DETERMINATION OF PARTICLE VELOCITY IN A FLUIDIZED BED BY THE LABELED ATOM METHOD

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The distribution of vertical and horizontal particle velocity in a fluidized bed has been investigated. The experimental results are presented below.

One of the important problems of fluidization which has not yet been finally solved is the question of the particle velocity in a fluidized bed.

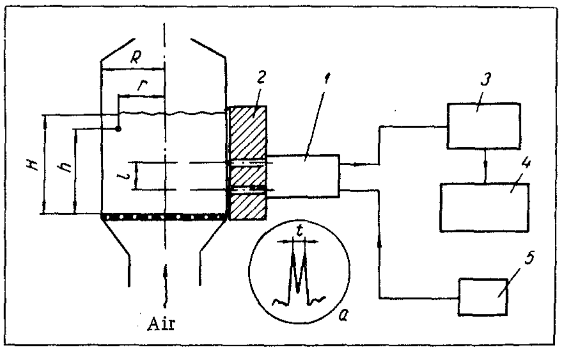

Fig. 1. Schematic of reactor and tracking device: 1) counter, 2) shield, 3) dc amplifier, 4) oscillograph, 5) power supply.

As distinct from indirect method of measuring particle velocity, such as motion-picture photography or a special probe immersed in the bed [1,2], in this paper we describe a method of measuring the particle velocity directly with the help of labeled atoms.

The method of determining the particle velocity U consists in measuring the time t for a particle to cover a distance l between two different points in the bed; for a more accurate determination of the velocity the distance l should be taken as short as possible, commensurable with the dimensions of the particle.

The experiments were conducted on a model reactor 60 mm in diameter. As the fluidized material we used an alumosilicate monodisperse pelletized catalyst. The average diameter of the pellets was 2.8 mm.

One of the catalyst pellets was labeled with radioactive isotope Co^{60}. The pellet was placed in the fluidized bed, where it participated in the motion together with the other similar pellets (particles).

The γ-radiation of the labeled particle was detected with a scintillation counter (Fig. 1), consisting of a photomultiplier of the FEU-19 type with a sodium iodide crystal. The counter was separated from the reactor by a lead shield. The shield had two parallel calibrated openings 3 mm in diameter. The distance l between the axes of the openings was 10 mm (3.5 d). The thickness of the shield was selected so that the γ-radiation of the particle was almost completely absorbed by the lead when the particle was located beyond the limits of the openings, i.e., outside the range of the counter. When the labeled particle crossed one of the openings the counter picked up the γ-radiation, which created current pulses in it. After amplification in a dc amplifier these pulses were recorded on film by an oscillograph.

By mounting the shield containing the openings in a vertical or horizontal plane, it is possible separately to track the movement of a particle in the vertical or horizontal direction.

If the particle crosses one of the openings, the oscillogram will register one pulse, if it crosses both openings two pulses (Fig. 1a). The interval between pulses corresponds to the time t taken by the particle to travel the distance l. Thus, pairs of pulses of the same amplitude define the passage of the particle along a given path. Knowing the time and distance of travel, we can easily find the vertical or horizontal velocity of the particle at a given point in the fluidized bed.

If the particle intersects the axes of the opening at a certain angle, the pulse amplitudes will be different. Pulses with different amplitudes were excluded from consideration. When the particle approaches the wall of the reactor (the counter), the counter signal is intensified and the pulse amplitude increases; conversely, as the particle moves away from the wall toward the center of the reactor the pulse amplitude decreases. From the pulse amplitude we were able to determine the position of the particle in the bed.

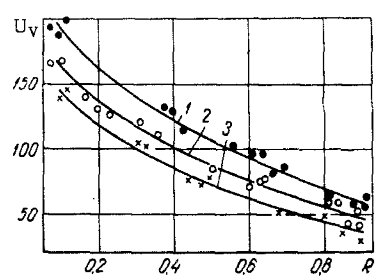

Fig. 2. Distribution of vertical particle velocity U_V (mm/sec) for upward motion as a function of the radius and the cross section of the bed (air velocity W = = 2.8 m/sec): a) at height H from the gas distributor, 2) 0.5 H, 3) 0.25 H.

The pulse amplitude mainly depends on the position of the radioactive particle relative to the counter and is inversely proportional to the square of the distance between particle and counter. The pulse amplitude depends only very slightly on variations in the density of the fluidized bed and the passage of gas bubbles in the zone of the γ-beam, and these are not factors of practical significance as far as the present method is concerned.

By means of a special device the reactor could be moved in the vertical direction without disturbing the fluidization conditions, thanks to which the particle velocity could be determined at any cross section of the bed.

The circuit of the photoelectronic part of the tracking device had a time constant $\tau = 0.01$ sec. This ensured the almost instantaneous registration of the motion of the particle in the bed. The activity of the labeled particle did not exceed 1 μc.

We conducted three series of experiments. In the first series we investigated the distribution of vertical particle velocity in different cross sections of the bed. In the second we determined the dependence of the vertical particle velocity on the fluidization number. The experiments were conducted at air velocities in the free cross section of the reactor of W = 2.4, 2.8, and 3.5 m/sec.

The critical fluidization velocity for the catalyst was $W_{cr} = 0.84$ m/sec. In the third series of experiments we investigated the distribution of horizontal particle velocity in a cross section of the bed.

