STUDY OF RESIDENCE TIME OF PARTICLES IN A COUNTERFLOW GAS SUSPENSION BY MEANS OF A RADIOACTIVE METHOD (TAGGED PARTICLES)

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Results are presented of an investigation of residence time of particles in a counterflow decelerated gas suspension using a radioactive technique. It is shown that the proposed method of mechanical deceleration with the aid of spiral mesh inserts permits different regimes of motion of the solid particles and considerably increases their residence time in the heat transfer chamber.

The compactness of various equipment using the principle of a through-flow gas suspension depends to a considerable extent on the residence time (for heat transfer, reactions, etc.) of the solid particles in the working section of the equipment. It is therefore clearly important to investigate ways of increasing the residence time or to decrease the absolute velocity (without change of height) of the dispersed particles moving in the gas suspension stream.

Other conditions being equal, the least residence time of the particles occurs for a direct-flow gas suspension (descending and ascending). When counterflow is used, in addition to the well-known advantages of a heat technology nature, it is possible to increase the residence time τ and to decrease the required height of the working section of the equipment, due to the effect of aerodynamic deceleration of the falling particles by means of a counterstream of air, this being evaluated by an aerodynamic deceleration coefficient, $k_v = \bar{v}_a/\bar{v}_s$ [1].

Theoretically, when $k_v \to 1$, $\tau \to \infty$. However, experiment shows that one can only attain $k_v \simeq 0.6–0.7$, since further approach of the velocity of the gases to the critical velocity, determined for the weighted mean particle size, leads to entrainment of the particles. Therefore the residence time of the particles in the counterflow is small (it is frequently calculated in fractions of a second), and is not much greater than the settling time of these particles in the stationary gas $k_v = 0$.

One of the simplest methods of improving the potential of the counterflow gas suspension is the use, in the working section of the equipment, of various inserts, which slow down the fall of the solid particles, and improve their distribution over the cross section of the chamber as far as possible. The effectiveness of such mechanical deceleration, in the form of grids spaced in cascade, was examined in [2]. Here the ratio of the residence time of the particles in the chamber with grids ("decelerated" gas suspension) to that in the chamber without them ("free" gas suspension), τ_d/τ_f, reached a value of several units.

The present paper presents the main results of a study of the residence time of particles in a counterflow gas suspension decelerated with the aid of mesh inserts in the form of a single-pass spiral (in principle multi-pass inserts are possible). We chose these inserts because they permit the most effective implementation of the mechanical deceleration method.

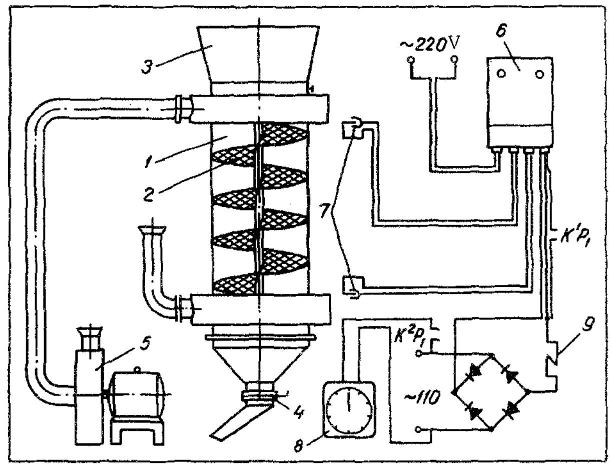

Fig. 1. Schematic of the experimental equipment.

It is true, of course, that for a final judgement of effectiveness, in addition to appraisal of the ratio τ_d/τ_f, it will be necessary later to study the aerodynamics and heat transfer intensity of such systems.

For a reliable evaluation of the residence time of particles in the counterflow gas suspension, and of the quantity τ_d/τ_f, we used the radioactive method of tagged particles.

