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EXPERIMENTAL DETERMINATION OF THE STATISTICAL CHARACTERISTICS OF GAS MOTION IN A FLUIDIZED BED

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UDC 532.546:519.24

A method is proposed for the determination of the statistical characteristics of the gas motion in a fluidized bed by the pneumatometric method. The dependences of these characteristics on the parameters of the process are obtained.

The experimental determination of the statistical characteristics of any random process encounters an important difficulty consisting in the fact that the measuring system distorts the fluctuations of the parameter under study because of the influence of its frequency properties. In many cases it is impossible to reconstruct the actual form of the realization, even when one has data on the dynamic properties of this system.

However, the problem of the experimental determination of the statistical characteristics of the fluctuations of any parameter can be solved without reconstructing the actual form of the realization. The methods of mathematical statistics [1] allow one to find them from the statistical characteristics of the distorted realization, taking into account the dynamic properties of the measuring system.

For the measurement of the instantaneous gas velocity in a fluidized bed we chose the pneumatometric method, which is distinguished by the simplicity and accessibility of the fabrication and calibration of the pickups and the reliability in operation. But when using this method one must allow for the distortions introduced by the measuring system, which can be divided arbitrarily into two types. The first type is the distortions connected with the presence of solid particles in the stream. The average gas velocities calculated from the readings of the pneumatometric probe prove to be overstated [2, 3, 4]. The second type of distortions is connected with the inertia of the measuring system and can be allowed for by an experimental determination of its amplitude–frequency characteristic curve.

A low-inertia Pitot–Prandtl tube, whose length together with the connecting channels was 150 mm and whose diameter was 2 mm, was used in our experiments. A membrane differential manometer made in conjunction with the tube served as the secondary instrument. The membrane movements were measured by an electronic system [5] using a 6MKh1S mechanotron. The pulsations were recorded on photographic film by a light-beam oscillograph. The graphs were quantified with a Siluét automatic reader. The data obtained from the Siluét instrument in five-track telegraphic code were processed in an Odra-1204 computer. The amplitude–frequency characteristic curve of the measuring system was taken by the method of supplying a unit jump to its input. The numerical values of the amplitude–frequency characteristic curve are as follows:

Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 30, No. 2, pp. 206-210, February, 1976. Original article submitted April 1, 1975.

$L(\omega)$ equals 1.00, 0.89, 0.69, 0.48, 0.39, 0.30, 0.25, 0.21, 0.16, 0.13, and 0.10 when $\omega\,(\mathrm{sec}^{-1})$ equals 0, 3, 6, 9, 12, 15, 18, 21, 24, 27, and 30, respectively.

The calibration curve of the measuring system for average values was determined experimentally using the method presented in [4] and by successive approximation of the linear function

$$\overline{W} = A\overline{W}_{\mathrm{f}} + B. \tag{1}$$

For the measuring system described $A = 0.9$ and $B = -1.5$ in the range of velocities $\overline{W} = 1\text{-}7$ m/sec.

The processing of the experimental data to obtain the statistical characteristics was performed in the following sequence.

a) The realization of a random process Δp of variation in the dynamic head of the gas was recorded using the measuring system. Then this realization was reorganized into the realization

$$W_{\mathrm{f},\omega} = \sqrt{\frac{2\Delta p}{\rho}}. \tag{2}$$

b) Estimates of the mathematical expectation $M_{\mathrm{f},\omega}$, the spectral density $S(\omega)_{\mathrm{f},\omega}$, and the correlation function $K(\tau)_{\mathrm{f},\omega}$ were determined from the well-known equations of [1].

