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EXPERIMENTAL DETERMINATION OF THE POROSITY FIELD IN A FLUIDIZED BED BY THE RADIOISOTOPE METHOD

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We propose a method for constructing the concentration field of the solid phase in a disperse system which differs from conventional methods in that performing the measurements does not affect the hydrodynamics of the system.

The experimental method of constructing the concentration field of the solid phase or the porosity of a disperse system is based on the measurement of the spatial coordinates of a representative particle tagged with the isotope ^{60}Co [1]. It was shown in [1] that a coordinate can be measured to an accuracy of $\pm 11 \cdot 10^{-3}$ m in apparatus of diameter D = 0.25 m and height 0.75 m. The accuracy of the measurement of a coordinate can be increased by an order of magnitude by increasing the response speed of scintillation counters to 10^{-7}-10^{-8} sec with an efficiency no worse than 10%. With such scintillators the absolute velocity of a particle can be determined with a probable accuracy of $\pm 2 \cdot 10^{-2}$ m/sec.

The concentration field of the solid phase or the porosity is determined experimentally by using an empirical probability density distribution function, the histogram of the random vector with components x, y, z, $|x| \leqslant D/2$, $|y| \leqslant D/2$, $0 \leqslant z < \infty$.

In constructing a histogram it is necessary to solve three fundamental problems: 1) into what sized cells should the coordinate axes be divided; 2) how many measurements should be made of the random quantity, i.e., what should the sample size be; 3) what are the necessary conditions to ensure mutual independence, in the probabilistic sense, of the magnitudes of any two measurements.

A cell in which the porosity is measured should contain enough (N) granules to permit neglecting the statistical fluctuations of the porosity, the relative fraction of which is determined by the magnitude of $1/\sqrt{N}$ [2]. On the other hand, the size of a cell is fixed from below by the accuracy of the measurement of the coordinate of the tagged particle. In our case we chose a $2 \cdot 10^{-2}$ m cell.

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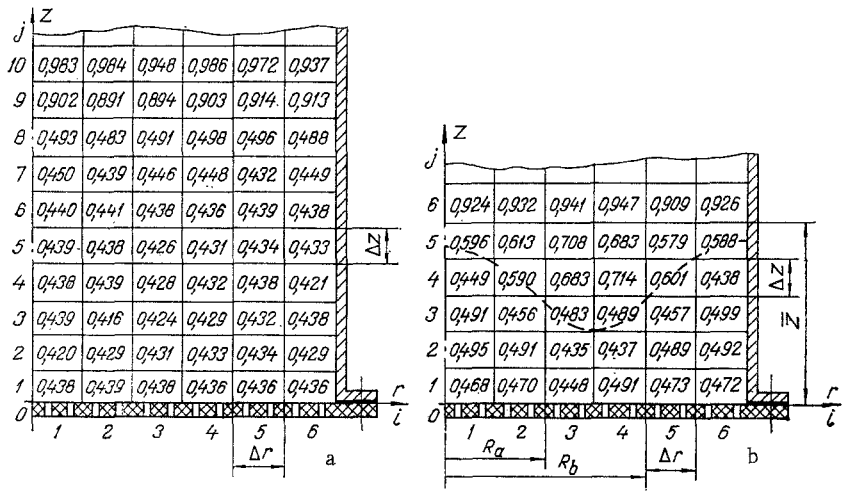

Fig. 1. Experimental porosity field in apparatus with D = 0.25 m: a) $d = 4 \cdot 10^{-3}$ m, $\rho_T = 1.14 \cdot 10^3$ kg/m^3 (aluminosilicate), cross section $\varphi = 0.057$, $W_w = 1.27$ m/sec, $W_{cr} = 1.01$ m/sec, G = 3.6 kg, $\Delta z = \Delta r = 2 \cdot 10^{-2}$ m; b) $d = 4 \cdot 10^{-3}$ m, $\rho_T = 1.14 \cdot 10^3$ kg/m^3, $\varphi = 0.057$, $W_w = 1.55$ m/sec, $W_{cr} = 1.01$ m/sec, G = 1.82 kg, $\Delta z = \Delta r = 2 \cdot 10^{-2}$ m. z and r are in m.

The sample size, i.e., the time of the experiment, depends strongly on the dimensionality of the random vector. Therefore, we took measures to decrease the dimensionality. This was achieved by using the symmetry of the gas distribution in the empty apparatus and consequently the symmetry in the time average of all field variables of the fluidized bed. Mathematically this implies transformation to cylindrical coordinates

$$x,\ y,\ z \Rightarrow z,\ r,\ r = \sqrt{x^2 + y^2}$$

and the assumption that the field variables are independent of the angle θ.

