heat transfer section along the

TABLE 1. Fractional Composition of the Ash

Fraction size, mm	Mass fraction, %	Fraction size, mm	Mass fraction, %	Fraction size, mm	Mass fraction, %
0,4	0,05	0,2—0,16	3,95	0,063—0,05	4,95
0,4—0,315	0,55	0,16—0,1	2,225	0,05—0,04	17,425
0,315—0,25	1,525	0,1—0,08	29,525	0,04	18,925
0,25—0,2	2,970	0,08—0,063	18,4		

S. M. Kirov Ural Polytechnic Institute, Sverdlovsk. Translated from Inzhenerno-fizicheskii Zhurnal, Vol. 61, No. 5, pp. 778-781, November, 1991. Original article submitted September 19, 1990.

 0022-0841/91/6105-1368$12.50

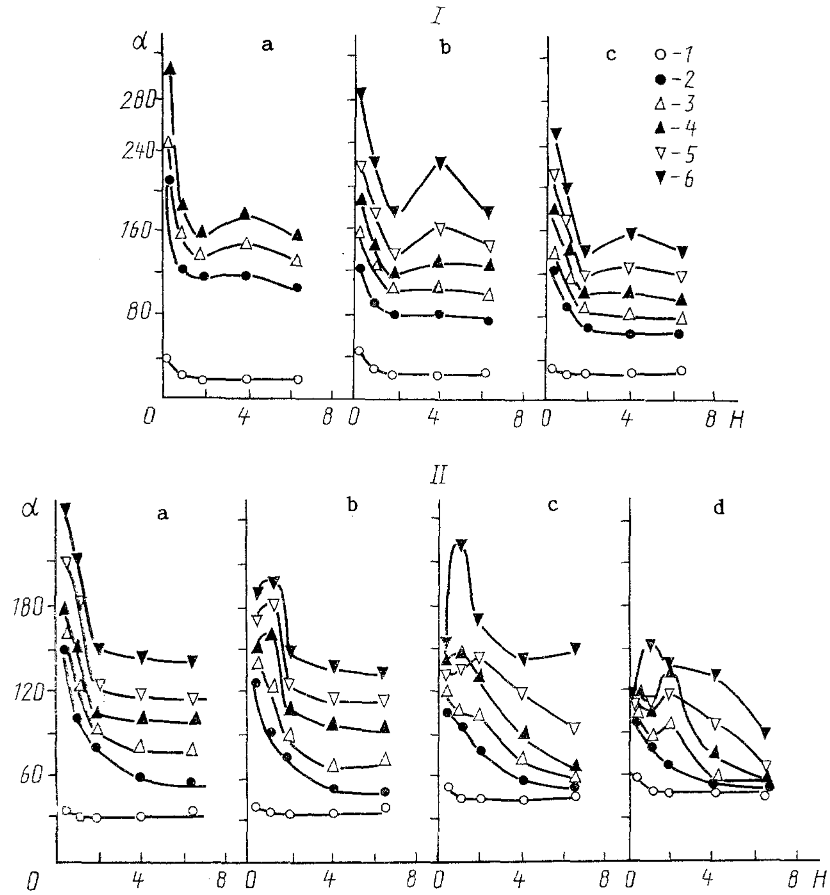

Fig. 1. Distribution of the convection—conduction heat transfer coefficient over the height of a circulation fluidized bed in a channel with a hood [I – a) w = 2.4 m/sec; b) 3.3; c) 4.3] and with a perforated grating at the inlet [II – a) w = 5.3 m/sec; b) 6.1; c) 8.3; d) 10.1]: 1) G_s = 0 kg/(m²·sec); 2) 5.91; 3) 9.9; 4) 16.54; 5) 26.48; 6) 43.29. α_K, W/(m²·K); H, m.

gas stream is small (less than the diameter D_t of the tube) the thermal boundary layer is formed on the annular calorimeter in the same way as for longitudinal flow over a plate, for which the formula has been proposed [2]:

$$\overline{\mathrm{Nu}_l} = 0{,}037\,\mathrm{Re}_l^{0,8}\mathrm{Pr}^{0,43}. \tag{2}$$

Comparison of our experimental data (35 points) with calculations using this formula gave an rms deviation of 4.8%.