c) The frequency distortions were eliminated from the estimates found:

$$M_{\mathrm{f}} = M_{\mathrm{f},\omega}, \tag{3}$$

$$S(\omega)_{\mathrm{f}} = \frac{S(\omega)_{\mathrm{f},\omega}}{[L(\omega)]^2}, \tag{4}$$

$$K(\tau)_{\mathrm{f}} = \int_0^\infty S(\omega)_{\mathrm{f}} \cos\omega\tau d\omega. \tag{5}$$

d) Using (1) and assuming that the relations for the average quantities are also retained for their instantaneous values, the distortions caused by the effect of the solid particles were eliminated:

$$M = AM_{\mathrm{f}} + B, \tag{6}$$

$$K(\tau) = A^2 K(\tau)_{\mathrm{f}}, \tag{7}$$

$$S(\omega) = \frac{2}{\pi}\int_0^\infty K(\tau)\cos\omega\tau d\tau. \tag{8}$$

Estimates of the other statistical characteristics can be obtained from those presented by using the well-known equations of the theory of random functions.

As shown in [4], the porosity at the point of measurement has little effect on the concrete form of the dependence (1). Zones with a very low average concentration of solid particles, i.e., the upper part of the bed, were an exception. There are no such zones in the main body of the bed and a porosity of more than 95% is observed only in bubbles. The effect of solid particles on the readings of a pneumatometric probe in bubbles and in the diluted phase is different, since in bubbles the particles have a high velocity, equal to or greater than $\overline{W}$, whereas in the diluted phase the particle velocity is close to zero. Consequently, in bubbles the particles should have about the same effect on the probe readings as the particles of the compact phase, since, although their concentration in the bubbles is low, they have a velocity which is an order of magnitude higher than the average particle velocity in the bed. Therefore, when crossing a bubble the concrete form of the calibration curve should not change greatly. The agreement (with an accuracy of 10%) of the average velocity and the mathematical expectation M of the random process can be a measure of the validity of the latter assertion.

The admissibility of finding estimates of the statistical characteristics from one sufficiently long realization follows from the ergodicity of the process. It is theoretically impossible either to prove or disprove the hypothesis of ergodicity for the systems to which a fluidized bed belongs. Therefore, by analogy with [6] the authors followed a purely engineering course, determining the "degree of ergodicity" of the process. For a steady-state process the condition of ergodicity will be

$$\lim_{T\to\infty}\frac{1}{T}\int_T W dt = M. \tag{9}$$

The convergence of the integral of (9) was tested for the various parameters of fluidization, including the limiting parameters. The "degree of ergodicity" was estimated using the quantity

$$u(t)=\frac{\left|M-\frac{1}{T}\int\limits_{T}W dt\right|}{M}. \tag{10}$$

In this case the condition of ergodicity will be written in the form

$$\lim_{T\to\infty} u(t)=0. \tag{11}$$

Furthermore, from the family of u(t) corresponding to different conditions of fluidization we chose the worst, i.e., the one which approaches zero most slowly. The minimum observation time, determined with a fixed uncertainty u(t) = 0.03, is T = 40 sec. The maximum size of the quantification step of the random process found in a similar way with the same fixed uncertainty is 0.025 sec.

A fluidized bed composed of spherical aluminosilicate particles 2-2.5 mm in diameter, for which the velocity of the onset of fluidization equals 0.8 m/sec, was studied in our experiments. The tests were performed in a cylindrical apparatus 172 mm in diameter and air served as the fluidizing agent. The gas distributor consisted of a yoke filled with lead shot and covered over with a grid having a clear opening of 40%. The experiments were set up with the aim of clarifying the influence of the initial bed height, flow rate of the fluidizing agent, and coordinate of the point of measurement on the statistical characteristics of the pulsations of the fluidizing agent. In the course of the experiments we analyzed 75 realizations of the random process with a total volume of 3000 points.

The results obtained showed that variation in the initial bed height in the range of from 43 to 129 mm does not affect the qualitative form of the estimates of the statistical characteristics of the velocity pulsations of the fluidizing agent. The latter depend most essentially on the flow rate of the fluidizing agent and the distance from the gas distributor to the point of measurement. It should be emphasized that the velocity profile of the gas at the entrance to the bed was flat. Characteristic dependences of the dispersion of the random process on the fluidization number are shown in Fig. 1.

