Local Holdups and Phase Propagation Velocity Measurement in GLSCFB Riser Using Electrical Resistance Tomography and Optical Fibre Probe

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Abstract

The application of Gas-Liquid-solid circulating fluidized beds (GLSCBE) has increased recently in chemical, petrochemical and biochemical industries. Electrical Resistance Tomography (ERT) and optical fibre probe were applied to investigate local phase holdups distribution. Since ERT is applicable only to conductive phase(s), e.g. liquid phase in this study, optical fibre probe was employed simultaneously to quantify all three phases. Water was used as continuous and conductive phase, air as the gas phase and glass beads as solid non-conductive phases. The local conductivity measured by a number of electrodes located at the periphery of the plane, was then further converted into a local phase concentration distribution based on Maxwell's relation. Fibre optic probe was also employed to measure gas holdup independently. A new model was developed to exploit the fibre optic data in differentiating gas bubbles from solid particles in the riser. Gas holdup was higher in the central region and decreased radially, while opposite trend was observed with solid holdup due to the drag forces imposed on solid particles by the gas and liquid upward flow in the riser. By applying cross correlation between the data obtained at two different levels in the riser, the propagation velocity of the nonconductive phase was obtained. Propagation velocity was higher in the central region compared to the wall region and increased with increasing liquid superficial velocity

Keywords: Three Phase Circulating Fluidized bed, Electrical Resistance Tomography, fibre optic, phase hold-up, Propagation velocity.

1. Introduction

Gas-liquid-solid circulating fluidized beds (GLSCFB) have been widely used in chemical, petrochemical and biochemical and environmental processes, such as hydrogenation, desulfurization, fermentation, due to its efficient mixing, heat and mass transfer capabilities. Most of the studies on gas-liquid-solid fluidization systems have mainly focused on conventional expanded bed regime in the past decades [1]. Different measurement techniques have been developed to measure phase holdups such as; optical fiber technique, ultrasound technique, electric conductive probe technique, process tomographic technique. Most of the techniques are suitable for two phase systems.

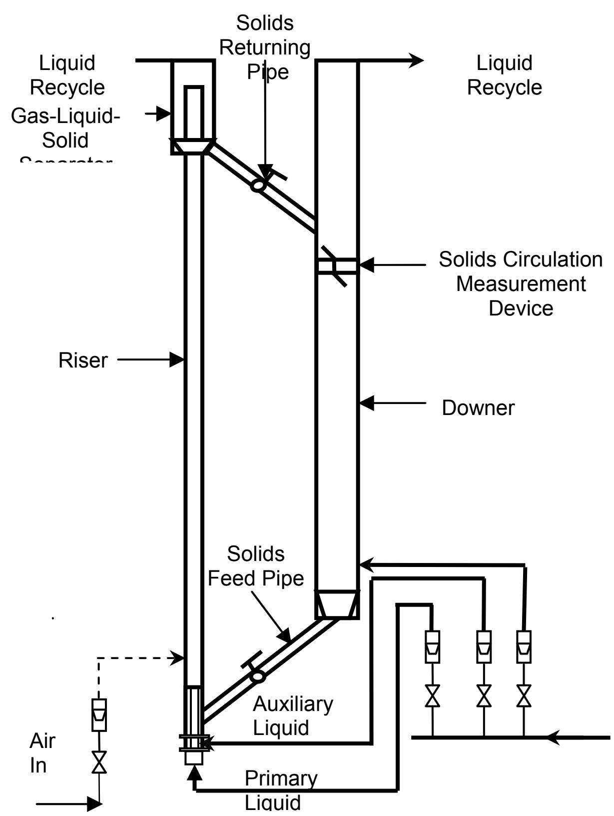

Figure 1: Schematic Diagram of GLSCFB system

However, there are no imaging techniques available for the study of three phase systems in real time. George et al.[2] developed a combined system of Electrical Impedance Tomography (EIT) and gamma-densitometry tomography (GDT) to measure distribution of phases in a vertical three-phase flow system simultaneously. Razzak et al.[3] measured phase holdups and velocities in a GLSCFB system by combining ERT and Pressure Transducers (PT). In this study, Electrical

Resistance Tomography (ERT), a newly developed method for the phase holdups measurement, is presented. However ERT cannot measure phase holdups for all the phases, therefore an optical fiber probe and pressure transducers are used simultaneously to measure phase holdups for all three phases. In the experiments, water was used as the liquid (continuous and conductive) phase, air as the gas phase and glass beads with 500 microns range as the solids phase.

