TEMPERATURE FIELD AND DYNAMICS OF A VERTICAL GAS JET IN A FLUIDIZED BED

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Experimental results are presented on the determination of the range of a jet and the boundaries of temperature variation of a fluidized bed in its vicinity.

Stable temperatures in a layer below 800°C are obtained in an experimental furnace as a result of the introduction into the upper zone of a fluidized bed of combustion products of natural gas consumed in an immersion burner [1]. With a constant output burner the temperature was almost constant over the entire volume of the fluidized bed except for a small zone near the gas entrance [2].

In [3] it is indicated that the heating of the bed is accomplished through intensive heat transfer by particles from the zone of the spray, thanks to which one can, in devices with an immersion burner, create a controlled atmosphere in the working volume of the fluidized bed, supplying it from below as the fluidizing medium. Data on the velocity and temperature fields near the burner orifice, which are presently absent from the literature, are needed to evaluate the advisability of using this system for heating a fluidizied bed and to determine the boundaries of the working zone.

Visual observations and the data of [4] indicate that after emergence from an orifice into a fluidized bed a jet directed vertically downward forms a gas spray with sharply defined boundaries. The presence of a gas spray is also observed upon the discharge into a fluidized bed of both horizontal jets and jets directed vertically upward [5, 6]. Within the spray particles are almost absent. The development of a gas jet in a boiling liquid occurs in a similar way [7], which is to be expected in light of the analogy between a boiling liquid and a fluidized bed [8]. Using this analogy, let us assume that an air jet with a density ρ_g is diffusing in a fluid with a density $\rho_{f.b}$ of the fluidized bed. These assumptions and observations of the behavior of particles at the boundary of the spray make it possible to suggest a simplified picture of the movement of a gas jet. The development of a gas jet directed vertically downward is characterized by the fact that the kinetic energy of the stream is gradually reduced to zero and it changes its direction toward the surface of the fluidized bed. The downward directed ("direct") stream extends from the burner orifice to the point of retardation of the jet at the end of the spray. The return stream flows in an annular channel formed on the inside by the "direct" stream and on the outside by the surface of the fluidized bed.

The experiments on the study of the interaction of a jet with a fluidized bed were performed on an apparatus with dimensions of 290 × 290 mm in plan and with filtration velocities close to the velocities of the start of fluidization. Preliminary experiments showed that an increase in the fluidization velocity to the optimum value (the velocity corresponding to the most intense "external" heat exchange [9] is understood as the optimum velocity) or higher caused pulsation of the spray dimensions, although it did not have a significant effect on the time average of its dimensions. Air (temperature 20-25°C) was blown into the bed through tubes with inner diameters of 10, 16, 20, and 25 mm. The tubes were mounted with the bottom cut at the level of the upper boundary of the compact bed; the practical advisability of this was demonstrated earlier [2]. The bed was made up of particles of electrocorundum with an equivalent grain size of 120 and 320 μ and of chamotte with a grain size of 250 and 320 μ. Air with a temperature of 20-25°C served as the fluidizing agent. The maximum depth of penetration of the jet (the length of the spray) was determined as follows. A vertical pneumatic tube (the cut of the opening for the total pressure measurement, equal to

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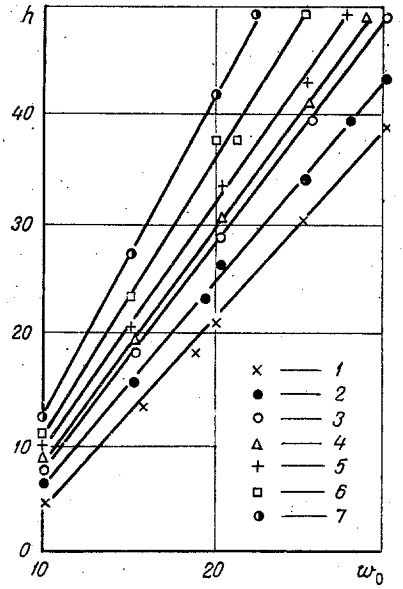