The height of the stationary bed of catalyst in the reactor was the same in all the experiments, namely, 44 mm. The ratio of the height of the bed to the diameter of the reactor H/D = 0.73. The initial porosity of the bed was 0.40–0.42. Upon fluidization of the catalyst the level of the stationary bed rose by 6–15 mm. The gas distributor had openings 1 mm in diameter. The perforation ratio was 2% of the reactor cross section. The experimental data obtained are presented in Figs. 2, 3, and 4.

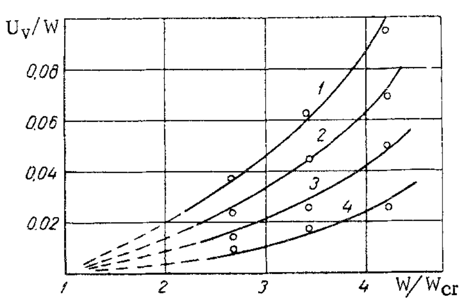

Fig. 3. Relative vertical particle velocity as a function of the fluidization number (cross section of bed at height 0.5 H from the gas distributor): 1) at a distance 0.1 R from the reactor axis, 2—0.3 R; 3—0.6 R; 4—0.9 R.

It is clear from Fig. 2 that the velocity of a particle decreases as it moves toward the wall of the reactor. The greatest particle velocity is found in the core of the bed. The particle velocity in the core is almost 3–4 times greater than close to the wall. As the particle moves over the height of the bed, its velocity is observed to increase with distance from the distributor.

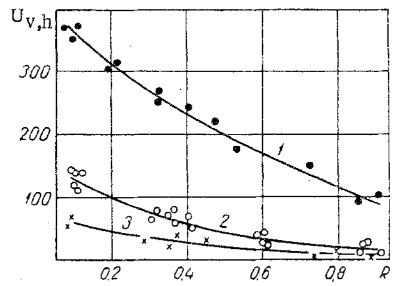

Fig. 4. Distribution of vertical and horizontal particle velocities $U_{v,h}$ (mm/sec) in the cross section of the bed 0.5 H above the distributor: 1) vertical velocity at W = 3.5 m/sec, 2 and 3) horizontal velocity at W = 2.5 and 2.3 m/sec, respectively.

The curves of Fig. 3 show that with increase in fluidization number the vertical particle velocity increases. In the core of the bed the particles preserve the maximum value of the velocity. We must therefore assume that entrainment of the fluidized material from the bed begins primarily from the core zone.

The particle velocity at a fluidization number $W/W_{cr} = 1$, as extrapolation of the curves of Fig. 3 shows, is equal to zero, which satisfies the condition of onset of fluidization.

The experimental data obtained were used to determine the dependence of U_v on the hydrodynamic and geometric conditions of fluidization. This dependence is satisfactorily described by the following empirical equation:

$$U_v = 0.011 W_{cr} (2 + h/H) [1.17 - (r/R)^{0.5}] (W/W_{cr} - 1)^{2.5},$$

where h, r are the coordinates of the particle in the bed.

This formula makes it possible to determine the vertical velocity of a particle at any point of the fluidized bed.

The critical velocity W_{cr}, as is known, is a function of many parameters (ρ, ν, d, g); therefore the formula has a generalized significance and can be used to calculate the particle velocities in a fluidized bed with fluidization numbers $W/W_{cr} \leq 5$.

Horizontal velocity. In the experiments to observe the horizontal displacement of the particle (the shield was turned through 90°) we also obtained oscillograms with paired pulses. Paired pulses of the same amplitude characterize horizontal displacement of the particle in a direction perpendicular to the axes, i.e., along a chord of the cross section of the bed.

It is clear from Fig. 4 that the horizontal velocity, like the vertical, has a maximum value in the core of the bed. As the particle approaches the reactor wall, its velocity falls considerably and close to the wall is equal to about 0.1 of the core velocity. With decrease in the velocity of the fluidizing air the horizontal particle velocity also decreases.

From a comparison of the vertical and horizontal velocities, with other fluidization conditions equal (Fig. 4), it is clear that the vertical velocity is 3–6 times greater than the horizontal velocity.

The presence on the horizontal particle velocity oscillograms of paired pulses with different amplitudes shows that the particles move not only in a direction perpendicular to the axis of the opening but also at an angle to it, i.e., along chords in different directions. It follows that the displacement of the particles in the horizontal plane may be both in the direction core → wall → core and in the direction wall → wall, avoiding the core of the bed.

Error of method. The accuracy of the experiment was mainly determined by the accuracy of measuring the time interval between pulses and the amplitude, which were used to find the velocity and the coordinates of the particle in the bed. Because of the high sensitivity of the scintillation counters the error of the method does not exceed 5%.

NOTATION

D—diameter of reactor; d—mean diameter of particle; U_v, U_h—mean vertical and horizontal particle velocities; W—mean air velocity in free cross section of reactor; W_{cr}—critical fluidization velocity; H—height of stationary bed of catalyst in reactor; h—height of cross section of bed; R—radius of bed; r—distance of particle from reactor axis; t, τ—time; ρ—density of medium; ν—kinematic viscosity; g—acceleration of gravity.

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