STATISTICAL STUDY OF FLUCTUATION OF GAS FLOW RATE IN CAPS IN FLUIDIZED-BED PROCESSING UNITS

A. P. Baskakov, V. G. Tuponogov,
and N. F. Filippovskii

UDC 66.036.5

Results are presented from correlational and spectral analyses of gas flow rate fluctuations in caps in fluidized-bed processing units with bed depths up to 0.8 m.

In a nonuniform fluidized bed of a finely dispersed material, the gas-distributing grate and gas supply line constitute an oscillatory system [1]. Observations [1, 2] have shown that a sharp increase in pressure occurs in the bed the moment bubbles leave it. There are likely sites where bubbles exit, these sites being determined by the presence of circulating loops of material in the bed volume [3]. To more fully represent the mechanism of nonuniform fluidization, it is important to determine the degree to which the gas-distributing caps work synchronously.

Studies were conducted on a unit with a grate 1.2 × 0.6 m containing 18 gas-distributing caps spaced 0.2 m apart. The cross section of the grate was 2.4%. Electrocorundum with a mean particle diameter $d_p = 400\ \mu$ and a critical fluidizing velocity $w_c = 0.3$ m/sec was fluidized with air in the unit. Calibrated Venturi tubes equipped with tensometric pressure-gradient transducers were installed in the caps to measure instantaneous gas flow rate. The transducers were connected through a multichannel data-measurement system with a control minicomputer. This setup permitted programmed inquiry of the transducers in any sequence with a minimum interval of 7.5 msec. The quantizing error, referred to the mean amplitude of the pressure-gradient pulsations, was 1%. From 500 to 6500 readings were accumulated in the computer memory from each transducer during the experiments. These readings were then analyzed and the data printed out.

Measurement of the instantaneous flow rates and calculations of the mean values with these data showed that the mean gas flow rate in the caps is roughly the same (differing by no more than 5%) in all of the fluidizing regimes, except for several of the caps near the wall. The rate of flow through these caps was 1.5-2 times lower and was nearly zero ($0.03\text{-}0.05 w_c F_c$) at low fluidizing velocities ($W = 1.3$). Meanwhile, significant nonuniformity of gas flow rate was seen between all of the caps during the initial fluidization of the settled material. Thus, to ensure that the material was loose before testing began, the bed was fluidized intensively for 5-7 min prior to the experiment.

The pulsations in gas flow rate in the caps are quite unique in character: sections with nearly constant frequency and amplitude alternate with sections characterized by small-scale pulsations. As a result, over a short period of time, one obtains an erroneous picture of the orderliness of the pulsations. For example, in the time T = 7 sec, a normalized autocorrelation function is obtained with periodic vibrations 0.2-0.4 which do not decay with amplitude. Also, due to the identical fundamental frequency of the pulsations in all of the caps in brief realizations, significant correlation coefficients may be obtained even for caps far from one another. To obtain representative statistical data, it is necessary to analyze very long realizations. The appearance of the autocorrelation function with a realization lasting 135 sec (Fig. 1) shows the random nature of the gas flow rate pulsations in the caps over time.

A certain order in the operation of the caps was observed across the grate. Caps closest to each other operate with a fairly high correlation coefficient (Fig. 2a). As the distance between caps increases, the coefficient decreases to zero. At large distances and with shallow beds, a negative correlation is seen. This is indication of predominantly antiphase fluctuations of flow rate. The area of the region of synchronous cap operation increases markedly with an increase in bed depth (Fig. 2b). Similar relationships have been obtained for pressure pulsations in the fluidized bed itself [2, p. 39]. It is evident that the source of the fluctuations in gas flow rate in the caps and the pressure pulsations in the bed are gas bubbles leaving the bed. An increase in the size of the bubbles is accompanied by an increase in the size of the zone of their effect and the amplitude of the flow rate pulsations. Meanwhile, the amplitude of the pressure-gradient pulsations on the constriction apparatus increases and the relative value (relative to the mean pressure gradient) remains nearly the same (Fig. 3) with an increase in fluidizing velocity.

The connection between the rate of gas flow through the caps and the pressure pulsations in the bed (and, accordingly, with the motion of the gas bubbles) is confirmed by the agreement between the fundamental frequencies and

---

S. M. Kirov Ural Polytechnic Institute, Sverdlovsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 43, No. 3, pp. 357-360, September, 1982. Original article submitted July 6, 1981.

0022-0841/82/4303-0949 $07.50 © 1983 Plenum Publishing Corporation

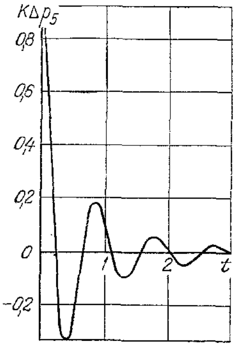

Fig. 1. Normalized autocorrelation function of gas flow rate fluctuations in cap No. 5: H = 0.8 m, T = 140 sec, Δt = 0.02 sec. t, sec.

