Imaging Horizontal Gas/Solid Jet Penetration in A Gas-solid Fluidized Bed Using Electrical Capacitance Volume Tomography

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Abstract

The horizontal gas-solid jet penetration of a gas-solid fluidized bed is studied using electrical capacitance volume tomography (ECVT). ECVT is a non-invasive imaging technique developed by the authors and it involves providing 3D concentration maps from capacitance sensors.. The fluidized bed under investigation is of 0.3m (12 inch) ID with a 0.5m ID disengagement section and has a total height of 2.4m. A gas-solid jet side injection, with 1 inch ID, penetrates the wall of the fluidized bed in the middle of the ECVT test region. Solids in the side injection are supplied through and blown into the fluidized bed using high pressure gas. Fluid catalytic cracking catalysts (Group A) are used in this study. The superficial gas velocity from the distributor of the gas-solid fluidized bed employed ranges from 0.03 to 0.24 m/s and the gas velocity from the side jet penetration ranges from 0 to 16 m/s. In this study, we observe and analyze gas and gas-solid side injection in the bubbling regime of the fluidized bed, variation in bubble shape, formation, and coalescence.

Introduction

Gas-solid fluidized beds have been employed extensively in chemical, petrochemical, metallurgical, food, and pharmaceutical industries. Fluidized beds provide good mass and heat transfer characteristics and high mixing rates between solid particles and gas. In industrial fluidized bed reactors, reactants of gas and solids are often introduced into reactors by horizontal jets at a certain height above the bed distributor to enhance the lateral mixing of solids. Although considerable research efforts have been placed on the phenomenon of the horizontal gas-solids jet penetration in gas-solid fluidized beds, further understanding on the hydrodynamics of horizontal gas-solids jets penetration are still needed for improving reactor design. Among the past several decades, little work has been done on horizontal gas-solids jet penetration phenomenon. Kozin and Baskakov (1967) studied horizontal gas jets using a specific design of a cap-air distributor and provided a penetration correlation. Merry (1971) measured penetration depths of horizontal air jets into three fluidized beds of different diameters using sand kale seed and steel shot to propose a correlation of the horizontal jet penetration depth. Hong et al. (1997) used a semi-theoretical correlation to predict horizontal-inclined jets

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penetration by visual observation of a 314 mm by 25 mm two-dimensional gas-solid fluidized bed with an angular changeable inclined jet at the side of the bed. However, accurate and simultaneous 3D measurements of the instantaneous shape and motion of volume solid fractions from jets and the hydrodynamics of coalescence of horizontal jet and bubble from the bottom of a distributor are needed to better understand side injection effect. Such measurements need to be carried out with three-dimensional non-intrusive techniques. In this study, Electrical Capacitance Volume Tomography (ECVT) is applied for the measurements of the instantaneous shape and motion of solids in jets.

Experimental Studies

Experimental setup

Figure 1 is the schematic diagram of the gas-solid fluidized bed with a horizontal gas/solid jet penetration system used in this study. The fluidized bed column made from Plexiglas is of 0.3 m ID with a 0.5 m ID disengagement section. A two-stage cyclone is installed at the freeboard of the fluidized bed to separates solids from gas. The distributor of the fluidized bed is made of a porous plate with a pore size of 20 μm and a fractional free area of 60%. The total bed height of the fluidized bed is 2.4 m. A horizontal tube with a 0.0254 m ID is mounted on the wall of the testing section of the fluidized bed, 0.3 m above the distributor to inject the mixture of solids and gas from the side. Solids are fed into the horizontal tube by a solids-feeder and a flow controller. A gas jet at a high speed velocity is mixed with the solids in the horizontal tube and the mixture of gas and solids is injected into the fluidized bed. FCC particles (Geldart group A) with a mean diameter of 60 μm and a particle density of 1400 kg/m^3 are used both as the fluidized solids in the fluidized bed and the injected solids from the side horizontal tube. The testing region of the fluidized bed with the horizontal gas-solid injection is mounted with the ECVT sensor, which will be discussed in the next section.