The experimental equipment (Fig. 1) consisted of the gas suspension deceleration test rig and an electronic unit for detection of the tagged particles. The deceleration rig consisted of a cylindrical chamber 1 of height 0.8 and diameter 0.34 m, in which were installed the demountable spiral mesh inserts 2. The free-flowing charge was fed in from the upper hopper 3, passed through the chamber, and went out through the value of the lower hopper 4. Room temperature air was supplied from below upwards by means of the fan 5, driven by a 1-kW electric motor at 2850 rev/min, mounted on one shaft along with the fan blades. The delivery nozzle carried a valve to allow smooth adjustment of the flowrate of air into the equipment, this being determined from measurement of the static pressure behind the entrance nozzle. The pressure drop Δp in the chamber was determined with the aid of static tappings located at the top and bottom of the chamber and a TsAGI micromanometer. The rig was made of clear plastic to allow visual observation. The electronic unit for recording the tagged particles consisted of a general-purpose, dual-channel electronic relay unit 6 (URAL-2-AM), a radioisotope detector 7, an electronic timer 8, an electromagnetic relay 9, and a power source.

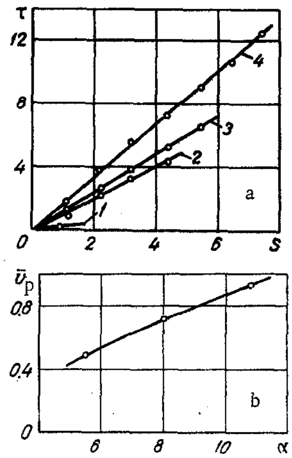

Fig. 2. Dependence of time of motion of particles in the chamber τ (sec) on the geometry and the insert: a) influence of path length S (m) and number of turns of spiral, n (1—in free fall, 2—with a spiral pitch h = = 0.2 m and n = 4; 3—0.15 m and 5.33; 4—0.1 m and 8); b) influence of slope of spiral, $\alpha°$ ($\bar{v}_p$ is the mean velocity of the particle, m/sec).

The electronic relay unit is triggered from the radioactive detector only when radioactivity is present. When the action of the radiation on the detector ceases, the relay unit returns to its original state. Therefore, to turn the electronic timer on and off it was necessary to add the electromagnetic relay to the circuit as an operating element for controlling the timer. When a tagged particle passed by the detector of the first channel, which was mounted in the top of the chamber, the relay of the first channel closed, completing the supply circuit to the electric timer. When the irradiation ceased, the contacts of the relay of the first channel of the electronic relay unit opened, the relay became self-locking, and the electric timer continued to measure time.

When the particle passed the detector of the second channel, which was mounted at the chamber exit, the contacts of the relay of this channel opened, the relay was de-energized, and the contacts supplying power to the electric timer opened, switching it off.

To achieve triggering of the relay unit when a tagged particle was present at a given height, and to avoid spurious triggering, the detector was located in a special lead container. The optimum thickness of the protective lead container was chosen experimentally, in terms of the construction of the equipment and the velocity and trajectory of the particle, and turned out to be $\delta_w = 30$ mm. To increase the sensitivity of the unit, and to alter the triggering time, as well as to reduce the activity of the source, a high-efficiency gas discharge counter was used as the detector.

The radiation source was a particle (bead of aluminum silicate), tagged with Co^{60} of activity 0.5 mg-eq. Ra. The particle diameter was 4.35 mm, its density 1.34 t/m^3, the weight of the bead was 0.0576 g, its surface area $0.157 \cdot 10^{-4}$ m^2, and its critical velocity 12.18 m/sec.

The fact that the weight of the tagged particle was practically no different from that of the untagged ones was verified as follows. After the particle was bored out with a drill of 1.2 mm diameter to a depth of 3 mm, its weight was $G'_{al} = 0.053$ g. The weight of the Co^{60} charge in grams is given by the formula [3]

$$G_{Co} = 8.9 \cdot 10^{-14} \cdot aTA,$$

where $a = (8.4/p_\gamma)\,M \cdot 10^{-3}$ is the activity of the radiation, in curies; T is the half-life, in seconds (for Co^{60} this is 5.3 yr); A = 58.94 is the atomic weight of Co^{60}; M = 0.5 is the activity, mg-eq. of radium; $p_\gamma = 13.2$ is the gamma constant of Co^{60}.