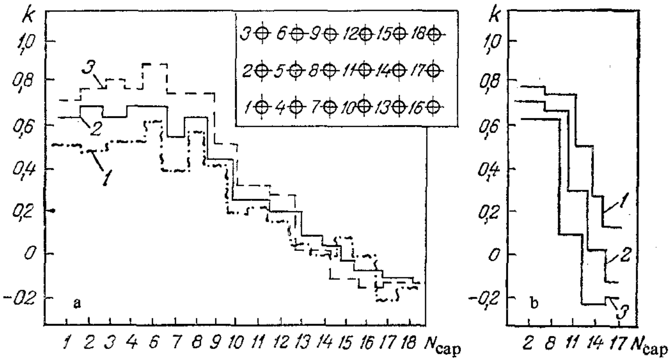

Fig. 2. Correlation of gas flow rate through cap No. 5: a) with all other caps (Δt = 7.5 msec; H = 0.5 m; 1) W = 1.5; 2) 2.3; 3) 3.5); b) with caps in the middle row (Δt = 7.5 msec; W = 3.5; 1) H = 0.8 m; 2) 0.5; 3) 0.3).

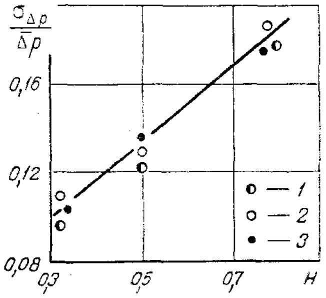

Fig. 3. Dependence of scale of gas flow rate pulsations in cap on bed depth: 1) W = 1.5; 2) 2.3; 3) 3.5. H, m.

the character of change in the amplitude of the pulsations. Table 1 compares our experimental data with data calculated using the formulas of Verloop and Hurtjes [4]: $f=\sqrt{q(2-\varepsilon)}/2\pi\sqrt{H\varepsilon}$ at a bed porosity $\epsilon = 0.4$, and the empirical formula [5] $f = 0.87/H^{0.5}d_p^{0.31}\rho_p^{0.24}$. Also shown in the comparison are data obtained on our unit, but with another gas distributor. The divergence of the latter from our data can be attributed to different methods of determining the fundamental frequency. In our experiments, as in [5], this is the frequency at which the spectral density function has its maximum. In [2], the frequency was somewhat exaggerated, since it was calculated from the number of times the oscillogram of the instantaneous value intersected with the mean, with the small-scale pulsations contributing here. Based on our data, the appearance of higher-frequency components of the flow rate fluctuation becomes more significant (the spectrum becomes broader) with a decrease in bed depth and fluidizing velocity. The reason is evidently an increase in the number of bubble exit sites on the surface, since far-removed bubbles should also affect the rate of gas flow through the caps, but to a lesser degree than the bubbles which break directly above the zone in question.

TABLE 1. Frequency of Gas Flow Rate Pulsations in Cap Compared to Frequency of Pressure Pulsations in Bed

Bed depth H, m	Freq. of gas flow rate pulsations in cap, Hz	Freq. of pressure pulsations in bed, Hz		
		[4]	[5]	[2]
0.3	2,08	1,82	2,25	2.8
0,5	1,56	1,41	1,73	2
0.8	1,04	1,12	1,37	1,4

Thus, the above studies show that fluctuations in gas flow rate in the caps are determined by pressure pulsations in the bed connected with the escape of gas bubbles at the surface. The flow rate pulsation in each cap does not have a stable period. The cross section of the gas-distributing grate, as the entire volume of the bed, is divided into several zones related to the most probable sites of bubble exit. The fluctuations in gas flow rate in the caps in these zones correlate with one another.

NOTATION

d_p, particle diameter, m; H, bed depth, m; w_c, critical fluidizing velocity, m/sec; F_c, area of grate covered by one cap, m^2; W, number of fluidizations; ϵ, bed porosity; T, duration of realization, sec; Δt, quantization level, sec; f, frequency of fluctuations, 1/sec; $\overline{\Delta p}$, mean pressure gradient in Venturi tube, Pa; t, time, sec; $\sigma_{\Delta p}$, standard deviation of pressure gradient, Pa; k, correlation coefficient of fluctuations in pressure gradient in caps; $K_{\Delta p}(t)$, normalized autocorrelation function of fluctuations in pressure gradient in cap; N, number of cap in grate.

LITERATURE CITED

1. V. A. Borodulya, Yu. A. Buevich, and V. V. Zav'yalov, "Stability of operation of units with a gas–solid fluidized bed," Inzh.-Fiz. Zh., 31, No. 3, 410-415 (1976).
2. A. P. Baskakov, B. V. Berg, A. F. Ryzhkov, and N. F. Filippovskii, Heat and Mass Transfer Processes in a Fluidized Bed [in Russian], Metallurgiya, Moscow (1978).
3. A. B. Whitehead, G. Gartside, and D. C. Dent, "Fluidization studies in large gas–solid systems. Part III. The effect of bed depth and fluidizing velocity on solids circulation patterns," Powder Technol., 16, 61-70 (1976).
4. J. Verloop and P. M. Hurtjes, "Periodic pressure fluctuations in fluidized beds," Chem. Eng. Sci., 29, No. 4, 1035-1042 (1974).
5. N. Sadasivan, D. Barretean, and C. Laquerie, "Studies on frequency and magnitude of fluctuations of pressure drop in gas–solid fluidized beds," Powder Technol., 26, 67-74 (1980).