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EXPERIMENTAL STUDY OF GAS HOLD-UP AND BUBBLE BEHAVIOR IN GAS –LIQUID BUBBLE COLUMN

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Abstract

Experimental reactor was a cylindrical bubble-column made of glass, with an inside diameter of 15cm and a height of 2.8(m). The column was equipped with two types of sparger, a porous plate and a perforated plate with the same porosity. In this study, liquid phase and gas phase were water and air respectively. Gas hold up, bubble size and effect of sparger type in different gas velocity were investigated. Gas hold up was determined with differential pressure method and used to estimate the transition velocity in slurry bubble column reactors. The results showed that with increasing the superficial gas velocity, the total gas hold up increases. Also perforated -type sparger increases the diameter of bubbles up to 35% and decreases gas hold up to about 40% respectively. Also it was found that the Hikita's correlation predicts the gas hold up value better than other presented correlations in this system.

Keywords: Gas hold up; Bubble column; Bubble size; Sparger

1. Introduction

Bubble columns are contactors in which a discontinues gas phase in the form of bubbles moves relative to a continues phase. The continues phase can be liquid or homogeneous slurry [1]. Bubble column reactors are used in diverse application such as absorption, catalytic relation, bio reaction and coal liquefaction [2]. This reactors offer many advantages over other kinds of multiphase reactors: simple construction, no mechanically moving parts, good heat and mass transfer properties, high thermal stability, good mixing, low power requirements and hence low construction and operating cost [3]. Most studies have shown that there are two basic flow regimes in bubble columns, homogeneous and heterogeneous [4-6]. When a column filled with a liquid is sparged with gas, the bed of liquid begins to expand "homogeneously" and the bed height increases almost linearly with the superficial gas velocity. This regime of operation in a bubble column is called the homogeneous bubbly flow regime. As the gas velocity is increased, the gas hold up, ε_g increases and at a certain gas velocity, $U_{transition}$, coalescence of the bubbles takes place to produce first fast-rising "large" bubble. The appearance of first large bubble changes the hydrodynamic picture dramatically. The regime of operating for superficial gas velocity exceeding $U_{transition}$ is commonly referred to as heterogeneous or churn turbulent regime [7-9]. This regime is of importance in industrial reactor operation [10]. Gas hold up is one of the most important parameters characterizing the hydrodynamics of bubble columns [11]. It can be defined as the percentage by volume of the gas in the two or three phase mixture in the column. Gas hold up depends mainly on the superficial gas velocity [1]. Other important parameter that has a strong influence on the hydrodynamic behavior is bubble size distribution. The large gas bubbles rise quickly through the column than small bubbles. Therefore the gas residence time decrease and cause to reduce the total gas hold up [3,10,12].

The relation between superficial gas velocity and gas sparger type with gas hold-up are important designing parameters to predicting the hydrodynamic behavior of slurry bubble-column reactors. According to different reported correlations, distinguishing the best correlation is the most important factor for scaling up the slurry bubble-column reactors. A large number of correlation for gas hold up have been proposed in the literature [13-15], but the large scatter in the reported data dose not allow a single correlation. In the present work, the effect of superficial gas velocity and sparger type on gas hold up and bubble size distribution in bubble column reactor have studied, and the best correlation for predicting the hydrodynamic behavior on bubble column reactors is suggested.

2. Experimental set up

Experimental set up consists of a cylindrical glass column with 15cm inner diameter and 2.8 m height. The column is equipped with two spargers in bottom, a perforated plate and a porous plate, both with 0.1 % porosity. Designing of perforated plate is based on Weber number, this sparger consist of 19 holes with 1 mm diameter. There are several techniques to measure the gas hold up and bubble size distributions such as: pressure drop measurements, γ radiation, optical fiber probes, particle image velocimetry (PIV), computer tomography (CT), and photographic method [11]. In all experiences the pressure at top of the column was atmospheric. Gas injected from bottom of the column. After injecting gas, the liquid bed expended and the hydrostatic pressure is change. With measuring the differential pressure through the column, the total gas hold up can be determined. For measuring the differential pressure through the column, a monometer is used, and for measuring bubble size distribution the photographic method is used. The liquid phase is water and gas phase is air. In figure 1 the experimental set up is showed.

