Pressure Fluctuation Measurements and Flow Regime Transitions in Gas-Liquid-Solid Fluidized Beds

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INTRODUCTION

Three different flow patterns have been observed in cocurrent upward gas-liquid-solid fluidization, namely, the coalesced bubble regime, the dispersed bubble regime, and the slug flow regime (Fan et al., 1984). The flow regime of a gas-liquid-solid fluidized bed is usually determined by visual observation. The transitions between flow regimes, however, are sometimes very difficult to determine visually; as a result, the exact flow rates at which the transitions occur cannot be found precisely. This study attempts to characterize the flow regimes in a gas-liquid-solid fluidized bed by the statistical properties of the wall pressure fluctuations, specifically the power spectral density function and the root mean square of the pressure fluctuations.

EXPERIMENTAL

A schematic diagram of the experimental apparatus is shown in Figure 1. The fluidized bed consists of a Plexiglas column of 0.102 m ID and of 1.07 m height. A gas-liquid distributor, located at the bottom of the column, provides uniform distributions of air and water (Fan et al., 1982). The particles used include glass beads of 1.0, 3.04, and 6.11 mm dia., 2.5 mm nylon beads, 2.27 mm alumina particles, and 0.70 mm activated carbon particles. Superficial air velocities in the experiments ranged from 0 to 22 cm/s, while superficial water velocities ranged from 0 to 16 cm/s. The flow regime for each run was determined by visual observation.

Two Validyne DP15 variable reluctance differential pressure transducers were used to obtain the pressure fluctuation data. The two transducers are located at distances of 0.212 m and 0.440 m above the gas-liquid distributor. The pressure tap tubes are curved downward to prevent air from entering the transducers. A piece of 200-mesh screen was soldered on the bed end of each tube so that particles would not enter the tube. The pressure transducers are connected to a D.C. power supply and a Validyne Model CD280 Multichannel Carrier Demodulator, which is interfaced with a VAX-11/780 computer system. Each transducer produces a voltage proportional to the measured pressure, which is digitized by means of an analog-digital converter on the VAX and stored. Each experimental run consists of 16,384 data points taken at 10 ms intervals, resulting in a total sampling time of 163.84 s. The digitized data acquired in this way were used to calculate statistical properties of the pressure fluctuations. The power spectral density function, which expresses the distribution of energy with frequency, was calculated by the fast Fourier transform method. Details of the statistical calculations may be found in Stearns (1975).

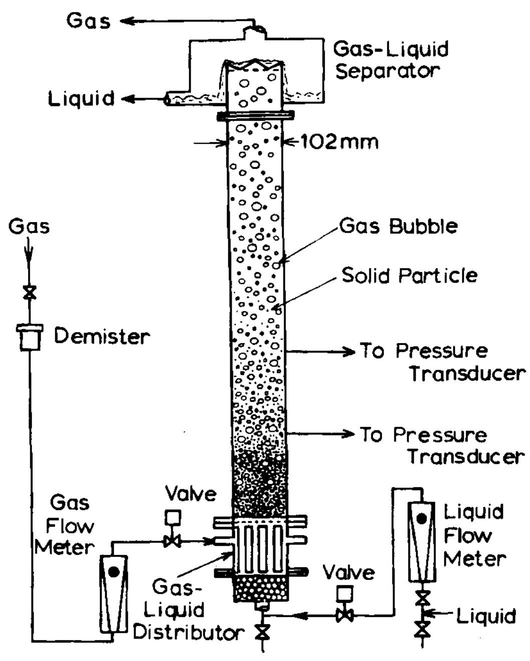

Figure 1. Diagram of experimental apparatus.

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RESULTS AND DISCUSSION

Typical pressure signals obtained in the experiments are shown in Figure 2. These pressure fluctuation signals appear very similar for dispersed bubble, coalesced bubble, and slug flow regimes. However, differences in the pressure signals become apparent when the statistical properties of the signals are calculated. The typical power spectral density functions of the pressure signals obtained in the dispersed, coalesced, and slugging regimes are shown in Figure 3. It can be seen that the power spectral density functions appear distinctly different for the three flow regimes. For each regime, there is a distinct peak between 0 and 2 Hz and a broad peak between 16 and 25 Hz, although the relative magnitude of these peaks differs for each regime. The power spectral density function is negligibly small at frequencies above 30 Hz for all three flow regimes. There appears to be almost no contribution of frequencies between 2 and 16 Hz to the power spectrum in the dispersed bubble regime, while the contribution of these frequencies is fairly large in the coalesced bubble regime and is quite large in the slug flow regime. These characteristics of the power spectral density function for the different flow regimes were observed for all particles used in the experiments.

