Characterization of Binary Gas-Solid Flow in a Semi-Batch Cylindrical Fluidized Bed Using Electrical Capacitance Tomography

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Highlights

- Measurements of time evolution of solid volume fraction distribution using ECT
- Comparison of dynamics of unary and binary gas-solid fluidization
- Effect of solid density, size, and shape on local solid volume fraction fluctuations in binary fluidization
- Effect of superficial gas velocity and mixture composition on flow dynamics

1. Introduction

Gas-solid fluidized beds used in industrial processes often involve mixture of particles with different size or shape or density leading to a complex flow behavior (eg. coal and inerts, coal and ash, biomass and inert used in gasification process). The difference in physical properties (size, density and shape) of solid phases give rise to a non-uniform mixing and segregation phenomenon. Such inherently unsteady flow influence the heat and mass transfer processes in fluidized bed reactors. Therefore, spatial and time-resolved measurements of local solid hold-up and velocities are important to comprehend dynamic characteristics of flow, which can elucidate the effects due to mixing of particles that differ in size, shape and density. Several researchers have investigated the segregation and mixing phenomenon of binary particles and main focus of their work done was to predict the minimum fluidization velocity, bed dispersed height, and flow regimes. The measurement techniques mostly used were rapid shut-off (freezing), pressure transducers, and digital image analysis. The instantaneous measurements of local solid volume fraction in binary gas-solid fluidization are not reported in the open literature. Such experimental measurements are crucial not only in understanding and characterizing the dynamic fluidization behavior, but also for development and rigorous experimental validation of CFD models. Therefore, the objective of present work is to characterize the local dynamics of binary gas-solid flow by varying density, size, and shape of the particles in a semi-batch cylindrical fluidized bed.

2. Methodology

Unary and binary gas-solid fluidization is performed in a 9 cm diameter cylindrical bed with 36 cm static bed height. Electrical Capacitance Tomography (ECT) was used to measure instantaneous local solid volume fraction over the cross-section of the bed. A photograph of the experimental set-up comprised of fluidized bed fitted with two ECT sensors and data acquisition system (DAS) is shown in Figure 1. Air was used as the fluidizing medium, glass beads (GB) (d_p = 100 and 900 μm; ρ_p = 2500 kg/m^3) and mustard seeds (MS) (d_p = 1000 μm; ρ_p = 720 kg/m^3) were used as the solid phases. Dynamics of fluidization of unary solids and binary (GB:MS and GB_100μm:GB_900μm in the weight ratio of 70%:30%, 50%:50%, and 30%:70%) solids was investigated for superficial gas velocities (U_G) in the range of 0.01 - 2.6 m/s. The velocity was varied in the wide range to study the segregation and mixing phenomena of the gas-solid binary fluidization. Further details of the set-up, and other solid phases which differ in shape and their respective compositions will be presented in full length manuscript.

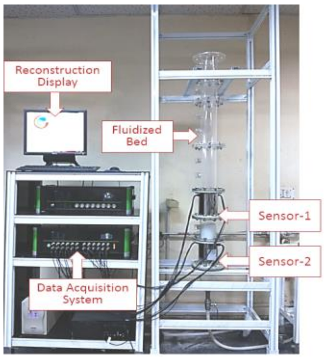

Figure 1: Experimental set-up

3. Results and Discussion

The time-evolution of solid volume fraction (α_s) along the bed diameter for unary GB (d_p = 900 μm), unary MS and binary (GB:MS = 70%:30%) system at U_G = 0.545 m/s and z = 27 cm from the distributor is shown in Figure 2. In the case of unary GB system, less α_s fluctuations along the bed diameter were observed (see Figure 2(a)) as the operating U_G (=0.545 m/s) was just above the minimum fluidization velocity of GB i.e. 0.54 m/s; whereas in the case of MS, large bubbles (or slugs) that covered the entire bed diameter were observed (see Figure 2(b)). In the case of binary system, bubbles were passing mostly through the center of

the column and size of bubbles was smaller in comparison to that observed for the unary MS and larger than that observed for the unary GB (see Figure 2(c)). Figure 3 shows the comparison of measured local α_s fluctuations for unary MS, GB and the binary system at different radial locations. At the center (r/R = 0) of the column, α_s fluctuations were found to be higher (see Figure 3(a)) and this corresponded to passage of single bubbles. However, near the wall (r/R = -0.95), the fluctuations were found to be smaller which corresponded to smaller bubbles or the small portion of the large bubbles (see Figure 3 (c)). Due to the large slugs observed in the case of unary MS, local α_s at r/R = 0, -0.5, and -0.95 showed similar trend (see Figures 3(a)-(c)). The power spectra of local α_s fluctuations of unary GB, unary MS and binary systems at r/R = 0 are shown in Figure 4. For unary MS (2.44 Hz) and binary system (3.46 Hz), single dominant frequencies were observed due to the periodic α_s fluctuations (see Figures 4(b)-(c)). The difference in dominant frequencies is due to the wide and narrow slugs observed in case of unary MS and binary systems. Multiple dominant frequencies which varied in the range of 1.18-3.26 Hz were observed in the case of unary GB due to aperiodic and small α_s fluctuations. In order to characterize the bubble size, variance of the local α_s fluctuations was calculated and the variance was found to decrease in order of unary GB, the binary and unary MS (results are not shown here).

