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A Hydrodynamic Experimental Study of Slurry Bubble Column

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Abstract

Slurry bubble column are used for a wide range of catalytic reactions in chemical industry for natural gas conversion to useful fuels with Fischer Tropsch Synthesis. In slurry bubble-column reactors are two principal flow regime: homogeneous and heterogeneous. Gas liquid mixture have different behavior in the homogeneous and heterogeneous regime, since the rate of heat and mass transfer depends on the hydrodynamic conditions.

The relation between superficial gas velocity, concentration of solid suspension, liquid height and gas sparger type with gas hold-up are important designing parameters to predict 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.

Our experimental reactor is a cylindrical bubble-column made of glass. With an inside diameter of 0.15(m) and a height of 2.8(m). the column are equipped two sparger, a porous plat and a perforated with the same porosity

Gas hold up can be determine with differential pressure then to estimate the transition velocity in slurry bubble column reactors. To study the influence of particle concentration on the hydrodynamics of slurry bubble column reactors, the results show that increasing the solid concentration (silica powder) decrease the total gas hold up. Also the diameter of bubbles are changed with sparger type at constant porosity and to make important effect on gas hold up.

The other important parameter on gas hold up in slurry bubble column is height. That increasing the liquid height in crease the resident time in the reactor there for increase the gas hold up but the are some limitations for increasing column height and determining the best height is important factor for scaling up and predicting hydrodynamic behavior.

Key words: slurry bubble column, gas hold up, sparger

Introduction

A bubble column is a device in which a gas phase is injected through a column of liquid to promote a chemical or biochemical reaction in the presence or absence of a catalyst suspended in the liquid phase [1]. These reactors are typically operated at high pressure (1-80 MPa), high temperature and high superficial gas velocity (30 m/s). The design and scale up of these reactors require comprehensive knowledge about hydrodynamic behavior under these operating conditions [2].

Most studies have shown that, there are two basic flow regimes in bubble columns; homogeneous and heterogeneous [3,4]. In a system with homogeneous regime the bubble size distribution is narrow and a uniform bubble size, generally in the range 1-7 mm is found [5]. With increasing the superficial gas velocity the bubble size distributions will be changed. In heterogeneous regime small bubbles combine in cluster to form large bubbles in size ranging from 20 to 70 mm. these large bubbles travel up through the column at high velocity (in the 1-2 m/s rang) [5]. Different parameters such as: superficial gas velocity, gas distributor, liquid high, solid concentration, … can effect on type of flow regime.

Shah et al. [6] show that gas hold up is one of the most important parameter for characterizing the hydrodynamics of bubble columns. It can be defined as the percentage by volume of the gas in the two or three phase mixture in column.

Effect of superficial gas velocity on gas hold up

The dependence of the gas hold up on superficial gas velocity is generally estimated by [6]:

$$e_G \propto u_G^{\ n}$$

The value of the n depends on flow regime. For the bubbly flow regime n varies from 0.7 to 1.2, and for heterogeneous regime n takes value from 0.4 to 0.7 [7]. In fact the gas hold up seems to increase linearly with superficial gas velocity in homogeneous flow regime and the gas hold up reach a maximum where the transition from homogeneous to heterogeneous flow regime occur then more none linear increase with superficial gas velocity[8].

Effect of gas hold up

The solid suspension into a bubble column causes to formation of large bubbles. An increase of bubble size increases the bubble rise velocity, and reduces the residence time of bubble in reactors [9].

The solid particles in bubble column reactors are in micron size and suspended in liquid. When the concentration of solid particle in liquid increases, the gas hold up is reduce [5].

Effect of gas distributor

There are different types of gas distributor, with different design in size and number of orifices. Most common distributors are prose plate and perforated plat. The initial bubble size and distribution at the entire orifice could be controlled by sparger characteristics. The balance between coalescence and break up of gas bubble show that the initial bubble size created at the gas sparger would not completely describe the behavior of gas bubble size distribution in entire column [10].

A large number of correlation for gas hold up have been proposed in the literature, but the large scatter in the reported data dose not allow a single correlation. In the present work, the effects of solid concentrations, sparger type and superficial gas velocity, on gas hold up into a bubble column reactor have studied, and the best correlation for predicting the hydrodynamic behavior on slurry bubble column reactors is suggested.