In dust-free air the value of α_K was the same for all the calorimeters except for the lowest (H = 0.43 m), which gave a higher value of α_K. Here one sees the influence of the gas distribution grating, which introduces added turbulization. With increasing distance from the grating this artificial turbulence attenuates and α_K stabilizes. As the specific charge of ash particles in the flow increased, the distribution of heat transfer coefficients over height in the equipment varied, and was sometimes complex.

In the upper part of the equipment (H > 4 m) the coefficient α_K was practically constant for specific charge levels G_s < 16.54 kg/(m²·sec) for all air speeds except for w = 8 – 10 m/sec, whee α_K is constant up to G_s < 9.9 kg/(m²·sec) (Fig. 1). In the lower part of the equipment, in the acceleration section, α_K increases sharply as the gas distribution grating is approached. This is connected with the nature of the distribution of bed density with channel height (Fig. 2). At a height H > 4 m the density is constant, but below this it falls steadily. With increase of the specific charge G_s the heat transfer coefficient α_K increases practically at all heights, except for the case when the calorimeter fell in the vortex action zone.

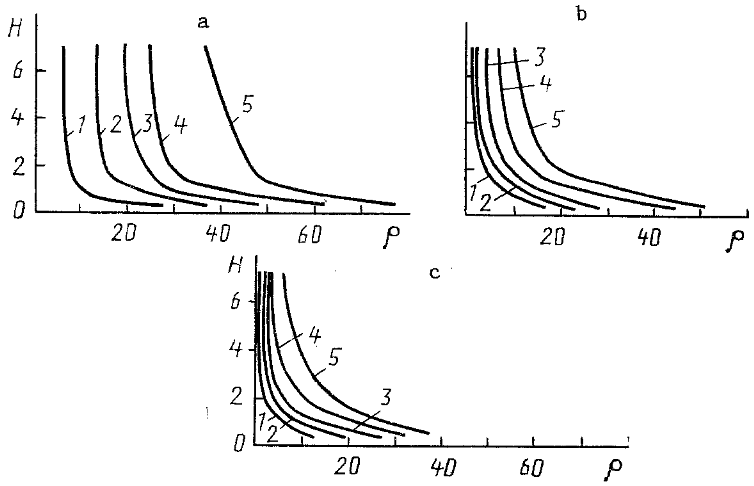

Fig. 2. Distribution of density with channel height for a circulation fluidized bed: a) with a hood inlet grating with w = 3.3 m/sec; b, c) with a perforated inlet grating with w = 5.3 m/sec (b) and 8.3 (c); 1) G_S = 5.91 kg/(m²·sec); 2) 9.9; 3) 16.54; 4) 26.48; 5) 43.29. ρ, kg/m³.

For G_S = 5.91 kg/(m²·sec) and practically all speeds of the fluidizing air the distribution of $\alpha_K(H)$ is a smooth exponential (see Fig. 1). With further increase of G_S the exponential dependence changes shape – a different kind of throat and dip appears. This stems from the complexity of aerodynamics of the circulation fluidized bed, and specifically from the formation of vortex zones over the range of height in the equipment, within which there is a substantial increase of the heat transfer coefficient, and in some cases the vortex motion becomes so intense that α_K in this zone becomes even much larger than at the gas distribution grating, where the flow density is a maximum. Judging from the variation of α_K there is in the channel a single powerful vortex which is displaced in height as the flow speed changes, drawing close to the gas distribution grating as the speed increases. Thus, while at a speed of w = 2-4 m/sec the flow is accelerated at height H ≈ 3-5 m (and here at the speed w = 4 m/sec the vortex attenuates and α_K decreases), in the speed range w = 5-10 m/sec one sees generation and development of vortex motion at height H ≈ 0.5-2 m. This can be seen well in Fig. 1. Here the gas distribution grating has a possible influence: for w = 2-4 m/sec a hooded grating was used, giving a more uniform flow distribution over the cross section of the equipment in its lower part, jets emerging horizontally from the hood apertures, and not vertically, as is the case with the perforated grating. It should also be noted that for w = 8-10 m/sec with increase of G_S the maximum heat transfer coefficient α_K is observed first in the lowest calorimeter, moves later to the region H ≈ 2 m, and then is established at height H ≈ 1 m at the maximum charge (see Fig. 1I, curves c).

