TRANSVERSE NONUNIFORMITY IN THE DISTRIBUTION OF INHOMOGENEITY IN SYSTEMS INCORPORATING A PSEUDO-FLUIDIZED BED

M. F. Mikhalev, V. G. Pravdin,
and Yu. A. Petrov

UDC 66.096.5

The effect of a variety of factors (gas velocity, catalyst grain size, initial height of the bed, and resistance of the gas distributor) on the transverse nonuniformity in the distribution of inhomogeneity in a pseudo-fluidized bed is considered. A method is proposed for analyzing experimental data so as to estimate the degree of this nonuniformity.

The nonuniformity in the distribution of gas flows over the cross section of a pseudo-fluidized bed is largely determined by the dimensions of the apparatus and the construction of the gas-distributing devices [1]. The efficiency of contact systems is accordingly greatly reduced [2].

In carrying out catalytic processes in a pseudo-fluidized bed, it is usual to make the flows as uniform as possible. Each different process is characterized by its own particular optimum degree of inhomogeneity in the bed.

The inhomogeneity of the bed and the uniformity of its distribution over the cross section of the latter give rise to the concept of "structure quality," which characterizes the contact between the gas and the solid phase in the main volume of the active material.

We may thus approach the problem of determining the degree of uniformity in the distribution of inhomogeneity over the cross section of the bed by considering the relative fluctuation in the local density [3]

$$\delta = \frac{\overline{|\Delta\rho|}}{\bar{\rho}} \cdot 100\%, \tag{1}$$

as a quantitative characteristic of the inhomogeneity of the pseudo-fluidized bed, where $|\overline{\Delta\rho}|$ is the statistical mean absolute deviation of the density from its mean value $\bar{\rho}$.

The results of our measurements were analyzed by means of an analog computer, the MN-7, using the principle of separating the varying component of the signal spectrum from the steady component with the help of a high-frequency filter [3].

The statistical collection time T for the steady and variable components of the signal $u_=$ and $u_\sim$ was taken as 60 sec.

The operation of preliminary division into time intervals T in order to obtain the average values was thus not required, since

$$\delta = \frac{\bar{u}_\sim}{\bar{u}_=} \cdot 100\% = \frac{\frac{2}{T}\int\limits_0^T u_\sim^{(+)} d\tau}{\frac{1}{T}\int\limits_0^T u(\tau)\, d\tau} \cdot 100\% = \frac{2\int\limits_0^T u_\sim^{(+)} d\tau}{\int\limits_0^T u(\tau)\, d\tau} \cdot 100\%. \tag{2}$$

Lensovet Technological Institute, Leningrad. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 17, No. 6, pp. 1016-1020, December, 1969. Original article submitted January 3, 1969.

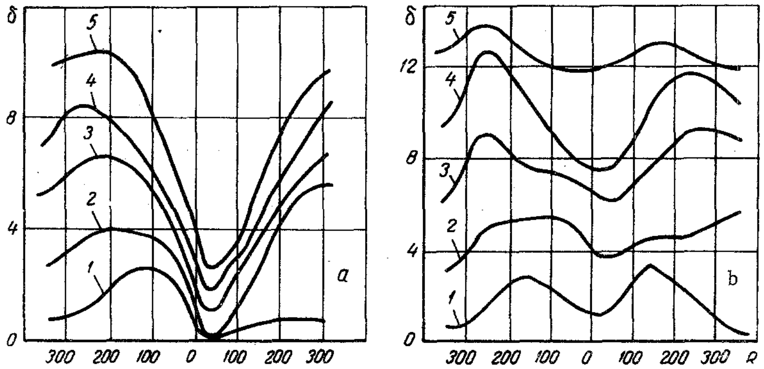

Fig. 1. Distribution of the relative density fluctuation δ, % over the cross section of the bed on placing the sensor at $h_x = 80$ mm (a) or 160 mm (b). Height of the bed $H_0 = 200$ mm. Fraction – alumino-silicate [1) 0.38 m/sec; 2) 0.44; 3) 0.48; 4) 0.52; 5) 0.57].

The relative fluctuation δ was measured at 17 points distributed over the diameter of the bed (in a system of diameter 0.9 m).