3. Result and Discussion

3. 1 Effect of Superficial Gas Velocity on Gas Hold-up

In this study the gas hold up have been measured at different superficial gas velocity, with differential pressure method, the results are shown in Figure 2. All the experiences show the positive effect of superficial gas velocity on gas hold up. This positive effect has been shown in the most published studies [16,11,17]. The homogeneous regime occurs at low gas flow, and turns into the heterogeneous regime at high gas flow. At low superficial gas velocity, the bubble size is small and uniform and bubble travel upwards in a helical path without any major collision or coalescence. With increasing the superficial gas velocity the bubbles are coalescenced therefore at high superficial gas velocity (more than about 9 cm/s) all the bubbles will be large [4,13,18]. The large bubbles have higher rise velocity than small bubbles, therefore residence time of large bubbles decrease and cause to decrease rate of increasing gas hold up. Krishna et al.[19] showed same result in Air-Tellus oil system. The transition from homogeneous to heterogeneous regime is observed at a superficial gas velocity between 0.9 to 0.11 m/s. The transition superficial gas velocity reported 0.1 m/s by Iordache et al. [20]. The dependence of the gas hold up on gas velocity is generally of the below form [21-22]:

$$\varepsilon_g = \alpha U_g^n \tag{1}$$

where: ε_g : gas hold up, U_g : superficial gas velocity

The value of n depends on the flow regime. In homogeneous flow regime, the value of n varies from 0.7 to 1.2 and in the churn- turbulent regime ε_g is weaker function of U_g , and n varies from 0.4 to 0.7. The value of n is strongly dependent on operating variables, physical properties of the system, as well as the design characteristics of the column [1,4,21]. In this study the value of n and α calculated in homogeneous and heterogeneous flow regimes.

$\varepsilon_g = 0{,}450\, u_g^{0.954}$ homogeneous flow regime (2)

$\varepsilon_g = 1{,}335\, u_g^{0.449}$ heterogeneous flow regime (3)

Many correlations for predicting gas hold up can be found in literatures. Table 1 shows some of these correlations. The comparison between measured and predicted gas hold up values are illustrated in Fig 3 and 4: It can be seen that Haikita 's correlation is better than other correlations for estimating gas hold up.

Table 1 Predicted correlations

Author	Correlation
Hikita et al. [13]	$\varepsilon_G = 0.672\, u_G^{0.574} \rho_l^{0.069} \rho_g^{0.062} \sigma^{-0.185} \eta_l^{-0.053} \eta_g^{0.107} g^{-0.131}$
Hugmark et al. [14]	$\varepsilon_G = 1 / [2 + (0.35 / u_G)(\rho_l \sigma / 72)^{1/3}]\ \dfrac{1}{2}$
Hikita & Kikukaw [23]	$\varepsilon_g = 0.505\ U_g^{0.47} \left(\dfrac{0.072}{\sigma}\right)^{2/3} \left(\dfrac{0.001}{\mu_l}\right)^{0.05}$
Reily et al. [24]	$\varepsilon_G = 296 U_G^{0.44} \rho_L^{-0.98} \sigma_L^{-0.16} \rho_G^{0.19} + 0.009$
Kumar et al. [15]	$\varepsilon_G = 0.728U - 0.485U^2 + 0.0975U^3$ $U = U_G \left[\rho_L^2 / \sigma (\rho_L - \rho_G) g\right]^{1/4}$