In parallel with measurement of the heat transfer coefficient we took visual observations of the behavior of the bed through the transparent glass in the channel wall at a height of H ≈ 1.5-2.5 m. These showed that the peak of α_K (and correspondingly the presence of the vortex) was accompanied by the generation of reverse motion of the material, with a short-duration sticking of material to the channel wall. From this we can postulate that the vortex arises for a specific concentration at any section of the channel. By differentiating the mean experimental dependence of the hydrostatic pressure on channel height we obtained the distribution of bed density with height (Fig. 2). By analyzing the curves $\alpha_K(H)$ and ρ(H) we can see that the developed vortex is observed in the density range ρ ≈ 15-25 kg/m³, and here the higher is the speed w, the less is the density at which it arises. Evidently, here again we see the influence of the grating, especially in the lower part of the channel, where the strongly turbulized flow is redistributed over the channel section under the influence of the particles inserted by the screw conveyor.

From what has been said one can see that the nature of the external heat transfer is determined in the main by the bed aerodynamics, and to decipher its laws is to understand the heat transfer mechanism in a circulation fluidized bed.

NOTATION

D_t) tube diameter, m; f) active grating cross section, %; G_s) specific charge of disperse material, kg/(m²·sec); H) distance from the gas distribution grating to the middle of the calorimeter, m; l) length of the heat transfer section, m; $\overline{Nu}_l = \alpha_K l/\lambda$) Nusselt number, describing external heat transfer on the plate; $Re_l = wl/\nu$) Reynolds number for the plate; Pr) Prandtl number; w) speed of filtration of gas, computed from the empty channel cross section, m/sec; α) total heat transfer coefficient, W/(m²·K); α_K) convection–conduction heat transfer coefficient, W/(m²·K); λ) thermal conductivity, W/(m·K); ρ) bed density, kg/m³; K) kinematic viscosity, m²/sec. The subscripts are: t) tube; ν) convective–conductive; r) radiative.

LITERATURE CITED

1. V. K. Maskaev, A. P. Baskakov, A. G. Usol'tsev, and I. V. Ivanov, Inzh.-fiz. Zh., 57, No. 5, 762-767 (1989).
2. A. A. Zhukauskas, Convective Heat Transfer in Heat Exchangers [in Russian], Moscow (1982).

RESONANCE REGIMES IN NONUNIFORM MOIST VIBRATION-FLUIDIZED BEDS

A. F. Ryzhkov and V. A. Mikula

UDC 536.24:66.096.5

Actual and approximate rheodynamic characteristics are presented for nonuniform, moist vibration-fluidized beds. Good correlation is obtained between calculated dynamic properties and experimental data.

We will examine several practically important relationships for specific cases which combine the presence of extremal (resonance) dependence of the pulsation characteristics on a spatial parameter H of an oscillating system and the frequency ω of the forced motions.

Introduction. The application of a combined method of fluidization makes it possible to input industrially required gaseous reagents and simultaneously to control the motion of a vibrating bed, mainly by increasing the working porosity of the charge. A large number of empirical correlations (see [1-3]) are used for describing the expansion of a vibration-fluidized bed. We applied Richardson's and Zackey's formula for our data [4] and were able to calculate the expansion of a homogeneous vibrating bed with thinly dispersed materials for a given aeration rate.

During the investigation of pressure oscillations in a vibrating bed it was established [5-7] that adding a steady gas flow to the vibration-expanded bed had no practical effect on the resonance character of the vibration liquefaction. The average pressure drop ΔP in the bed for $W \ll 1$ corresponds to vibration liquefaction, but for $W \geq 1$ to a fluidized bed. The frequency spectrum of the pressure pulsations for combined fluidization becomes bimodal with peaks at the vibration frequency and the resonant frequency of the fluidized bed. Thus, the fluidized bed is a limiting case of a vibration-fluidized bed, in which the pulsation has only low-frequency components, while the forced high-frequency oscillators are almost totally damped. A similar case was investigated experimentally and theoretically by Rietema [8] by submersing a vibrating screen in a fluidized bed. When the whole gas-dispersing lattice was vibrated, the increase of the fluidization number to W = 5-10 caused a 50-70% erosion of the pulsation amplitude at the applied frequency. Here the energy of the remaining pulations still exceeded the level of pulsations in the fluidized bed by an order of magnitude. From this it follows that the expansion of the bed is a basic factor through which the gas flow affects the bed dynamics.

S. M. Kirov Ural Polytechnic Institute, Sverdlovsk. Translated from Inzhenerno-fizicheskii Zhurnal, Vol. 61, No. 5, pp. 782-789, November, 1991. Original article submitted October 16, 1990.