According to the above formula, the weight of the cobalt charge is $G'_{Co} = 2.745 \cdot 10^{-7}$ g. Allowing for the weight of the material used in sealing the boring (BF-2), the weight of the charged particle coincided with the original weight of the aluminum silicate bead.

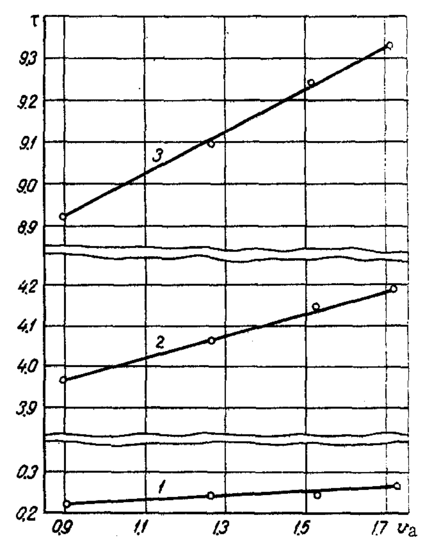

Fig. 3. Influence of air velocity, v_a (m/sec) and mesh diameter d_{ap}, on residence time τ (sec) of particles in the chamber of the gas suspension deceleration rig: 1) in free fall; 2) with a mesh with $d_{ap} = 5$ mm, $d_{ap}/d_p = 1.15$; 3) $d_{ap} = 2.8$ mm, $d_{ap}/d_p = 0.64$.

First, to verify the method, we conducted tests to determine the time of free fall for the tagged particle alone, which was compared with the theoretically calculated value at $v_a = 0$. The time τ was found according to [1] from the expression

$$H = \frac{v_s^2}{g} \ln \frac{(v_s^2 - v_{r.i}^2)^{0.5} \operatorname{ch} \beta}{v_s},$$

where

$$\beta = \frac{g\tau}{v_s} + 0.5 \ln \frac{v_s + v_{r.i}}{v_s - v_{r.i}}.$$

When $v_a = 0$, $v_{t.i} = v_{r.i} = 0$, we obtain

$$H = \frac{v_s^2}{g} \ln \operatorname{ch} \frac{g\tau}{v_s},$$

where $H = H' + H_c$ is the height through which the particle drops, being the length of the path of the particle up to the start of the control section, plus the length of the control section $H' = 0.27$ m, $H_c = 0.8$ m.

When the particle passed the upper detector its velocity was $v_p > 0$. Therefore, according to the above formula (with $H = H' = 0.27$ m), a tentative time for the start of motion was determined, this being $\tau' = 0.24$ sec. The total time for the particle to fall to the lower detector ($H = 1.07$ m) was $\tau = 0.5$ sec. Then the time calculated for passage through the control section is $\tau_c = 0.5\ \tau' = 0.5 - 0.24 = 0.26$ sec. Repeated determination (up to 30 times) of the test time for the particle to pass through the control section, gave $\tau_{exp} = 0.25$ sec. This value agrees with that calculated with an error of +4%, which is within the limits of experimental error. For this reason this technique of conducting the tests was applied afterwards to the counterflow motion in air $v_a > 0$ of a single particle and of a mass of particles.

The influence of aerodynamic deceleration of the air on the change of velocity of the tagged particle at small values of $k_v(0-0.14)$ turned out to be very small. Therefore the change of residence time of the particle in the chamber with a spiral insert may be mainly due to the effect of mechanical deceleration. To study the influence of the geometrical characteristics of the spiral insert on the time of motion of the particle, we made up three complete helical spirals of cardboard, with pitch $H = 0.2$, 0.15 and 0.1 m, slope 10°30', 8° and 5°20', and number of turns n = 4, 5,33, and 8, respectively. The height of the insert was $H = 0.8$ m, which corresponded to that of the rig chamber. The solid phase used in these tests was spherical beads of aluminum silicate of diameter $d_p = 3$, 3.5, 4.35, 5 mm. The tests were performed for each fraction separately. The time during which the particle rolled along the spiral was determined visually.