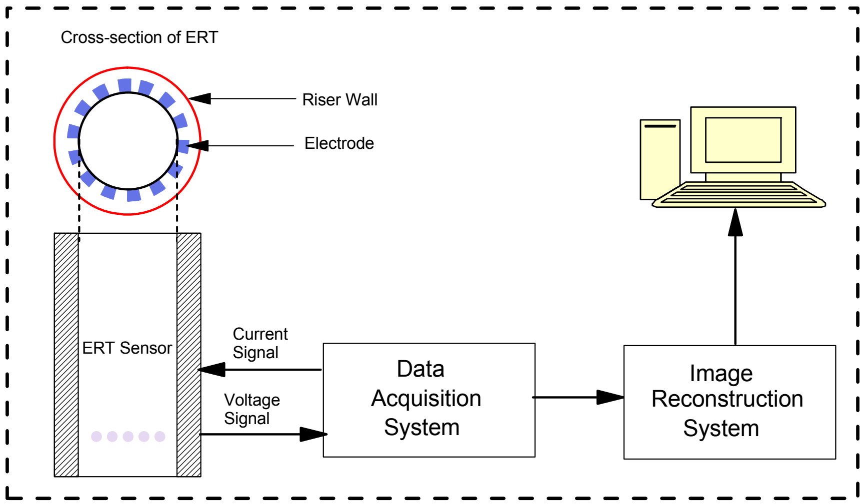

Figure 2: Schematic diagram of the measurement prinicple of ERT.

A schematic diagram of the typical ERT setup is shown in Figure 2. The ERT consists of a sensor section, an electronic circuit and a PC-based data acquisition system. The inner diameter of the sensor section is built equal to the inner diameter of the riser so that the sensors can be lined up with the riser.The optical fiber probes used in the present study were model PV- 5, produced by the Institute of Process Engineering, Chinese Academy of Sciences, are capable of measuring solids concentration in three phase fluidized beds. Details of the optical fiber probes system are shown schematically in Figure 3. All experiments were conducted with two different types of particles which were similar in size but different in density and shape. Particle density of glass beads was 2500 kg/m^3. Schematic diagram of the experimental set-up of GLSCFB is shown in the Figure 1. The GLSCFB consists of two main sections, riser and downer, both made of Plexiglas.

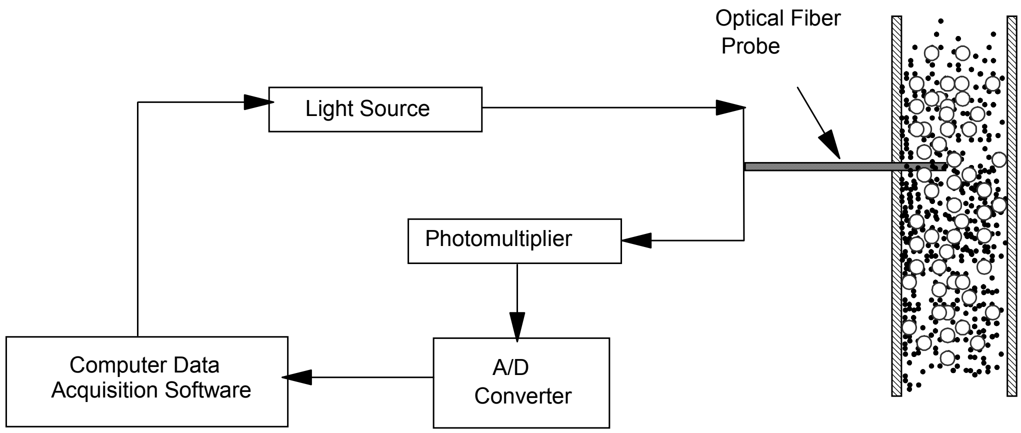

Figure 3: Optical Fibre Probe system for gas holdup measurement in GLSCFB riser.

Combination of these measurement techniques provided valuable information about the hydrodynamics of GLSCFB riser. Average phase holdups, and local distribution of phases were obtained. The phase propagation velocity was estimated by applying cross correlation technique to the two sets of data obtained at upstream and downstream planes in ERT experiments. All measurements in this work were carried out at seven radial positions (distributed radially, centered at r/R = 0, 0.2034, 0.492, 0.6396, 0.7615, 0.8641, 0.9518).

2. Method

A schematic diagram of the typical ERT setup and Optical Probe system have shown in Figure 1b and c. For each driving current, the ERT measures the electrical potential distribution through the electrodes flush mounted on the pipe wall. With input values of the electrical potentials and currents, the local conductivity (or resistivity) of the mixture can be reconstructed through a state-of-the-art optimization algorithm. The conductivity distribution is then further converted into a local phase concentration distribution based on Maxwell's relation.