The height at which the capacitive sensor (of rod construction) was placed above the gas-distributing system equalled $h_x = 80$ mm, since at this height the dynamic effect of the gas jets had no appreciable effect.

A convenient indicator of the uniformity in the distribution of inhomogeneity is the variation coefficient $\Delta\langle\delta\rangle$, which is to the ratio of the mean square deviation $\sigma\langle\delta\rangle$ to the arithmetic mean value of $\bar{\delta}$:

$$\Delta\langle\delta\rangle = \frac{\sigma\langle\delta\rangle}{\bar{\delta}} \cdot 100\%, \tag{3}$$

where

$$\sigma\langle\delta\rangle = \sqrt{\frac{\sum_{i=1}^{n}(\delta_i - \bar{\delta})^2}{n}}, \tag{4}$$

$\delta = (1/n)\sum_{i=1}^{n}\delta_i$ (i = 1, 2, ..., n) is the number of measurements made in the space.

Experiments were carried out with two granular materials used under industrial conditions:

1. A wear-resistant vanadium catalyst in aluminosilicate with a mean grain diameter of d = 0.75 mm ($0.5 \ll d \ll 1.0$) and an apparent density $\rho_k = 1460$ kg/m^3.
2. Aluminosilicate, d = 1.5 mm ($1.0 \ll d \ll 2.0$), ρ_k 1100 kg/m^3. Initial height of the bed $H_0 = 100$-400 mm.

The gas distributor was a double perforated lattice with staggered apertures. The proportion of the active section $\varphi = 2.4\%$, the diameter of the holes $d_0 = 3.4$ mm, the distance between them t = 20 mm.

First of all it was essential to verify the sensitivity of the method employed with respect to the determination of low-mobility zones in the bed. For this purpose we measured δ along the perimeter of the apparatus above the lattice, with a seam of width 2t covering the apertures.

Using the proposed method we detected the formation of a stagnation zone in this case (Fig. 1). However, with the sensor at a height of $h_x = 160$ mm the effect of the seam was hardly felt at all.

The foregoing measurements show that, if the distribution of the inhomogeneity at a height of $h_x = 80$ mm is uniform, then there will be no appreciable changes in the profile of the density pulsations over the height of the bed, although the extent of the inhomogeneity will increase substantially. The increase in the inhomogeneity of the bed with respect to the height of the latter observed during the measurements, and also the changes taking place on increasing the velocity of the gas (Figs. 1 and 2) and the grain diameter, in no way contradict the results presented in [1, 3].

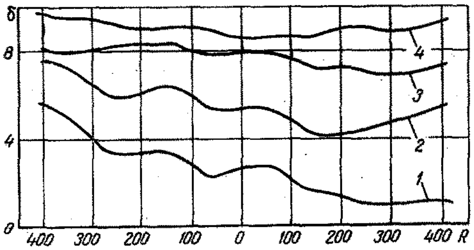

Fig. 2

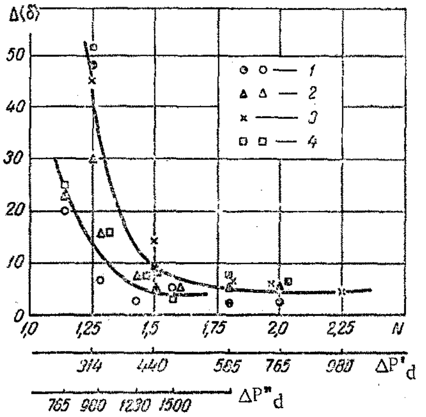

Fig. 3

Fig. 2. Distribution of relative density fluctuation δ, % over the cross section of the bed (height of the bed $H_0 = 400$ mm; fraction – catalyst): 1) 0.25 m/sec; 2) 0.30; 3) 0.35; 4) 0.40.

Fig. 3. Effect of the pseudo-fluidization number N and the lattice resistance ΔP_d, N/m² on the uniformity of the inhomogeneity distribution through the cross section of the bed ($\Delta P'_d$ for the pseudo-fluidization of the catalyst, $\Delta P''_d$ for the pseudo-fluidization of the alumino-silicate): 1) $H_0 = 100$ mm; 2) 200; 3) 300; 4) 400. Black symbols indicate the d = 0.75 mm fraction, light symbols d = 1.5 mm.