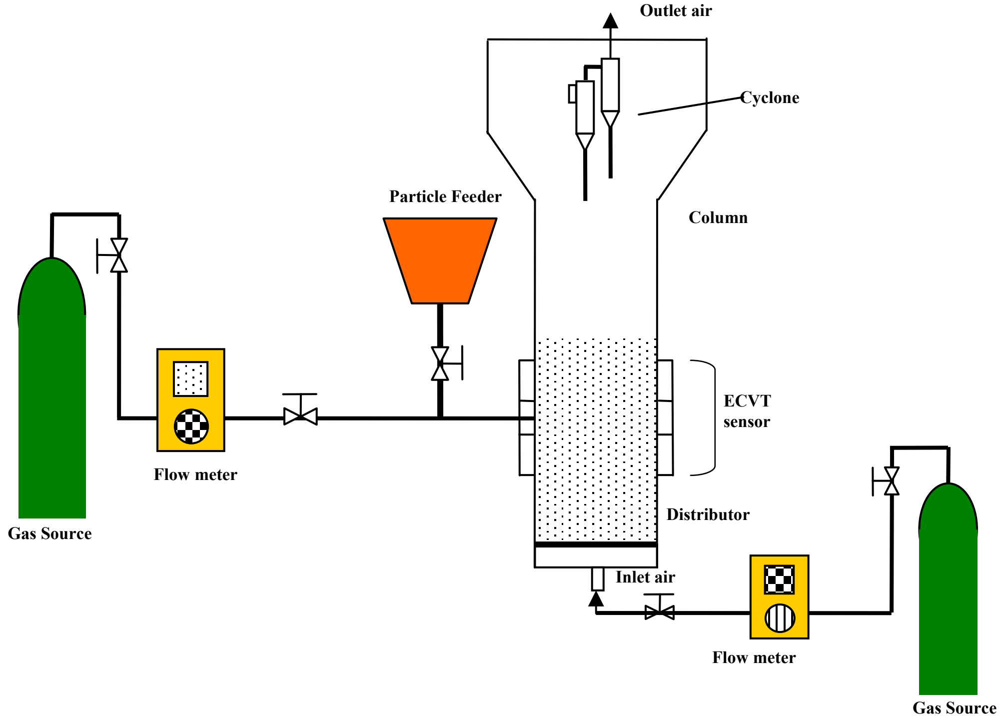


Figure 1. Schematic diagram of the gas-solid fluidized bed with a horizontal gas/solid jet penetration system

Electrical capacitance volume tomography

ECVT system consists of three basic parts: (1) a three-dimensional capacitance sensor, (2) a data acquisition system to obtain capacitance signals, and (3) a computer system to reconstruct and view the images. Figure 2 is a schematic diagram of the ECVT system used for the measurement of horizontal gas-solid penetration in the gas-solid fluidized bed. The volume tomography technology acquires 3D images directly from the measured capacitance data. (Warsito and Fan, 2005; Warsito, et al., 2007; Marashdeh et al. 2008). The image reconstruction is based on optimizing a set of objective functions related to both the measured capacitance and reconstructed image itself. The configuration of the three-dimensional capacitance sensor is illustrated in Figure 3. It has three layers with four electrodes in each layer and a total of twelve channels, each electrode has a rectangular plate shape. The edges of two side-by-side electrodes in the middle layer are modified to accommodate the penetration tube. The acquisition frequency is 80 Hz and the reconstruction resolution is of $20 \times 20 \times 20$ pixels for the three-dimensional images.