Figure 2 shows the dependence of the time of motion of the particles of aluminum silicate on the geometrical characteristics of the helical inserts (a dependence on particle size was not observed). Since in this case the straight-line fall in free settling is replaced by curvilinear motion—rolling along a helical trajectory—an increase in residence time is quite normal. We note that the use of helix angles α considerably less than the angles of natural repose of the particles does not disturb the continuity of motion of of the particles along the spiral. For the tests with the helical inserts washed by an airstream, we used

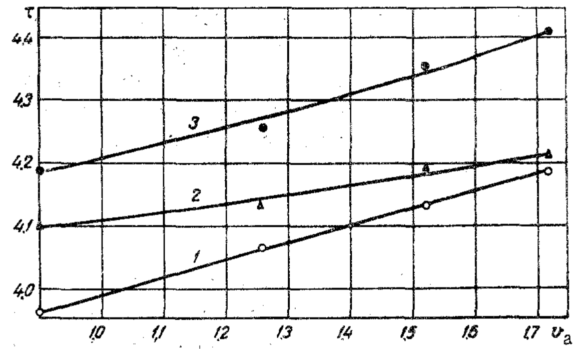

Fig. 4. Dependence of the time of motion of particles, τ (sec), along spiral mesh for $d_{ap} = 5$ mm on the air velocity v_a (m/sec) and the weight concentration μ (kg·hr/kg·hr): 1) with $\mu = 0$; 2) 0.543—0.683; 3) 1.25—1.75.

meshes with aperture diameter $d_{ap} = 2.8$ and 5 mm (and aluminum silicate of size $d_p = 4.35$ mm). In the first case ($d_{ap}/d_p < 1$), only rolling of the aluminum silicate particle occurs, while in the second ($d_{ap}/d_p > 1$), rolling is replaced with spilling of the particles from one turn to another. The pitch of the helix was 150 mm, the helix angle—8°, and the number of turns—5.33. The air velocity was varied over the same range as in the test with the free gas suspension, keeping noticeably below the critical velocity and velocity fluidization of the particles on the mesh. Thirty measurements in each regime were made, satisfactory repeatability of the results being obtained.

According to Fig. 3, the best results were obtained with $d_{ap}/d_p < 1$. Then τ_d/τ_f was of the order of 40, changing only a little with increase of air velocity, which agrees with the data obtained earlier. In the tests with $d_{ap}/d_p > 1$, the increase of residence time with the spiral inserts over the time in the chamber without inserts was $\tau_d/\tau_f \simeq 18$. Even in this case the proposed mechanical deceleration of the particle motion leads to a larger increase in τ_d/τ_f than do grids located in cascade [2].

Figure 4 shows the results of tests, not with a single particle, but with a mass of particles containing a number of tagged particles of aluminum silicate. The tests were made with a spiral insert with $d_{ap}/d_p > 1$ and with variation of the mass flow concentration μ up to 1.75 kg·hr/kg·hr. It is easy to see that increase of particle concentration leads to some increase of τ, and therefore, of τ_f/τ_d, due to the influence of neighboring particles on the conditions of individual motion. However, since the constraint then created on the motion is small, and the change in τ_f/τ_d is very small, the influence of concentration when $\mu \le 1.5-2$ (~0.0003–0.00035 m^3/m^3) may be neglected. This conclusion agrees with the ideas regarding the influence of concentration presented in [1].

From an examination of the different conditions of use of spiral inserts in a counterflow gas suspension, one can find regimes which bring the dispersed system studied close to a counterflow fluidized bed. As previous tests have shown, in that case there is formed on turns with $d_{ap}/d_p < 1$ a fluidized bed of particles of aluminum silicate continuously descending along a spiral path. However, the aerodynamic resistance of the chamber is then noticeably in excess of its resistance when operating in the nonfluidized regime at a rate of 10–15 kg/m^2.

NOTATION

d_p—particle size; k_v—aerodynamic particle deceleration coefficient; v_a—air velocity; v_s—critical particle velocity; $v_{t.i}$ and $v_{r.i}$—absolute and relative initial particle velocities; h—pitch of helix; α—helix angle; S—length of entire helix along generator; H—height of helical insert; n—number of turns; v_p—particle velocity; G—weight; μ—weight concentration; τ—time.

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