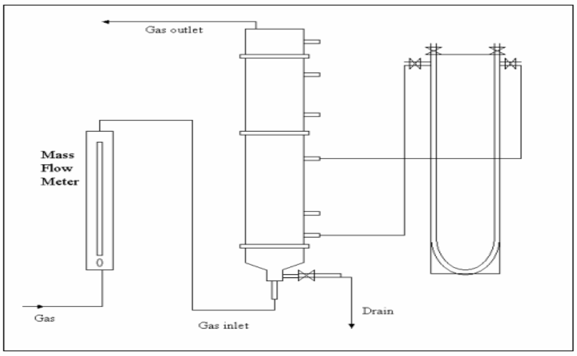

Fig 1 Experimental set up

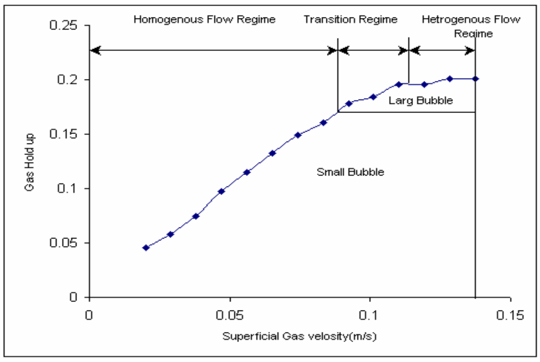

Fig 2 Effect of superficial gas velocity on gas hold up in air-water system

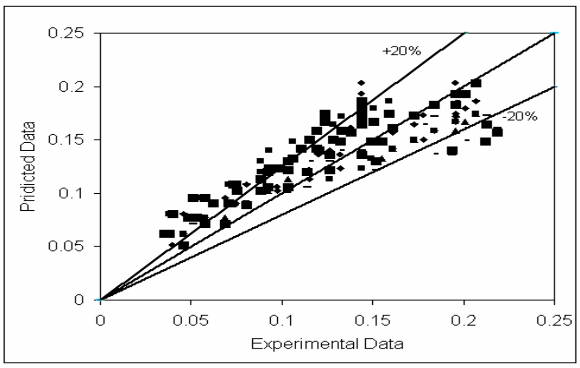

Fig 3 Comparison between predicted value and experimental data of gas hold-up

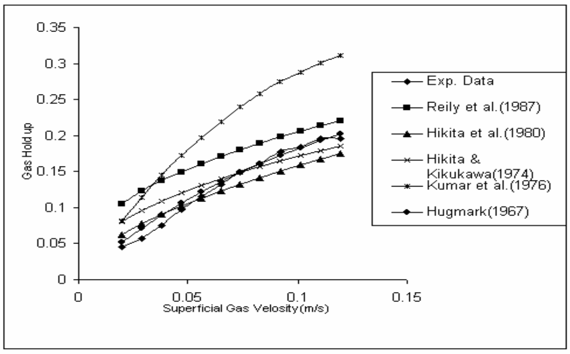

Fig 4 Comparison between correlations and experimental data

3.2 Effect of Sparger type on Gas Hold-up and Bubble size.

In this study two different spargers are used: Perforated plate and porous plate bothwith 0.1% porosity [Fig 5].