From these observations, it appears that the contribution of frequencies between 2 and 16 Hz to the power spectral density is somehow related to the bubbling characteristics of the flow regime. For the dispersed regime, where bubbles are small and of approximately uniform size, the contribution of frequencies between 0 and 2 Hz is very large and the contribution of frequencies between 2 and 16 Hz is small. For the slug flow regime, which contains a wide distribution of bubble sizes, the opposite is true. It should be noted that in three-phase fluidized beds, unlike two-phase beds, uniform slugging is not obtained and there are always small bubbles present in the system (Matsuura and Fan, 1984). Consequently, there is a broad distribution of bubble frequencies in the slug flow regime rather than a single dominant frequency. The broad peak in the power spectrum near 20 Hz has also been observed by Glasgow et al. (1984) for wall pressure fluctuations in an airlift fermentor involving two (gas and liquid) phases. They attributed this peak to damped interfacial disturbances and/or surges in the air distributor following bubble detachment.

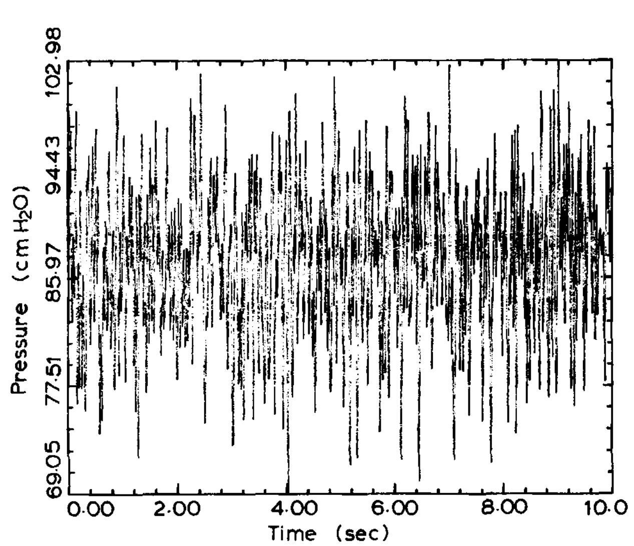

Figure 2. Typical pressure fluctuation signals; 3.04 mm glass beads, U_l = 6.77 cm/s, U_g = 13.2 cm/s.