Figure 4 shows the signals produced in the gas-liquid-solid system for a particular operating case, U_g = 4.88 cm/s. It can be observed that bubble produces distinctively bigger signals than those of solid particles. Signals associated with large bubbles can be easily distinguished and differentiated for the signal produced for liquid-solid system. The amplitudes of the small bubbles signals were quite small and quite close to that of solid particles, which made it difficult to differentiate this bubbles. By combining both ERT and Optical probe techniques gas, liquid and solids holdup distinguished and measured.

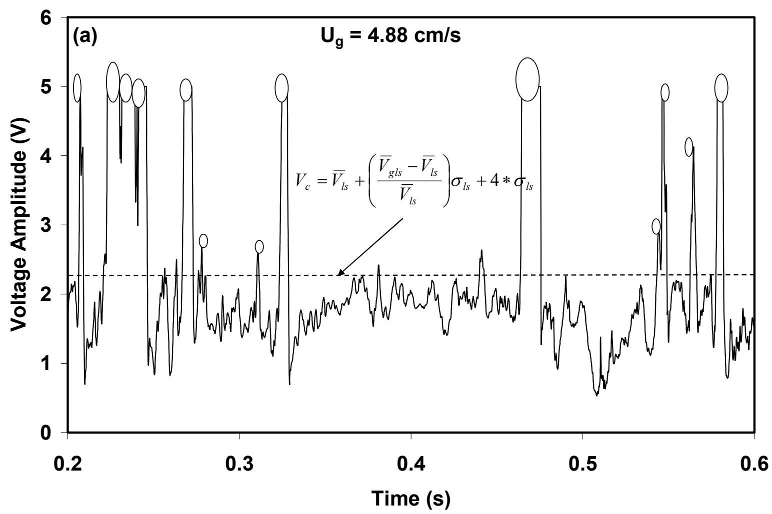

Figure 4: Gas holdup measurement method using optical probe.

The interfacial propagation velocities of the non-conductive phase/phases are obtained by cross-correlation technique. Two imaging planes are placed in short distances in the ERT sensors. The image reconstructed by the ERT was divided into a number of finite elements, each having a value which was indicative of the resistivity/conductivity of the region occupied. Propagation velocity was estimated by applying cross-correlation analysis to phase distributions at the two levels. The total number of finite elements used to measure propagation velocities was 256 per plane. If it takes a time lag, τ, for a void wave to propagate from upstream plane to downstream plane, the wave velocity is

$$C_k = \frac{d}{\tau} \tag{1}$$

where d and τ are the distance between the two sets of electrodes and the time lag of the interfacial wave propagation, respectively. The distance is set by the ERT manufacturer and the time lag is obtained from cross-correlation analysis. Basically, a cross-correlation function can be defined as

$$S_{AB} = \lim_{T \to \infty} \frac{1}{T} \int_{-T/2}^{T/2} \sigma_A(t) \cdot \sigma_B(t+\tau) dt \tag{2}$$

for a certain period of time, T. The function describes the general dependence between the upstream, $\sigma_A(t)$, and the downstream, $\sigma_B(t)$, conductivities.

3. Results and Discussions

Figures 5 have shown the solids, gas and liquid holdup measured by using newly invented combined methodology. With this method local phase holdup successfully measured in situ for the first time in GLSCFB system. Figure 2 b, and c show the radial distributions of gas and solids phase holdups at different superficial gas velocities where superficial liquid velocity U_l=5.6 cm/s in the GLSCFB riser. All measurements were carried out at an axial location of H=2.02 m above the distributor. Solids holdup initially remains constant at the central location and increases radially toward the wall. Opposite trend was observed for the gas holdup as it sharply decreased in wall region. On the other hand with the increase of gas superficial velocity liquid holdups (not showing in the figure) are decrease. And holdup found lower at the central region and gradually increases radially towards the wall.

Phase propagation velocity under different superficial liquid and solid velocities for glass beads is shown in Figure 6. The nonconductive phase propagation velocity was higher at the central region and decreased radially towards the wall region for all superficial liquid velocities applied. Gas bubbles have a tendency to move upward in the central region. The liquid velocity was higher at the central region and imposed higher drag force on particles in that region. Liquid superficial velocity had also a profound effect on the phase propagation velocity. The rate of change in propagation velocity was much higher at higher liquid superficial velocities.