The pulsations of minimum amplitude are observed in the zone of the apparatus near the grid. The spectral composition of the pulsations here is uniform and the spectral density curve (Fig. 2a) declines from the frequency ω = 0. The correlation function hardly oscillates about zero (Fig. 2b). The velocity pulsations of the gas in the zone near the grid are the most random, although their size is relatively small. Such a

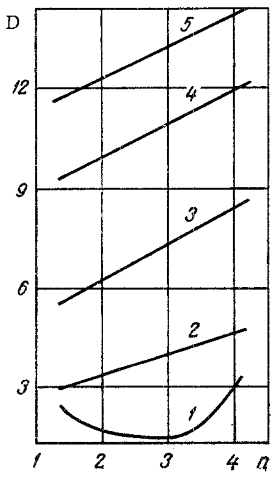

Fig. 1

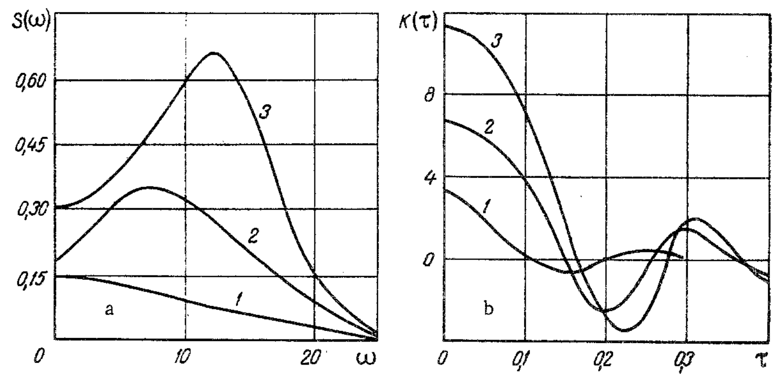

Fig. 2

Fig. 1. Dependence of dispersion of random process of velocity pulsations of gas in a fluidized bed on the fluidization number at different distances from the gas distributor: 1) y = 6 mm; 2) 26; 3) 86; 4) 126; 5) 166 mm.

Fig. 2. Typical appearance of graphs of spectral densities (a) and correlation functions (b) of the random process of velocity pulsations of gas in a fluidized bed at different distances from the gas distributor: 1) y = 6 mm; 2) 86; 3) 126 mm. ω, sec^{-1}; τ, sec.

character of the pulsations in the zone near the grid can evidently be explained by the existence of a gas interlayer and by the low concentration of solid particles. The gas velocity is made up of a constant component (70-80%) and a stochastic component of low amplitude with a low periodicity.

The dispersions increase in the middle part of the bed, where intensive circulation of the solid particles exists. A considerable element of periodicity is displayed. The constant component of the gas velocity has a value of less than 50% of the total velocity. A maximum appears in the spectral density curve which lies in the frequency range of 5-15 sec^{-1}, depending on the fluidization conditions.

The periodicity of the pulsations is displayed most clearly in the upper part of the bed and the correlation function has a clearly expressed oscillatory character. Pulsations with frequencies of 10-15 sec^{-1} predominate in the spectrum. The fraction of the constant component of the velocity is less than 20%.

Thus, in the range of our tests the constant component of the gas velocity declines while the pulsation component increases with height in the fluidized bed. The error of the experiments performed does not exceed 15% in the authors' opinion.

NOTATION

W, $\overline{W}$, instantaneous and average velocities of fluidizing agent; Δp, dynamic head; ρ, density of fluidizing agent; $L(\omega)$, amplitude–frequency characteristic curve of measuring system; M, D, $K(\tau)$, $S(\omega)$, mathematical expectation, dispersion, correlation function, and spectral density of random process of variation in velocity of fluidizing agent; τ, argument of correlation function; ω, frequency; t, time; T, duration of realization of random process; n, fluidization number; y, distance from gas distributor to point of measurement. Indices: ω, quantity found with distortions arising due to nonuniformity of frequency characteristic curve of measuring system; f, quantity found with distortions connected with the presence of solid particles in the stream.

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