Experimental set up

Experimental set up consist of a cylindrical glass column with 0.15 m inner diameter and 2.8 m height. The column is equipped with sparger 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 21 holes with 1 mm diameter.
In all experiences the pressure at top of the column was atmospheric. Gas injected from the bottom of column. After injecting gas, the liquid bed expended and the hydrostatic pressure was changed. 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.
The liquid phase is water, gas phase is air and solid particles are silica powder. In figure 1 the set up is showed.

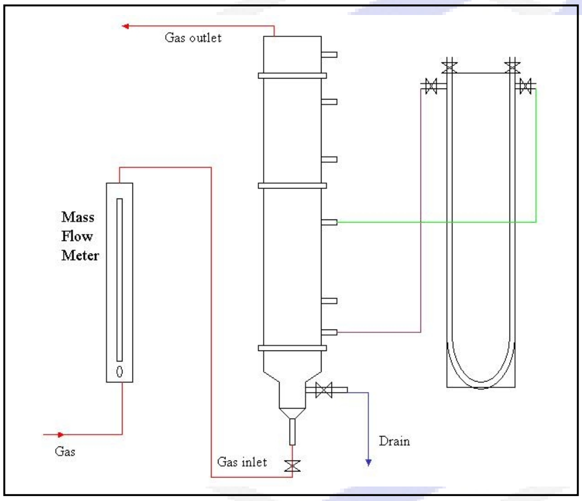

Figure 1- Experimental set up

Result and Discussion

Effect of superficial gas velocity

For studying the superficial gas velocity effect on gas hold up the two phase system is used. All the experiences show the positive effect of superficial gas velocity on gas hold up (figure 2). At low gas velocity the uniform bubble distribution is seen and all the bubbles are small, after increasing the gas velocity, gas volume through the column increase, but after finding a maximum on gas hold up the rate of increasing gas hold up decrease. This maximum is transition point and in studying the hydrodynamic properties in slurry bubble column reactors, finding the gas velocity on transition point is one of the most important parameter for predicting slurry bubble column hydrodynamic behavior.
At low superficial gas velocity the bubble size is small (< 7 mm) and with increasing the gas velocity the bubbles are coalescences therefore at transition regime the small

and large bubbles are seen through the column. At high gas velocity (more than 9 cm/s) all the bubbles will be large. This regime is heterogeneous. The large bubbles have higher rise velocity than small bubbles, therefore residence time of large bubble decrease and cause to decrease rate of increasing gas hold up.

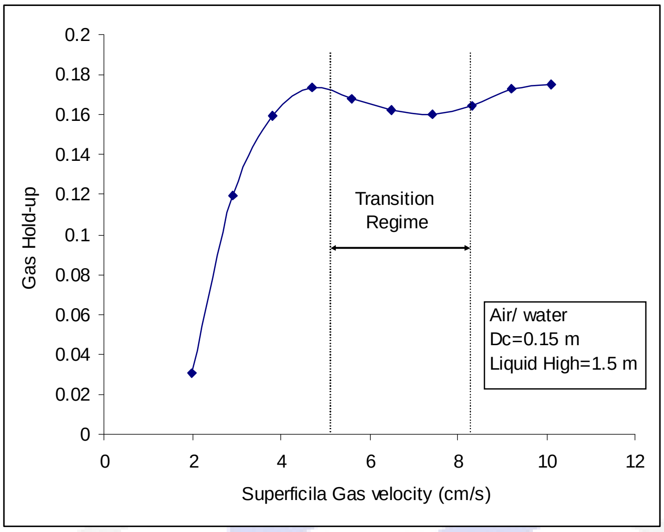

Figure 2 – Effect of superficial gas velocity on gas hold up

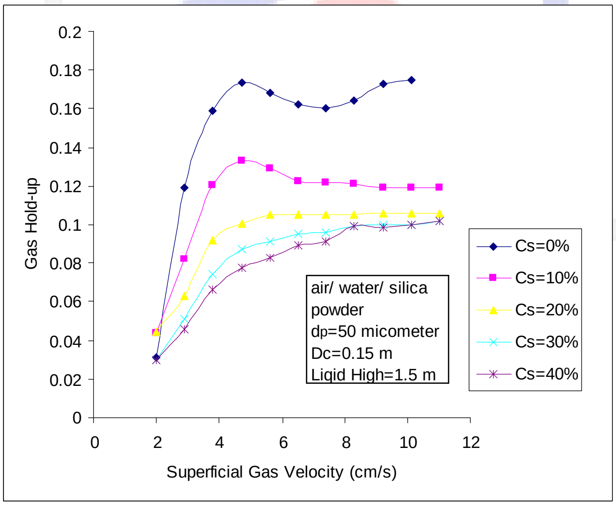

Figure 3-Effect of solid concentration on gas hold up

Effect of solid concentration

Concentrations of solid particle in the liquid phase in slurry bubble columns changes the gas hold up at different superficial gas velocity. This effect is shown in figure 3. It is seen that the gas hold up decrease with increasing the solid concentration.