If M is the number of cells along the r axis, $M = D/2\Delta r$, and L is the number of cells along the z axis, $L = H_{max}/\Delta z$, $\Delta z = \Delta r = 2 \cdot 10^{-2}$ m, then in accordance with the recommendations in [3], the optimum number of measurements of the random vector is of the order $(ML)^2$. We note that at the beginning of the experiment, when the fluidization process is developing, the maximum height of the surges H_{max} was determined visually, and then the number L was calculated. The transformation to the symmetry of the field variables and the method of calculating L for the actual bed enabled us to decrease the length of a single experiment to 2-3 h.

The question of the correctness of the construction of the histogram was solved purely instrumentally. Each measurement of the z and r coordinates of the tagged particle consists of two operations: the accumulation of the number of current pulses from the gamma counters over $5 \cdot 10^{-3}$ sec, and the processing of these readings on a minicomputer over 1.67 sec. Since this time is substantially longer than the time between two pulsations of the bed, we can conclude that two neighboring measured locations of the tagged particle are independent.

The experiment yielded a large block of $\varphi(i, j)$ numbers of the entrances of the tagged particle into cell number (i, j), where i is the number of the cell along the r axis, and j is the number along the z axis:

$$\sum_{i=1}^{M} \sum_{j=1}^{L} \varphi(i,\ j) = (M \times L)^2.$$

The magnitude of the porosity was found from

$$\varepsilon(i,\ j) = 1 - \frac{G\varphi(i,\ j)}{2\pi\rho_T \Delta z \Delta r^2 i (M \times L)^2}.$$

The error of the measurement of the porosity in the chamber of the apparatus was determined on a model bed with the system parameters shown in Fig. 1a. The modeling consisted in trying to obtain a uniform fluidization regime near the critical state of the bed.

It can be seen from Fig. 1a that for $j = 1$ and $1 \leqslant i \leqslant 6$ the values of the porosity are more uniform and differ less from one another than in the other cells. This is accounted for by the dominating effect of the uniform gas distribution on the bed of granular material in the first cell along the z axis. Therefore, it is expedient to calculate the error of the measurement of the porosity from

$$\delta = \frac{\max \varepsilon (i,\ j = 1) - \min \varepsilon (i,\ j = 1)}{\max \varepsilon (i,\ j = 1)} \cdot 100\ \% = 0{,}7\ \%.$$

At the upper boundary of the fluidized bed, above which $\varepsilon = 1$, we determine the error from

$$\delta = \frac{1 - \min \varepsilon (i,\ j = 6)}{1} \cdot 100\ \% = 2{,}7\ \%.$$

These calculations enable us to state that our measurement of the time average of the porosity field is in error by no more than 3%.

The method proposed for measuring the time average of the porosity field enabled us to make a quantitative comparison of the calculated [4] and experimental values of certain characteristic scales of a fluidized monodisperse bed. In the present article we are concerned with the characteristic scales $\bar{Z}$, $\bar{R}$, and $\bar{R}_0$ [4], the first two of which characterize the linear dimensions of the fill to the constant height z above the grid of the apparatus, and the last determines the dimensions of the regions above the grid which are free of particles of granular material which are stationary with respect to z.

Let us recall that these three characteristic scales describe the geometry of the structure of the fluidized bed in the region near the grid $0 \leqslant z \leqslant \bar{Z}$, where $\bar{Z}$ is the characteristic depth of the fill [4]. The expression of these scales in terms of the primary variables of the problem of the porosity field, the velocity of the gaseous phase, the pressure field in it, and the probability density distribution function of solid particles in geometric and kinematic space were derived in [4] by assuming that the pressure of the gaseous phase above the grid does not vary with r, and that the flow rates of the gaseous phase through the part of the grid occupied by the fill of particles and the part free of it are commensurable.

Figure 1b shows the time average of the porosity field of the bed with the parameters listed on the figure. The values of $\pi\bar{R}_0^2$ and $\bar{R}_0$ were determined over the cross section of the ring $R_a \leqslant r \leqslant R_b$ above which an increase in porosity is observed. The value of $\bar{R}$ was determined similarly. The experimental and calculated values of the characteristic scales considered agree within 20%.

NOTATION

ε, porosity; x, y, z, components of position vector of tagged particle; D, H_{max}, diameter and height of fluidized bed apparatus; G, weight of bed; d, ρ_T, diameter and density of fluidized bed particles; W_w, W_{cr}, working and critical fluidization speeds; $\bar{Z}$, $\bar{R}$, $\bar{R}_0$, characteristic scales of fluidized bed.

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