Gas-Liquid Flow Characterization in Bubble Columns with Various Gas-Liquid Using Electrical Resistance Tomography

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Abstract. Electrical resistance tomography (ERT) is an advanced and new detecting technique that can measure and monitor the parameters of two-phase flow on line, such as gas-liquid bubble column. It is fit for the industrial process where the conductible medium serves as the disperse phase to present the key bubble flow characteristics in multi-phase medium. Radial variation of the gas holdup and mean holdups are investigated in a 0.160 m i. d. bubble column using ERT with two axial locations (Plane 1 and Plane 2). In all the experiments, air was used as the gas phase, tap water as liquid phase, and a series of experiments were done by adding KCl, ethanol, oil sodium, and glycerol to change liquid conductivity, liquid surface tension and viscosity. The superficial gas velocity was varied from 0.02 to 0.2 m/s. The effect of conductivity, surface tension, viscosity on the mean holdups and radial gas holdup distribution is discussed. The results showed that the gas holdup decrease with the increase of surface tension and increase with the increase of viscosity. Meanwhile, the settings of initial liquid conductivity slightly influence the gas holdup values, and the experimental data increases with the increase of the initial setting values in the same conditions.

1. INTRODUCTION
Bubble columns are widely used as gas–liquid contactors in many applications due to their simple construction, low operating cost, high energy efficiency and good mass and heat transfer rates (Kazakis et al., 2008), such as absorption, oxidation, fermentations, bio-reactions, coal liquefaction and waste water treatment etc.. During the past few years, special attention has been paid to local and global bubble flow characteristics as a key parameter that determines the overall reactor performance owing to the complexity of fluid mechanics in these systems (Dukovic et al, 2000; Fan et al, 1989). Developing qualities as well as quantitative understanding of the axial and radial holdup distribution in bubble columns turn to be essential (Jin et al., 2006).

Among all of those applications of process tomography as a robust noninvasive tool for direct analysis of the characteristics of multiphase flows, electrical resistance tomography (ERT) talent showing itself, owing to its noninvasive and fast data acquisition features, ERT might provide very useful tools for measuring and monitoring bubble column operation online (Wang et al, 1999; Jin et al., 2007). The speed of the technique to capture real-time data of highly fluctuating flow systems may be one of the most important concerns for the purpose of imaging multiphase flows in the process industries. And due to its high-speed capability, low construction cost, high safety and suitability for small or large vessels, ERT is considered to be the most powerful tool among other available tomography techniques.
In this study, the effect of conductivity, surface tension, viscosity on the mean holdups and radial gas holdup distribution was discussed using electrical resistance tomography with two axial locations (Plane 1 and Plane 2).

2. Experimental

2.1 Experimental setup

The experimental setup was a transparent perspex acrylic column with 2.5 m high and an inner diameter of 0.16m as shown in Fig. 1.

Two rings of ERT sensors, each composed of 16 rectangular electrodes, were mounted in the inner wall of the column in a non-invasive fashion. The electrodes were made of stainless steel with a contact area of 8 mm (w) by 16 mm (h). The data collection rate was 2 frames per second with an excitation signal frequency of 9.6 kHz. Meanwhile, two differential pressure sensors for measuring the differential pressure drop were placed along the column above the distributor. The differential pressure sampling frequency was 100 Hz. Two neighboring pressure-sampling ports were connected to the high end and low end of each different-pressure transducer, respectively.

Fig. 1. Schematic diagram of bubble column

2.2. Experimental systems and operating conditions

All the experiments were carried out at ambient pressure and temperature conditions (20±1°C). Sodium oleate and Ethanol were used to reduce the liquid surface tension, Glycerin to change the liquid viscosity and KCl solution to change the liquid conductivity. The gas phase was atmospheric air for all runs, while several liquids were employed as liquid phase. Their physical properties are presented in Table 1. The superficial gas velocity varied from 0.02 m/s to 0.2 m/s.

| Liquid phase       | Conductivity, $\sigma_L$ mS/cm | Viscosity, $\mu_L$ (mPas) | Surface tension $\sigma_L$ (mN/m) |
|-------------------|--------------------------------|---------------------------|----------------------------------|
| Tap water         | 0.96                           | 1.0                       | 71                               |
| KCl solution      | 1.10-1.90                      | 1.0                       | 71                               |
| Ethanol solution 0.2% (v/v) | 0.96                        | 1.0                       | 69.5                             |
| Ethanol solution 0.6% (v/v) | 0.96                        | 1.0                       | 68.6                             |
| Ethanol solution 5% (v/v) | 0.96                        | 1.0                       | 59.7                             |
| Ethanol solution 10% (v/v) | 0.96                        | 1.0                       | 53.4                             |
| Sodium oleate solution | 0.96                      | 1.0                       | 33                               |
| Glycerin solution 8% (v/v) | 0.96                      | 1.29                      | 71                               |
2.3. Experimental procedures and calculation methods

The adjacent electrode pair strategy was adopted using 10mA injection current at 9.6 kHz for parameter measurement. Data collection rates for plane 1 and plane 2 were 50 ms, with time for image reconstruction and other overheads, yielding approximately two images per second. With conductivity data from ERT, the local gas volume fraction ($\varepsilon_g$) can be determined by applying the Maxwell equation (Maxwell, 1873).

$$\varepsilon_g = \frac{2\sigma_1 + \sigma_2 - 2\sigma_{mc} + \sigma_{mc} \sigma_2 / \sigma_1}{\sigma_{mc} - \sigma_2 / \sigma_1 + 2(\sigma_1 - \sigma_2)}$$

(1)

Where $\sigma_1$ is the conductivity of the first phase, $\sigma_2$ is the conductivity of the second phase, and $\sigma_{mc}$ is the local value of mixture conductivity distribution. If the second phase is assumed to be nonconductive material, such as air in this study, the above equation can be simplified as follows.

$$\varepsilon_g = \frac{2\sigma_1 - 2\sigma_{mc}}{2\sigma_1 + \sigma_{mc}}$$

(2)

The local mixture conductivity ($\sigma_{mc}$) is determined from the pixel conductivity of ERT image.