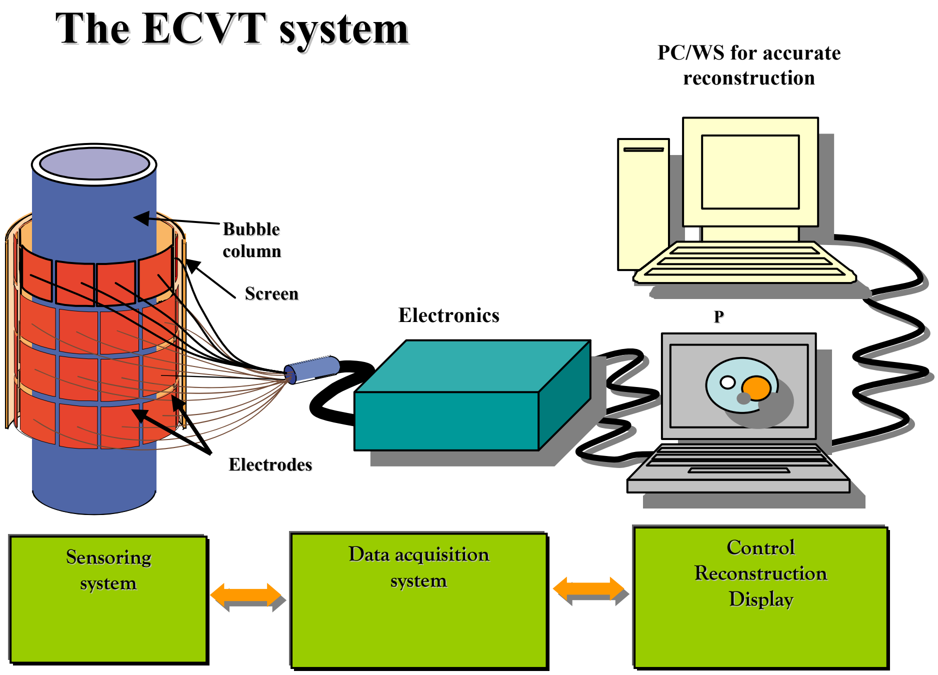


Figure 2. ECVT system

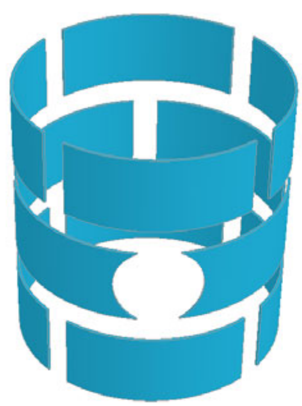


Figure 3. ECVT sensor configuration

Results and Discussion

Comparisons between the ECVT, ECT and the optical fiber probe measurements

Figure 4. shows the comparison between the time-averaged cross-sectional solids concentrations obtained by ECT, optical fiber probe (Bing Du et al., 2005), and volume solids concentration by ECVT for the 12-in gas-solid fluidized bed with FCC fluidized particles. The results obtained by ECVT, ECT and the optical fiber probe are comparable. It is observed that the solids concentrations obtained by the ECVT technique are slightly higher than those measured by ECT which is attributed for the high spatial resolution of ECT(32×32) compared to that of ECVT ($20 \times 20 \times 20$).

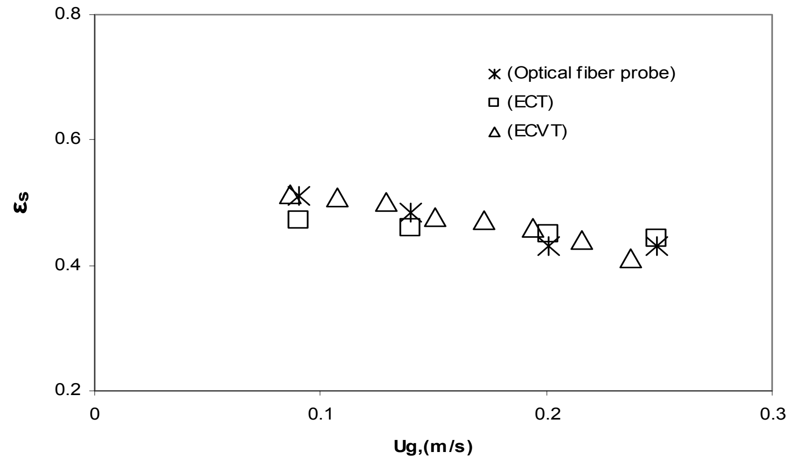
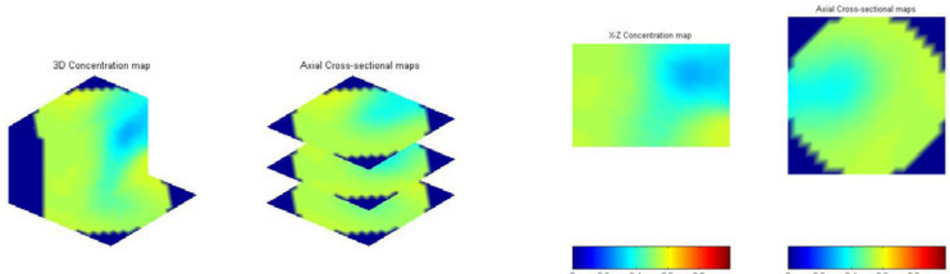


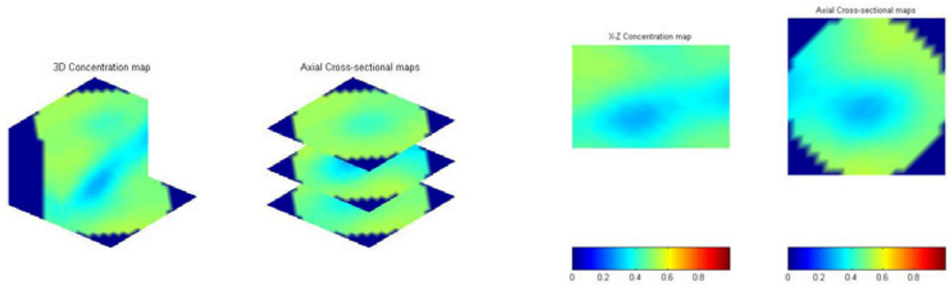
Figure 4. Comparison between the time-averaged cross-sectional solids concentrations obtained by ECT, optical fiber probe and volume solids concentration by ECVT for a 12-in gas-solid fluidized bed