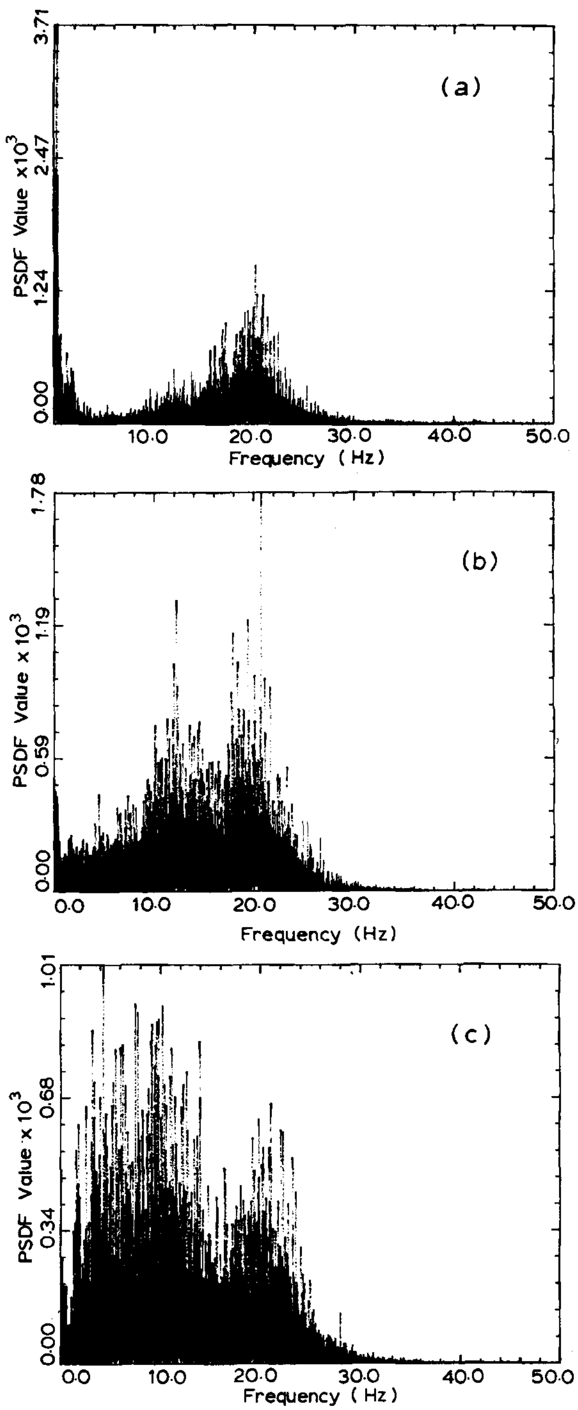

Figure 3. Power spectral density function for 3.04 mm glass beads.
(a) Dispersed bubble regime; U_l = 15.8 cm/s, U_g = 3.3 cm/s.
(b) Coalesced bubble regime; U_l = 9.03 cm/s, U_g = 3.3 cm/s.
(c) Slug flow regime; U_l = 6.77 cm/s, U_g = 13.2 cm/s.

It is noted that the power spectral density function at very low frequencies is much larger for the dispersed regime than for the coalesced or slugging regime. This allows a potential method for determining the transition from the dispersed regime to the coalesced regime and from the dispersed regime to the slug flow regime. It was found that the cumulative power near zero frequency (the sum of the discrete power spectral density function for frequency values below approximately 0.6 Hz) rises sharply at the observed transition from the coalesced regime to the dispersed regime and drops sharply at the observed transition from the dispersed regime to the slug flow regime for all types of particles investigated.

The root mean square (RMS) of the pressure fluctuations was calculated for each experimental run. It was observed that the RMS of the pressure fluctuations decreases nearly linearly with superficial water velocity in the coalesced regime. In the dispersed regime, the RMS of the pressure fluctuations remains nearly steady or decreases only slightly with superficial water velocity for all the particles tested. Also, the RMS of the pressure fluctuations was observed to increase nearly linearly with superficial air velocity in the coalesced regime and to remain nearly steady or increase only slightly with superficial air velocity in the slug flow regime. This suggests that the variation of the RMS of the pressure fluctuations with flow rate may provide an objective method of characterizing the transitions from the coalesced regime to the dispersed regime and to the slug flow regime. It is interesting to note that a previous study has found that the mean bubble size in the coalesced regime decreases with increasing liquid flow rate and increases with increasing gas flow rate (Rigby et al., 1970). Thus it appears that the RMS of the pressure fluctuations may have a direct relation to mean bubble size.

The visually observed flow regime transition velocities for coalesced to dispersed, coalesced to slugging, and dispersed to slugging are plotted against particle terminal velocity in Figure 4. It can be seen that the transition velocity between the coalesced bubble and dispersed bubble regimes shows a clear rise and fall with particle terminal velocity. This same trend has been reported for a 76.2 mm ID gas-liquid-solid fluidized bed by Fan et al. (1985). Comparison of those results with the results from this work show that the line representing the increase of transition velocity with particle terminal velocity at low particle terminal velocities is shifted upward for the larger column, i.e., the coalesced to dispersed transition velocities at a given particle terminal velocity are higher for a larger diameter column. However, the line representing the decrease in transition velocity with particle terminal velocity at higher particle terminal velocities is practically identical for both size columns. It can be seen from Figure 4 that the coalesced to slugging and dispersed to slugging transition velocities are practically independent of particle terminal velocity.

ACKNOWLEDGMENT

This work was supported by National Science Foundation Grant CPE-8219160.

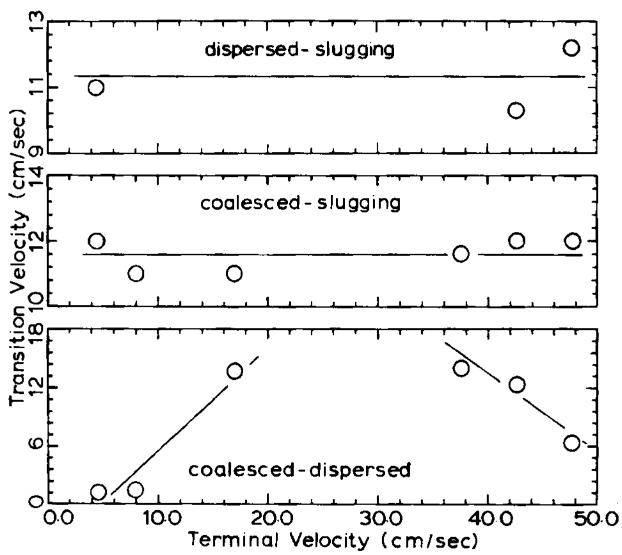

Figure 4. Variation of flow regime transition velocity with terminal velocity of particle in water.

NOTATION

U_g = superficial gas velocity
U_l = superficial liquid velocity

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Manuscript received Mar. 8, 1985, and revision received Apr. 15, 1985.