The axial holdup can be measured from the two differential pressure signals. On the assumption that values of liquid acceleration term and the wall friction term were normally small and could be neglected, the mean gas holdup ($\varepsilon_g$) was calculated by equation (Jin et al., 2004).

$$\varepsilon_g = \frac{\Delta P}{\rho_l g \Delta H}$$

(3)

Where $\Delta P$ is the differential pressure between two pressure sensor points, $\Delta H$ the vertical distance between two pressure sensor points, and $\rho_l$ liquid density.

3. RESULTS AND DISCUSSION

3.1 Effect of conductivity on the overall holdups

Fig.2 shows relationship between solution conductivity and overall gas holdups in the same condition by mean of ERT. From Fig.2, liquid conductivity behavior slightly influences the gas holdup values, and the gas holdup increases with the increase of the initial conductivity values. According to the results using differential pressure method in Fig.3, the gas holdup values under conditions of difference conductivity remains unchanged. This reason can be explained that resistance field is sensitive to process condition and system temperature, which result in nonlinear dependence on gas holdups from Eqn.(2). As a result, calibration techniques of ERT are required, and the system conditions should be monitors in a certain range.
3.2 Effect of surface tension on the overall holdups
Surface tension of the liquid is an important physical parameter, but also an important factor that can affect gas holdup in gas-liquid column. The effect of surface tension on the gas holdups is studied by adding sodium oleate to change the surface tension in the air-water system and water-ethanol systems as shown Fig.4 and Fig.5. The results showed that the gas holdup increases with the decrease of surface tension in both two kinds of systems. However, the gas holdup in sodium oleate solution is much higher than one with tap water in the homogeneous regime, which is obvious different compared with the water-ethanol systems. It is considered that smaller bubbles are formed generally in tap water at first, and subsequently the coalescence phenomenon take place. However, the bubbles in a surfactant system have no tendency for coalescence (Bennett et al, 1999), which results in gas holdup for sodium oleate solution is much higher in the homogeneous regime.
3.3 Effect of viscosity on the overall holdups

Viscosity of the liquid is an important physical property, and it also influence the performance of the flow. In this paper, experiment by adding glycerol to increase the viscosity of liquid (surface tension will remain basically unchanged) to study the impact of viscosity on the gas holdup, as it is shown in Fig.6, gas holdup increase with the increase of viscosity, the result is consistent with the analysis of Khare et al. (1990). Khare pointed out that with the increase of viscosity in the liquid, on the one hand, gas gathering strengthen, the average diameter of the bubble increase. On the other hand, increasing the viscosity makes the bubble up drag increased. So, in a certain range of viscosity, the gas holdup increase with the increase of liquid viscosity.
3.3. The radial holdup profiles
Radial holdup profiles for different liquid systems as mentioned above are shown in Fig. 7. The radial gas holdup increases with an increase of gas velocity. Meanwhile, the radial gas holdup profiles are steeper at the central region of the column with an increase of gas velocity, namely the higher gas holdups at the centre of the column and lower gas holdups at the wall of the column. According to these results, it is notified that the form of radial gas holdup distribution for different gas-liquid systems cannot change. But the form of radial holdups is different for various gas liquid system.
4. CONCLUSION
Electrical resistance tomography is used to study the overall and radial holdup in a series of different gas-liquid systems in bubble column. The effect of conductivity, surface tension, viscosity on the mean holdups and radial gas holdup distribution was discussed. The results showed that the gas holdup decrease with the increase of surface tension and increase with the increase of viscosity. Meanwhile, it is found that the settings of initial liquid conductivity slightly influence the gas holdup values, and the experimental data increases with the increase of the initial setting values in the same conditions. Different systems cannot affect the form of radial gas holdup distribution. So the measurement technique of electrical resistance tomography has verified the validity and effectiveness for gas liquid system in this operating condition. However, the conductivity of liquid phase should not be neglected as a impactful factor, more attention should be paid to measure gas-liquid flow behavior.

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NOMENCLATURE

| Symbol  | Description                                      | Unit     |
|---------|-------------------------------------------------|----------|
| ΔH      | The vertical distance between two pressure sensor points | [m]      |
| ΔP      | The differential pressure between two pressure sensor points | [Pa]     |

Greek Letters

| Symbol  | Description                                      | Unit     |
|---------|-------------------------------------------------|----------|
| ρ_l     | Liquid density                                   | [kg/m³]  |
| σ_1     | The conductivity of the first phase              | [mS/cm]  |
| σ_2     | The conductivity of the second phase             | [mS/cm]  |
| σ_mc    | The local value of mixture conductivity distribution. | [mS/cm]  |
| μ_L     | Liquid viscosity                                 | [mPas]   |
| σ_L     | Liquid surface tension                           | [mN/m]   |
| ε_g     | Overall gas holdups                              | [-]      |

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