Fig. 1

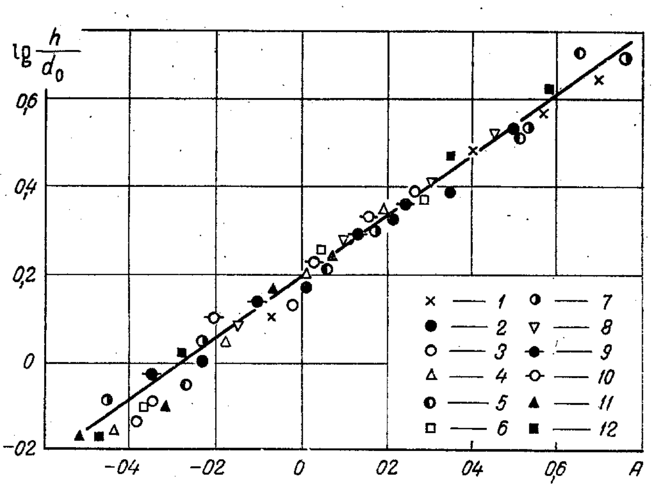

Fig. 2

Fig. 1. Dependence of maximum length h (mm) of spray on velocity w_0 (m/sec) of discharge of gas from a tube with inner diameter d_0. 1, 2, 3, and 4) Bed of electrocorundum with a particle size of 120 μ and with d_0 of 10, 16, 20, and 25 mm, respectively; 5 and 6) bed of chamotte with a particle size of 250 μ, d_0 of 12 and 20 mm; 7) bed of aluminosilicate catalyzer [4] with a particle size of 250 μ, d_0 = 18 mm.

Fig. 2. Determination of range of jet: 1, 2, 3, 4) bed of electrocorundum with a particle size of 120 μ and d_0 of 10, 16, 20, and 25 mm, respectively; 5 and 6) bed of chamotte with a particle size of 250 μ, d_0 of 20 and 12 mm; 7) bed of aluminosilicate catalyzer with a particle size of 250 μ, d_0 = 18 mm; 8, 9, 10, and 11) bed of corundum with a particle size of 320 μ, d_0 of 10, 16, 20, and 25 mm, respectively; 12) bed of cahmotte with a particle size of 320 μ, d_0 = 20 mm. The line corresponds to the calculation by Eq. (2). $A = \log w_0^2 \rho_g / 2gd_0(\rho_{f.b} - \rho_g)$.

5 × 0.5 mm, was protected by a screen from the entry of particles) was mounted at the axis of the blowing tube and was moved downward until the velocity of the jet at the stream axis became equal to zero. This was judged from an MMN micromanometer, whose readings upon the further downward movement of the pneumatic tube, passing through zero, were equal to the pressure differential in the fluidized layer between the openings in the pneumatic tube for the measurement of the total and static pressures. The distance in height between these openings was 5 mm; the error in determining the maximum depth of penetration of the jet into the fluidized bed did not exceed ±2.5 mm.

It should be noted that the maximum length of the visible spray corresponds to the maximum depth of penetration of the jet into the fluidized bed. This fact was established in experiments on the apparatus described above using tubes located near a transparent wall (made of plastic).

The mounting and movement of the pneumatic tube was accomplished with a device marked off in millimeters. The results of the experiments are presented in Fig. 1.

The depth of penetration of a jet into a fluid depends on the kinetic energy of the jet. In the simplest case this dependence, usually applied to a fluid [7] with allowance for the buoyant force, which is calculated for the gas cavities in a fluidized bed in accordance with Archimedes law [10], can be written as

$$h(\rho_{f.b} - \rho_g) g = n \frac{\rho_r w_0^2}{2}. \tag{1}$$

From this, by introducing the inner diameter of the tube into Eq. (1), one can obtain two dimensionless complexes describing the process:

$$\frac{h}{d_0} \text{ and } \frac{\rho_g w_0^2}{2gd_0(\rho_{f.b} - \rho_g)}.$$

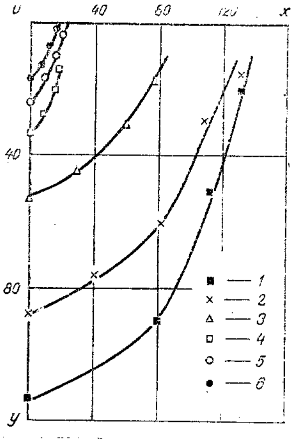

Fig. 3

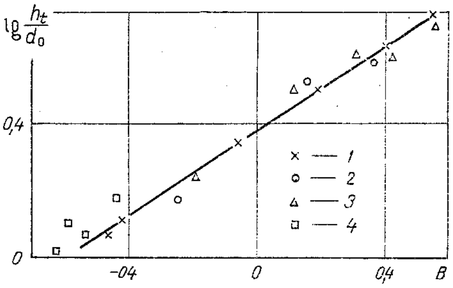

Fig. 4

Fig. 3. Boundaries of zone of variation in the temperature of the bed in the region of a vertical jet: 1, 2, and 3) bed of electrocorundum with a particle size of 320 μ, d_0 = 72 mm, w_0 of 20.4, 15.7, and 10.7 m/sec, respectively, temperature of fluidized bed $t_{f.b}$ of 490, 510, and 520°C, and temperature t_0 of gas at exit from immersion heater of 742, 813, and 833°C; 4, 5, and 6) bed of electrocorundum with a particle size of 120 μ, d_0 = 10 mm, w_0 of 20, 15, and 10 m/sec, respectively, $t_{f.b}$ = 39°C, and air temperature t_0 of 70, 73, and 75°C; x and y) width and length of zone of fluidized bed, measured from the center of the burner orifice (tube), mm.

Fig. 4. Determination of the maximum depth of the zone of temperature variation of the bed in the region of a vertical jet: 1, 2, 3) bed of electrocorundum with a particle size of 120, 200, and 320 μ, respectively, d_0 = 10 mm; 4) bed of electrocorundum with a particle size of 320 μ, d_0 = 72 mm (installation with an immersion burner [2]). B = low $w_0^2\rho_g/2gd_0(\rho_{f.b}-\rho_g)$.

An analysis of the experimental data in the form of the dependence between these complexes (Fig. 2) made it possible to obtain the following equation for the range of the jet:

$$\frac{h}{d_0} = 1.55\left[\frac{\rho g w_0^2}{2gd_0(\rho_{f.b}-\rho_g)}\right]^{0.68}, \tag{2}$$

and using it one can calculate the length of the spray, which is needed for an estimate of the dimensions of the idle zone near the burner orifice when designing installations with a fluidized bed heated by an immersion burner.

It is interesting to note that the maximum diameter of the spray in the region of the burner cut varies little with an increase in the velocity w_0, whereas the length of the visible spray increases sharply.

To study (in the same apparatus) the temperature field in the region of the cut of the tube a jet of air with a temperature of 70-80°C was blown into a fluidized bed having a temperature of 20-25°C. After a steady state was reached the temperature of the fluidized bed was measured in the vicinity of the spray. The temperature was measured with Chromel–Alumel thermocouples having unprotected hot junctions. The mounting and movement of the thermocouples were accomplished with a coordinate mechanism.

Similar measurements of temperature fields were conducted on an installation with an immersion burner, described in [2].

As seen from the experimental results (Fig. 3), the boundary of the temperature variation (the isothermal surface at which the temperature differs by 3-5°C from the temperature of the fluidized bed) depends on the velocity of discharge of the jet from the tube and the inner diameter of the tube. The size of the region bounded by this isothermal surface is greater than the aerodynamic size of the spray. With an increase in the velocity w_0 the length of the zone of temperature variation increases sharply while its width increases slightly. All this, as mentioned earlier, is also characteristic of the size of the visible spray. This makes it possible, by using the same method of analysis of the experimental data as in the determination of the range of the jet, to obtain an expression for the determination of the maximum axial size h_t (the depth) of the temperature variation near the cut of an immersion burner:

$$\frac{h_t}{d_0} = 2.4 \left[\frac{\rho_g w_0^2}{2gd_0(\rho_{f.b} - \rho_g)} \right]^{0.67}. \tag{3}$$

A comparison of the values of h_t/d_0 calculated from (3) (line) and the experimental values (points) is presented in Fig. 4.

NOTATION

ρ_g and $\rho_{f.b}$ are the density of gas and of fluidized bed;
h is the range of jet (length of spray);
g is the acceleration of gravity;
n is the coefficient of penetration of jet into bed;
w_0 is the velocity of discharge of jet at exit from tube;
h_t is the maximum depth of variation of temperatures measured along axis of tube (immersion burner) from its cut.

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