Effect of solids on flow regime transition in three-phase bubble columns

P. C. Mena, F. A. Rocha, [1]J. A. Teixeira, [2]J. Drahos, [2]M. C. Ruzicka
Department of Chemical Engineering, Faculty of Engineering, University of Porto, 4200-465 Porto, Portugal (pmena@fe.up.pt), [1]Center of Biological Engineering, University of Minho, 4710-057 Braga, Portugal, [2]Institute of Chemical Process Fundamentals, Czech Academy of Sciences, Rozvojova 135, 16502 Prague, Czech Republic

In bubble column reactors there are two principal flow regimes [1,2,3], the homogeneous (HoR) and the heterogeneous (HeR). These reactors have different behaviour in HoR and HeR, thus the dependences of the rates of mass, heat and momentum transfer on the design and operating parameters (such as reactor geometry, gas and liquid flow rates and properties of the contacting phases) are also very different. Therefore, for rational reactor design and operation it is of crucial importance to know the range of parameters over which a certain regime prevails and the regime transition conditions [4].

The effect of the presence of solids on gas holdup in bubble columns has been extensively investigated. Most of the published work reports that the gas holdup decreases with increasing solid concentration [5-14]. However, a favourable effect of solids on gas holdup has been also observed by Douek et al. [15]. In spite of all these efforts, information on the effect of solids on homogeneous-heterogeneous regime transition is very scarce. Krishna et al. [16] found that the transition gas holdup was significantly reduced due to the presence of silica particles. Xie et al. [17] reported that as pulp consistency is increased, the regime transition is delayed.

The goal of this work was to examine the influence of solid particles on homogenous regime stability and regime transition in a three phase bubble column. For that, two studies were done, one focused on the regime transition and the other on visualization of bubble-particle interaction.

The regime transition experiments were performed in a cylindrical bubble column of 0.14 m diameter. Air, distilled water and calcium alginate beads (d_{eq}=2.1mm) at concentrations up to 30%(v/v) were the phases. The dependence of the gas holdup *(e)* on the gas flow rate *(q)* was measured. At low solid loading, the experimental data *e(q)* show a slight increase of gas holdup with solid concentration, which is not normally observed. At higher solid loading, a significant reduction of gas holdup with solid concentration is observed. This suggests that solid concentration could play a dual role in the homogeneous regime stability: low concentrations stabilize, while high concentrations destabilize. The critical point, where the HoR loses stability and the transition begins, was evaluated using the drift flux plot. The critical values of gas flow rate and voidage were the measures of the homogeneous regime stability. For low solid volume fraction, a stabilizing effect of the presence of solids is shown by an increase in the critical values, while for higher solids volume fraction (ϕ_s>3%) the critical values decrease, witnessing a destabilizing effect of the solids.

The visualization study was performed in a 0.07 m diameter cylindrical bubble column, using a standard and high-speed cameras. This work shows important phenomena that result from the bubble-particle interactions, which partly explains the regime transition results. At low solid loading, bubble-particle collisions lead to reduction of bubble rise velocity that results in higher gas holdup and a delay of the transition. At higher solid loading, the bubble coalescence rate increases with the solid content that decreases the gas holdup and advances the transition.

References

[1] W. D. Deckwer, Bubble Column Reactors, Wiley, Chichester, 1992.
[2] F. Kastanek, J. Zaharadnik, J. Kratochvil, J. Cermak, Chemical Reactors for Gas Liquid Systems, Ellis Horwood, Chichester, UK, 1993.
[3] O. Molerus, Principles of Flow in Disperse Systems, Chapman & Hall, London, 1993.
[4] J. Zahradnik, M. Fialova, M. Ruzicka, J. Drahos, F. Kastanek, N. H. Thomas, Duality of the gas-liquid flow regimes in bubble column reactors, Chem. Eng. Sci. 52 (1997) 3811-3826.
[5] L. -S. Fan, G. Q. Yang, D. J. Lee, K. Tsuchiya, X. Luo, Some aspects of high-pressure phenomena of bubbles in liquids and liquid–solid suspensions, Chem. Eng. Sci. 54 (1999) 4681-4709.
[6] V. S. Thompson, R. M. Worden, Phase holdup, liquid dispersion, and gas-to-liquid mass transfer measurements in a three-phase magnetofluidized bed, Chem. Eng. Sci. 52 (1997) 279-295.
[7] W. –J. Lu, S. –J. Hwang, C. –M. Chang, Liquid velocity and gas holdup in three-phase internal loop airlift reactors with low-density particles, Chem. Eng. Sci. 50 (1995) 1301-1310.
[8] B. Gandhi, A. Prakash, M. A. Bergougnou, Hydrodynamic behaviour of slurry bubble column at high solids concentrations, Powder Technol. 103 (1999) 80-94.
[9] J. Wen and S. Xu, Local hydrodynamics in a gas-liquid-solid three-phase bubble column reactor, Chem. Eng. J. 70 (1998) 81-84.
[10] X. Luo, D. J. Lee, R. Lau, G. Yang, L. –S. Fan, Maximum Stable Bubble Size and Gas Holdup in High-Pressure Slurry Bubble Columns, AIChE J. 45 (1999) 665-680.
[11] J. W. A. De Swart, R. E. van Vliet, R. Krishna, Size, structure and dynamics of "large" bubbles in a two-dimensional slurry bubble column, Chem. Eng. Sci. 51(1996) 4619-4629.
[12] S. Banisi, J. A. Finch, A. R. Laplante, M. E. Weber, Effect of solid particles on gas holdup in flotation columns–I. Measurement, Chem. Eng. Sci. 50 (1995) 2329-2334.
[13] W. -J. Lu, S. -J. Hwang, C. -M. Chang, Liquid velocity and gas holdup in three-phase internal loop airlift reactors with low-density particles, Chem. Eng. Sci. 50 (1995) 1301-1310.
[14] J. Reese, P. Jiang, L. -S. Fan, Bubble Characteristics in three-phase systems used for pulp and paper processing, Chem. Eng. Sci. 51(1996) 2501-2510.
[15] R. S. Douek, G. F. Hewitt, A. G. Livingston, Hydrodynamics of vertical co-current gas-liquid-solid flows, Chem. Eng. Sci. 52 (1997) 4357-4372.
[16] R. Krishna, J. Ellenberger, C. Maretto, Flow regime transition in bubble columns, Int. Commun. Heat Mass Transfer 26 (1999) 467-475.
[17] Xie, S. M. Ghiaasiaan, S. Karrila, T. McDonough, Flow regimes and gas holdup in paper pulp–water–gas three-phase slurry flow, Chem. Eng. Sci.58 (2003) 1417-1430.

Acknowledgements

P. C. Mena gratefully acknowledge financial support from the Commission of the European Communities for the Marie Curie Training Site (contract No. HPMT-CT-2000-0074) in the Institute of Chemical Process Fundamentals, Prague, Czech Republic.