The mean particle size of silica powder is 50 mm and density of powder is 2100 kg/m^3.

Solid particles change the physical properties of slurry, such as: density and viscosity. If the viscosity and density of liquid increase the gas hold up will be decrease. In three phase system solid particle increase the bubble, bubble coalescence, and cause to make large bubbles. An increase of bubble size increase bubble rise velocity, and reduce the resident time of bubbles in reactor, therefore the total gas hold up decrease.

Effect of sparger on gas hold up

In this work two different spargers are used: a perforated plate and a porous plate. The orifice diameter of perforated plate is 1 mm and the porous plate consists of micro size pore. The initial bubble size and distribution at the orifice could be controlled by the sparger characteristics. Several investigators have reported that gas sparger had a minimal effect on the bubble sizes and gas holdup if the orifice diameters were larger than 1-2 mm [10, 11].

Figure 4 shows the effect of sparger type on gas hold up. When the perforated plate is used, the initial size of gas bubbles is larger, and then the gas hold up reduces. When small gas bubbles are formed, the transition from homogeneous to heterogeneous flow regime is delayed; since the rate of bubble coalescence becomes smaller. The small bubbles have larger resident time therefore cause to increase gas hold up. It is seen that the initial bubble size is not only effected reason for changing bubble size, but it is more important.

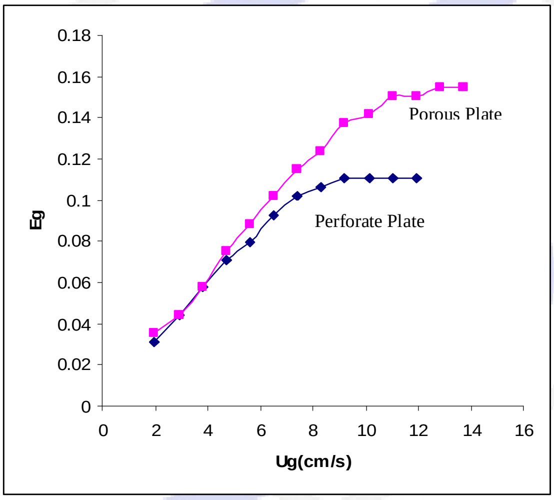

Figure 4 – Sparger type effect on gas hold up
(air-water system L/d=8)

Table 1 shows some different correlations for predicting gas hold up and figure 5 shows the experimental data and predicting value for gas hold up. It can be seen that Reily et al. correlation is better than other correlations for determining gas hold up.

Table 1- Gas hold up correlations

Author	Correlation
Raily et al. [12]	$e_g = 296 U_g^{0.44} r_L^{-0.98} s_L^{-0.16} r_g^{0.19} + 0.009$
Kumar et al. [13]	$\varepsilon_G = 0.728U - 0.485U^2 + 0.0975U^3$ $U = U_G[\rho_L^2 \sigma(\rho_L - \rho_G)g]^{1/4}$

Hikita et al. [14]

$$e_g = 0.672\,(\frac{r_g m_l}{s})^{0.578}(\frac{m_l{}^4 g}{r_l s})^{-0.131}(\frac{r_g}{r_l})^{0.062}(\frac{m_g}{m_l})^{0.107}$$