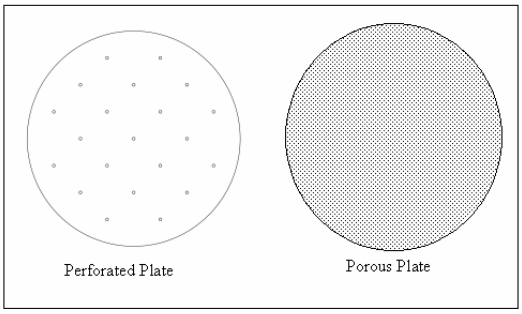

Fig 5 Two sparger types are used in the experimental set up

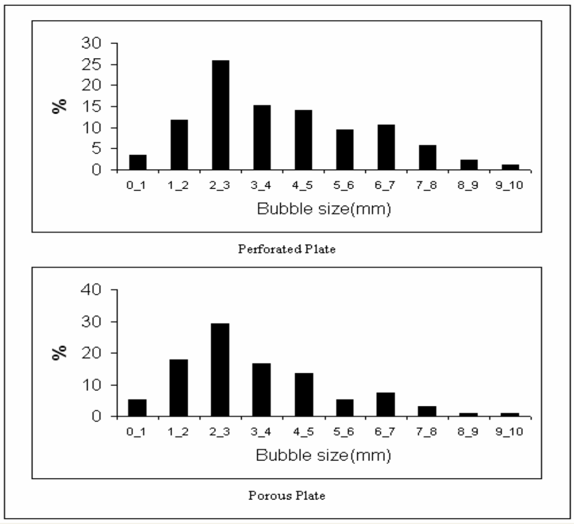

Fig 6 Bubble size distribution

Designing of perforated plate is based on Weber number. According to Mersmann [25], a W_e>2 is necessary to assure bubble breakage and axial mixing in the liquid. The Weber number for gas is given as follow:

$$W_e = \frac{\sigma_g U_{G,o} d_o}{\sigma} = \frac{\sigma_G U_{G,o}^2 D_c^4}{N_o^2 d_o \sigma} \quad (4)$$

Where
N_o - number of openings on sparger
σ_G - gas density
d_o - orifice diameter
$U_{G,o}$ - gas velocity from orifice
σ - surface tension
D_c- column diameter

The orifice diameter of perforated plate is 1 mm and the porous plate consists of micro size pores. The initial bubble size and distribution at the orifice could be controlled by the sparger characteristics. Fig 6 shows the bubble size distribution at 2.9 cm/s of superficial gas velocity with different spargers. The sauters mean bubble diameter was calculated with following equation [26]:

$$d_{32} = \frac{\sum_i^N d_i^3}{\sum_{i-1}^N d_i^2} \quad (5)$$

With using equation (5) the Sauters mean bubble diameter in system equipped with perforated plate is 6.23 mm and in system equipped with porous plate is 5.71 mm.

Krishna et al. [19] shows that $V_b \propto d_b$ (V_b -bubble velocity, d_b -bubble diameter), therefore system equipped with porous plate, the bubble size is smeller, V_b is lower, and the gas hold up is higher. The large bubbles have higher rise velocity than small bubbles, and the residence time decreases and cause to decrease gas hold up. Fig 7 shows the effect of sparger type on gas hold up. It should be mentioned that gas hold up depends on the break up and coalescence of the gas bubbles in the column. Porous plate with smaller pore diameters, have been found to generate smaller gas bubbles when compared to perforated plate [27]. Therefore the gas hold up in system that equipped with porous plate at high superficial gas velocity is approximately 40% higher than system equipped with perforated plate.

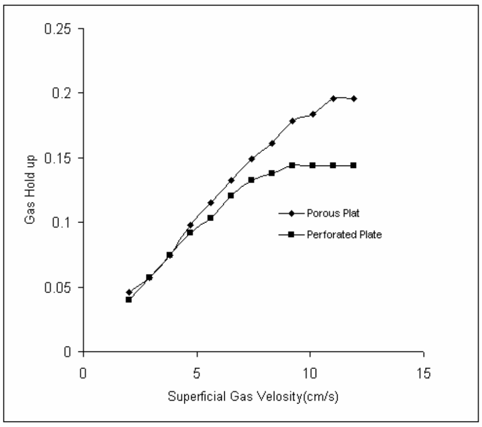

Fig 7 Effect of sparger type on gas hold up

4. Conclusion

The influence of superficial gas velocity and sparger type on gas hold up in bubble column has been studied. Experimental data shows that the total gas hold up is increased with increasing superficial gas velocity. The initial bubble size is depended on sparger type. The large bubbles have higher rise velocity and decrease the gas hold up. Also it is found that the Hikita's correlation predicted the gas hold up value better than other presented correlations.

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