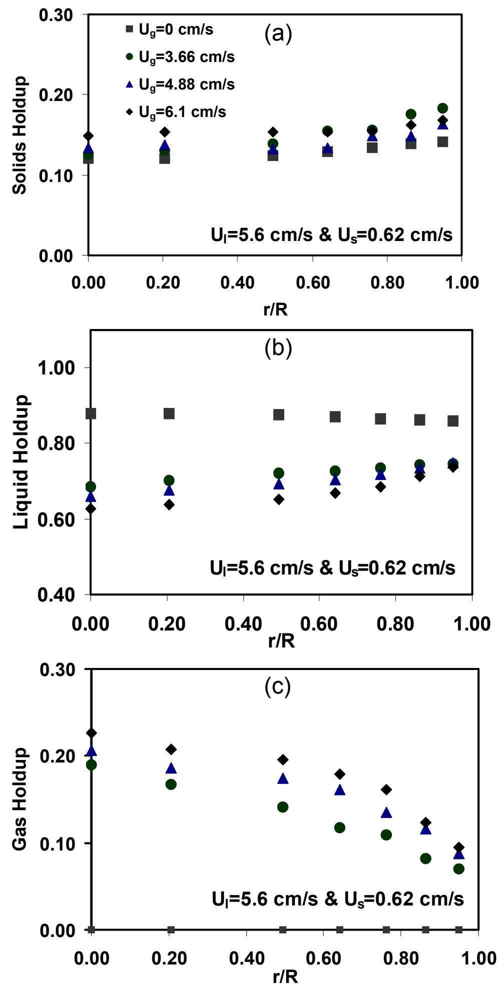

Figure 5: Radial distribution of (a) solids (b) liquid and (c) Gas phase holdups under different gas superficial velocity at Ul = 5.6 cm/s & Us = 0.62 cm/s using glass beads.

4. Conclusions

Radial distribution of phase hold-ups and phase propagation velocities were determined successfully by applying Electrical Resistance Tomography and fibre optic methods. ERT signals are influenced by conductive phase(s) only, therefore the application of fibre optic method was necessary to determine phase hold-ups for all three phases. An empirical method was developed for quantification of the fibre optic data. The fibre optic signals obtained for glass beads and lave rocks were substantially different in amplitude and average values, which required minor modifications in the model. Although the fibre optic was not sensitive to the small gas bubbles the model provided reasonably good results. Different results were obtained

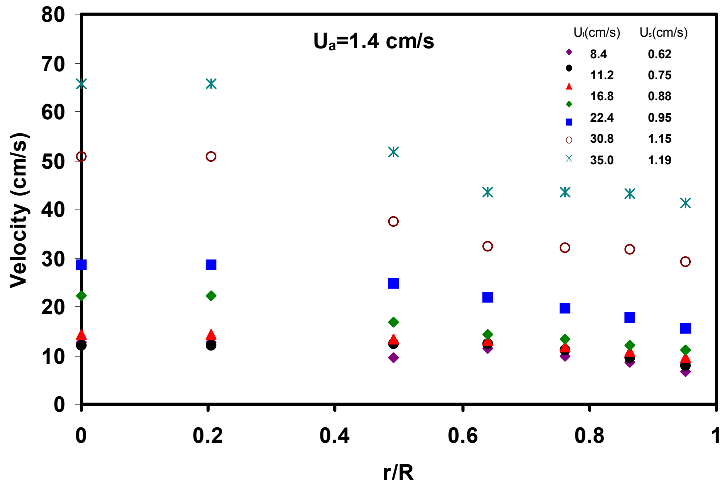

Figure 6: Radial distribution of combined gas-solid phase propagation velocity profile under different superficial liquid and solid velocities for glass beads.

for glass beads and lava rock particles but both particles showed similar trends in radial distribution of phase holdups and propagation velocities. Gas holdup was always higher in the central region and decreased radially towards the wall while solid holdup showed opposite trend. Solid propagation velocity was also higher in the central region compared to the wall region due to higher velocities of the gas and liquid phases which imposed larger drag force on particles in that region.

4. References

[1] Muroyama, K., Fan, L.S., Fundamental of gas-liquid-solid fluidization. *AIChE J.* (1985) 40, 83-92.

[2] George, D.L., shollenberger, K.A., Torczynski, J.R., O' Hern, T.J., Ceccio, S.L., Three-phas material distribution measurement in a vertical flow using gamma-densiometry tomography and electrical-impedance tomography. *Int. J. of Multiphase Flow*. (2001) 27, 1903-1930.

[3] Razzak, S. A., Barghi, S., Zhu, J-X., Eectrical Resistance Tomography for flow characterization of a Gas-Liquid-Solid Three-Phase Circulating Fluidized Bed. *Chem. Eng. Sc.* (2007) 62, 7253-7263.