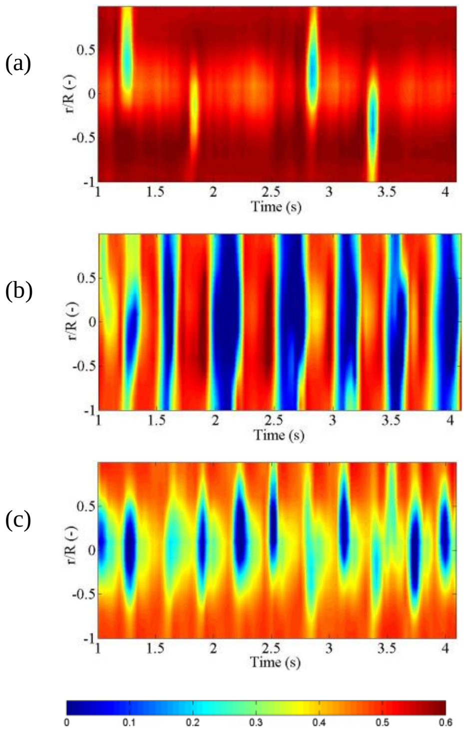

Figure 2. Time evolution of solid volume fraction for (a) GB (d_p = 900 µm), (b) MS, and (c) binary (GB:MS = 70%:30%) along the diameter of the bed at z = 27 cm and U_G = 0.545 m/s.

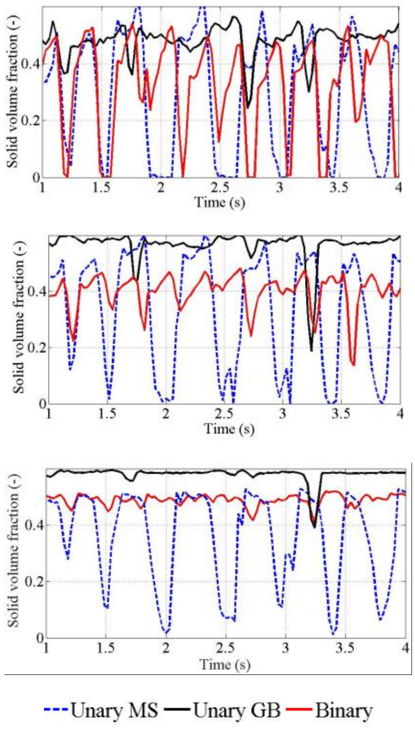

Figure 3. Time-evolution of solid volume fraction at (a) r/R = 0, (b) r/R = -0.5 and (c) r/R = -0.95 at z = 27 cm and U_G = 0.545 m/s.

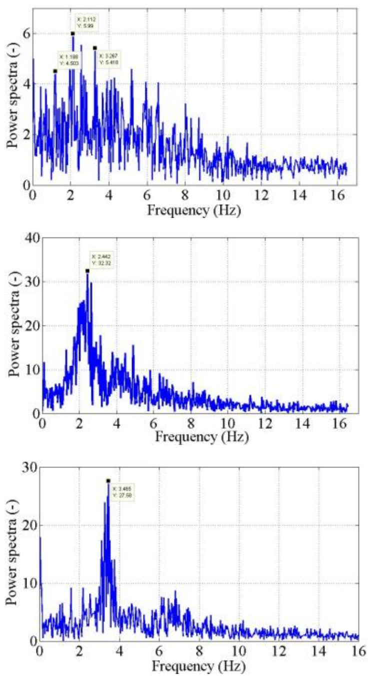

Figure 4. Power spectra of local α_s fluctuations for (a) GB (d_p = 900 µm), (b) MS, and (c) binary (GB:MS = 70%:30%) at r/R = 0, z = 27 cm and U_G = 0.545 m/s.

4. Conclusions

Local solid volume fraction fluctuations measured using ECT were used to characterize segregation of binary solids at lower gas velocities and the fluidization characteristics of unary and binary solids at higher gas velocities. Effects of the solid physical properties (size ratio, density ratio, and shapes) and mixture compositions on dynamic characteristics of binary gas-solid flow were investigated for a wide range of superficial gas velocities. Detailed analysis of the aforementioned studies will be presented in full length manuscript. The present work will be useful to understand the dynamic behavior of binary gas-solid fluidization which differ in size, shape, and density and the measurements will be used to validate the Eulerian CFD models.

Keywords: Binary fluidization, Solid volume fraction, Dynamics, ECT