Hughmark [15]

$$e_g = \frac{1}{2 + (\frac{0.35}{u_g})(\frac{r_l s}{72})1/3}$$

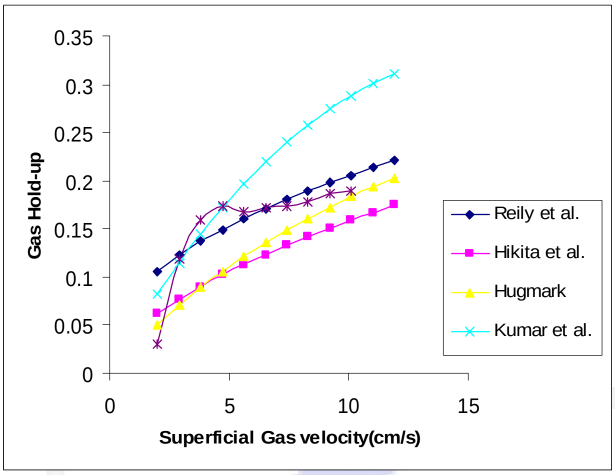

figure 5- test of experimental data for total gas Hold-up against the correlation in table

Conclusion

It can be concluded that: the total gas hold up is increased with increasing superficial gas velocity, and decrease with increasing solid concentration.
The initial bubble size which is depended on sparger type, changes the gas hold up value. Results of this research shows that the porous plate make higher gas hold up than perforated plate. Also, it is found that the Reily 's correlation predicted the gas hold up value better than other presented correlations.

References

1. Amir Sarrafi, Mohammad Jamialahmadi,Hans Muller-Steinhagen, Johan M.Smith, "Gas Holdup in Homogeneous and Heterogeneous Gas-Liquid Bubble Column Reactor", The CANADIAN Journals of Chemical Engineering, vol 77 (1999).
2. Xukun Luo. DJ. Lee, Raymond Lan, Guoqiang Yang, Liang-Shih Fan, "Maximum stable Bubble size and Gas Holdup in High-Pressure Slurry Bubble Column", AICHE Journal, vol 45 No. 4, (1999).
3. R Krishna, J. Ellenberger, C. Maretto, "Flow regim Transition In Bubble Columns", Int. Comm. Heat Mass Transfer, vol. 26, No. 4, (1999)
4. Magaud, F., Souhar, M., Wild, G., Boisson, N., “Experimental Study of Bubble Column Hydrodynamics,” Chemical Engineering Science, Vol. 56, (2001), pp.4597-4607.
5. R. Krishna, S. T. Sie, "Design and scale-up of the Fischer-Tropsch bubble column slurry reactor", Fuel Processing Technology 64 (2000) 73-105

6. Y. T. Shah, B. G. Kelkar, S. P. Godbole, "Design Parameter Estimation for Bubble Column Reactors", AICHE Journal, vol. 28, No. 3, (1982).
7. Deckwer, W.,-D., Bubble Column Reactor, (John Wiley and Sons, Chichester, 1992).
8. Krishna, R., Ellenberger, J., "Gas Holdup in Bubble Column Reactors Operating in the Churn-Turbulent Flow Regime," AIChE Journal, Vol. 42, (1996), pp. 2627-2634.

9. R. Krishn, "A Scale-up Strategy for a Commercial Scale Bubble Column Slurry Reactor for Fischer-Tropsch Synthesis", *Oil & Gas Science and Technology*, Vol. 55, No. 4, (2000).
10. Akita, K., Yoshida, F., "Gas Holdup and Volumetric Mass Transfer Coefficient in Bubble Columns", Industrial Engineering Chemistry Process Design and Development, Vol. 12, (1973), pp. 76-80.
11. Wilkinson, P.M., Spek, A.P., van Dierendonck, L.L., "Design Parameters Estimation for Scale-Up of High-Pressure Bubble Columns," AIChE Journal, Vol. 38, (1992), pp. 544-
12. Reilly, I.G., Scott, D.S., de Bruijn, T.J.W., Jain, A., Piskorz, J., "A Correlation for Gas Holdup in Turbulent Coalescing Bubble Columns", The Canadian Journal of Chemical Engineering, Vol. 64, (1986), pp. 705-717.
13. Kumar, A., Degaleesan, T.E., Laddha, G.S., Hoelscher, H.E., "Bubble Swarm Characteristics in Bubble Columns", The Canadian Journal of Chemical Engineering, Vol.54 (1976), pp. 503-508.
14. Hikita, H., Asai, S., Tanigawa, K., Segawa, K., Kitao, M., "Gas Hold-Up in Bubble
Columns", The Chemical Engineering Journal, Vol.20 (1980), pp. 59-67.
15. Hughmark, G.A., "Holdup and Mass Transfer in Bubble Columns", Industrial Engineering Chemistry Process Design and Development, Vol. 6 (1967), pp. 218-221.