PARTICLE MOVEMENT IN A GAS-SOLID FLUIDIZED BED*

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The photographs of particle movement were taken in a two-dimensional fluidized bed and statistically analyzed. The circulation of the solid phase was proved to exist from the mean particle velocity and the scale of movement concerning space and time was obtained from the autocorrelation coefficient of particle velocity. These informations will be available for simulating the solid mixing in fluidized beds.

Introduction

The informations of particle movement are necessary for simulating the mixing process of solids in a gas-solid fluidized bed. The authors took continuous photographs of particle movement and analyzed the statistical behavior of the solid phase.

§1 Experiment and Analysis

1.1 Apparatus and particle used

The experimental apparatus was a two-dimensional column, 450mm in width, 15mm in thickness and 900mm in height and was made of acryl resin plate. A sintered plastic plate (Hoverglide) was used as the air distributor.

The major part of fluidized solids was PVC particles colored with the black paint (helizarine black T) and mixed with about 0.2% white tracer particles. Their mean size was 1.0mm and the density was estimated to be 1.05.

The fluidizing air was passed through a conditioning chamber and its temperature and humidity were maintained constant.

1.2 Method of measurement and analysis

The particle movement near the wall was recorded by a photograph taken with a 16mm cine camera and measured in an area at a fixed point. The size of the area was 10mm×10mm when the characteristics of particle movement was measured with respect to space and 20mm×20mm when it was measured with respect to time.

The correlation coefficient with respect to space for the horizontal velocity component is given by the following equation:

$$R_s(\Delta x) = \frac{1}{N_s - 1} \cdot \frac{1}{\sigma(x_1, y) \cdot \sigma(x_2, y)} \sum_{i=1}^{N_s} \{v(x_1, y, \theta_i) - \bar{v}(x_1, y)\} \{v(x_2, y, \theta_i) - \bar{v}(x_2, y)\} \quad (1)$$

The coefficient for the vertical velocity component is also calculated by the similar equation. The correlation coefficient with respect to time is given by the following equation:

$$R_t(\Delta \theta) = \frac{1}{N_t - 1} \cdot \frac{1}{\sigma^2(x, y)} \sum_{i=1}^{N_t} \{v(x, y, i\tau) - \bar{v}(x, y)\} \times \{v(x, y, (i+j)\tau) - \bar{v}(x, y)\} \quad (2)$$

The spectral density of particle velocity was calculated

after numerical integration of Fourier-transform of $R_t(\Delta \theta)$. The computation was carried out with the digital computer HITAC 5020E.

§2 Results

The following results are reported for the experimental condition where the static bed height is 25cm and $u/u_{mf} = 1.9$ ($u_{mf} = 48\text{cm/sec}$).

2.1 Circulation velocity

The particle velocity contains the time-average component at each point. Particles circulate upwards in the center region and downwards near the wall (Table 1).

2.2 Characteristics of particle movement with respect to space

Fig. 1* shows the correlation coefficients with respect to space. The horizontal integral macro scale is 2.24cm, while the vertical integral macro scale is 0.85cm at the same area. And their values increase at the upper part of the bed.

2.3 Characteristics of particle movement with respect to time

The correlation coefficients in Fig. 2* decrease rapidly and oscillate irregularly after a certain delay in time. This characteristics of the coefficient corresponds to that of the fluctuation which consists of random components

Table 1 Mean and standard deviation of particle velocity

x [cm]	y [cm]	$\bar{v}_x$ [cm/sec]	$\bar{v}_y$ [cm/sec]	σ_x [cm/sec]	σ_y [cm/sec]	ρ [—]
-20.0	7.7	0.3	-3.1	4.7	7.3	-0.037
-20.0	14.7	-0.6	-2.4	2.3	5.8	0.469
-16.5	7.7	0.4	-3.1	6.9	8.5	-0.122
-16.5	16.2	-2.3	-5.6	6.6	8.9	0.232
-16.5	26.2	0.0	-1.8	5.1	7.1	0.221
-12.0	7.7	0.9	-1.7	6.5	10.1	-0.058
-11.5	16.2	1.1	-3.5	8.4	12.5	0.030
-11.5	26.2	-0.8	-3.4	6.0	10.8	-0.002
-5.5	8.2	1.9	-2.1	9.9	12.7	0.069
-5.5	16.2	0.0	-4.7	8.2	13.4	-0.140
-5.5	26.2	-1.3	-1.3	8.6	12.5	-0.085
0.5	8.2	2.9	-0.2	10.9	18.2	0.012
0.5	16.2	0.7	0.7	14.9	19.9	-0.105
0.5	25.7	-0.4	-0.2	13.3	18.4	-0.074
10.5	7.7	-0.2	5.5	12.3	59.0	-0.136
10.5	16.2	-3.5	2.4	14.3	17.4	0.109
10.5	26.2	-0.8	6.0	11.8	20.3	-0.002
20.5	7.7	-0.8	-1.5	6.2	11.6	-0.136
20.5	16.2	0.0	-2.4	3.6	9.2	-0.139
20.5	26.2	-0.8	-5.7	5.6	11.2	0.335

* Received on March 22, 1968

* The position of the area observed is described in the upper part of the figure.

Fig. 1 Correlation coefficient of particle velocity with respect to space ($\bullet$ for v_x and $\circ$ for v_y)

Fig. 2 Correlation coefficient of particle velocity with respect to time ($\bullet$ for v_x and $\circ$ for v_y)

and periodical components. The spectral density exhibits the maximum at the frequency of 0~2cps.

2.4 Standard deviation and distribution of particle velocity

The standard deviation of the particle velocity reaches

Fig. 3 Spectral density of particle velocity ($\bullet$ for v_x and $\circ$ for v_y)

its maximum at the horizontal coordinate between 0 and 10cm due to the eccentric distribution of air flow (Table 1).

The simultaneous distribution of the horizontal velocity component and the vertical velocity component differs from the uni-modal normal distribution of two variables. These results will give the informations on the scale of particle movement concerning space and time, and also the informations on transition probability from cell to cell. And then solid mixing can be simulated¹⁾.

Nomenclature

f	= frequency	[sec ⁻¹]
M	= integer corresponding to the maximum lag time	[—]
N	= total number of the data	[—]
R	= autocorrelation coefficient	[—]
S	= spectral density	[—]
u	= air velocity	[cm/sec]
v	= particle velocity	[cm/sec]
x	= horizontal coordinate	[cm]
Δx	= difference of x	[cm]
y	= vertical coordinate	[cm]
θ	= time	[sec]
$\Delta \theta$	= lag time	[sec]
ρ	= correlation coefficient between the horizontal and the vertical component of the particle velocity	[—]
σ	= standard deviation of the particle velocity	[cm/sec]
τ	= unit of lag time	[sec]

Subscripts

1, 2	= position
mf	= minimum fluidization
s	= space
t	= time
x	= horizontal velocity component
y	= vertical velocity component

Superfix

—	: time average
^	: smoothed

Literature cited

- 1) Mori, Y. and K. Nakamura: Preprint of 32nd Annual Meeting of the Society of Chemical Engineers, Japan, No. 358, Part 2 (April, 1967, Tokyo)