The profiles of the relative pulsations δ thus obtained (Fig. 2) are fairly stable. Visual observations of a bed with a nonuniform distribution of gas over its cross section indicate that the regions in which most of the motion of the bubbles occurs are stable in time. The mean degree of inhomogeneity increases with increasing velocity of the gas. For a constant gas velocity and a constant height h_x, the value of $\overline{\delta}$ varied very little for initial bed heights of $H_0 = 200$-400 mm, although for $H_0 = 100$ mm the absolute value was greater. This was due to the fact that for $H_0 = 100$ mm the sensor lay almost on the surface, at which, of course, there was a considerable increase in the size of the gas bubbles before they passed out from the bed.

The results of our investigations into the distribution of the inhomogeneity with respect to the cross section of the bed (Fig. 3) show that:

1) A bed of material with grains of diameter d = 1.5 mm is fluidized more stably throughout the whole cross section of the bed, and the nonuniformity index $\Delta\langle\delta\rangle$ is low in this case, even for a velocity close to the velocity at the onset of fluidization;
2) for a catalyst bed, with d = 0.75 mm, there is a much greater nonuniformity, indicating its tendency to form channels and stagnant zones;
3) with increasing gas velocity the uniformity of the flows increases and the bed starts working uniformly. An increase in the initial height of the bed causes no marked changes in the distribution of the flows with respect to the cross section of the bed.

In a number of papers [4-6] the resistance of the gas–distributor system ΔPd is treated as equal to the resistance of the bed $\Delta P_d\ \Delta P_b$.

On reaching uniform fluidization the relative resistance for the d = 1.5 mm fraction was $\Delta P_d/\Delta P_b = 2.0$-$0.4$ and for the d = 0.75 mm fraction $\Delta P_d/\Delta P_b = 0.98 - 0.21$. This indicates that the resistance of the lattice should not in fact be equated to the resistance of the bed. The gas-regulating action of the lattice resistance is apparently determined principally by the composition of the bed material and the velocity of the supply gas, not by the initial height of the bed.

We note that any increase in the resistance of the gas distributor above that which is necessary for the uniform feeding of the fluidizing agent into the bed does not produce any increase in the uniformity of the gas flows, but leads to additional energy losses.

NOTATION

δ	is the relative density fluctuation, %;
$\bar{\rho}$	is the statistical arithmetic-mean value of the instantaneous density of the bed $\rho(\tau)$, kg/m^3;
$\lvert\bar{\rho}\rvert$	is the statistical absolute mean deviation of the density from its average value $\bar{\rho}$, kg/m^3;
T	is the statistical collection time, sec;
$u_\sim$, $u_=$	are the varying and steady signal components, V;
$\Delta\langle\delta\rangle$	is the variation coefficient, %;
d	is the mean grain diameter, mm;
ρ_k	is the apparent density, kg/m^3;
H_0	is the initial height of the bed, mm;
n	is the number of readings over the whole space;
R	is the distance of the measuring point from the axis of the apparatus, mm.

LITERATURE CITED

1. N. I. Gel'perin, V. G. Ainshtein, and V. B. Kvasha, Fundamentals of the Technique of Pseudo-Fluidization [in Russian], Khimiya, Moscow (1967).
2. A. M. Rozen and V. S. Krylov, Theoretical Foundations of Chemical Technology, Vol. 1 [in Russian], No. 3 (1967).
3. M. É. Aérov and O. M. Todes, Hydraulic and Thermal Foundations of the Operation of Devices Incorporating Stationary and Fluidized Granular Beds [in Russian], Khimiya, Leningrad (1968).
4. V. E. Soroko, Candidate's Dissertation [in Russian], LTI im Lensoveta, Leningrad (1965).
5. S. S. Zabrodskii, Hydrodynamics and Heat Transfer in a Pseudo-Fluidized Bed [in Russian], Gosénergoizdat, Moscow–Leningrad (1963).
6. J. W. Hiby, Chem. Ing. Technik, 36, No. 3 (1964).