Horizontal Gas/Solid Jet Penetration

Figure 5 shows the three-dimensional and two-dimensional views (from left to right, 3D Concentration map, axial cross-sectional maps at top, middle, and bottom of the monitoring region, X-Z concentration map, axial cross-sectional map in the middle, respectively) of jet penetration from the side horizontal tube of the fluidized bed. The fluidized bed is operated at two different superficial gas velocities: 0.032 m/s (Figure 5a) and 0.108 m/s (Figure 5b). The gas jet velocity is 15.5 m/s for both cases. The gas jet penetration length at high superficial gas flow rate is greater than that at low superficial gas flow rate. Figure 6 shows the images of penetration of gas-solids mixture jet from the side horizontal tube with Ug 0.032 m/s, gas jet velocity 16 m/s, and solid jet velocity 16 m/s. The horizontal penetration length of the gas-solids mixture is high and the jet penetrates the center of the column. Figure 7 shows the coalescence of bubbles from fluidized bed distributor and gas jet penetration with Ug 0.108 m/s and gas jet velocity 15.5 m/s. The jet penetrates the gas-solid fluidized bed and meets the bubble from the bottom of the distributor to form a “large” rising bubble toward the bed surface.



(a)



(b)

Figure 5. views of fluidized bed with gas jet penetration from the side horizontal tube: (a) Ug=0.032 m/s, gas jet velocity=15.5 m/s; (b) Ug=0.108 G/s, gas jet velocity=15.5 m/s.

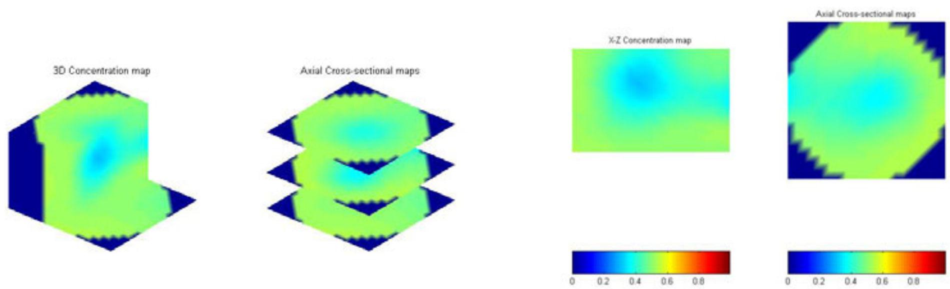
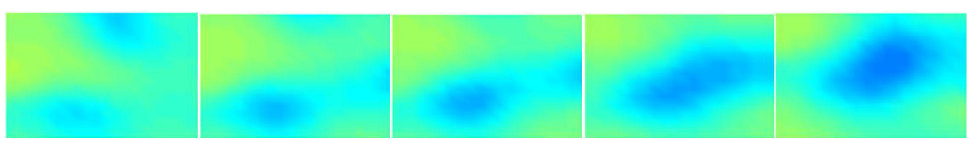


Figure 6. Images of fluidized bed with gas-solid jet penetration mixture jet from the side horizontal tube: Ug=0.032 m/s, gas jet velocity=16 m/s, solid jet velocity=16 m/s.



t=0 t=25 ms t=50 ms t=75 ms t=100 ms

Figure 7. Coalescence of bubbles from fluidized bed distributor and gas jet penetration: Ug=0.108 m/s, gas jet velocity=15.5 m/s

Conclusion

ECVT is successfully applied for the visualization of horizontal gas-solid jet penetration of a gas-solid fluidized bed. Three-dimensional images of the horizontal gas jet and gas/solids mixture flow structures are obtained by ECVT. The accurate, instantaneous, and quantitative volume solids fraction of the gas-solid fluidized bed is provided. The images show the process of coalescence of horizontal gas jet and bubbles from the distributor in the gas-solid fluidized bed. ECVT shows its robustness and powerful capability for the three-dimensional visualization and quantitative measurements of gas-solid fluidization system and horizontal gas-solid penetration system.

Acknowledgements

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