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Short communication

Effect of superficial gas velocity on gas hold-up profiles in foaming liquids in bubble column reactors

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Abstract

In an extension to our previous work [Chem. Eng. J. 84 (2001) 247], we continue our investigation in the present communication on the effect of superficial gas velocity on radial gas hold-up profiles for air-aqueous solutions of *n*-butanol. Radial variation of gas hold-up was investigated in 0.385 m i.d. bubble column using gamma ray tomography. The gas phase was air and the liquid phase comprised of aqueous solution of *n*-butanol of three different concentrations, 0.02, 0.2 and 0.5% v/v. The range of superficial gas velocities studied is 0.06–0.24 m/s. Two perforated sparger plates were used having the same free area (FA = 0.42%) and two hole diameters (1 mm, multipoint sparger; 25 mm, single point sparger). The bubble size was found to reduce and the hold-up profiles were found to become flatter with an increase in butanol concentration and H_D/D ratio.

Keywords: *n*-Butanol; H_D/D ratio; Hold-up profiles; Bubble column; Sparger design/effect

1. Introduction

Bubble columns are widely used for a variety of gas–liquid or gas–liquid–solid reactions. The formation of foam layer on the top of the dispersion is common phenomenon for many reactions involve organic solvents. Parasu Veera et al. [1] measured the hold-up profiles in foaming liquids and discussed extensively the effect of foaming agent concentration at superficial gas velocity of 0.18 m/s. It was noted that the shape of the profiles depends upon the combined effect of superficial gas velocity, the sparger design and the concentration of foaming agents. In the present communication, we extend the discussion on the effect of superficial gas velocity on radial hold-up profiles for the range of 0.06–0.24 m/s.

2. Experimental set-up

Experiments were carried out in a perspex cylindrical bubble column of 385 mm i.d. and 3.2 m height. A schematic diagram and further details of the experimental set-up and procedure can be obtained from Parasu Veera and Joshi [2]. Two different sieve plate spargers were employed with equal free area of 0.42% and hole diameter of 1 mm (623 holes) and 25 mm (single hole). In all the experiments, liquid phase was aqueous alcohol solution (*n*-butanol) of three concentrations, 0.02, 0.2 and 0.5% v/v and the gas phase was air.

3. Results and discussion

The effect of butanol concentration on hold-up profiles was found to depend upon sparger design, H_D/D ratio and superficial gas velocity. The results for multipoint and single point sparger are shown in Figs. 1 and 2, respectively. In order to understand these effects quantitatively the cross-sectional average hold-ups have been estimated at three H_D/D locations, two sparger designs and the four levels of superficial gas velocities. The results are shown in Figs. 3 and 4. The following observations can be made:

1. At a superficial gas velocity of 0.06 m/s the variation in ε_G with respect to butanol concentration is nominal in all cases (Figs. 3 and 4).
2. At H_D/D ratio of 0.259, the ε_G for multipoint sparger is much higher (2–3 times) than the single point sparger.

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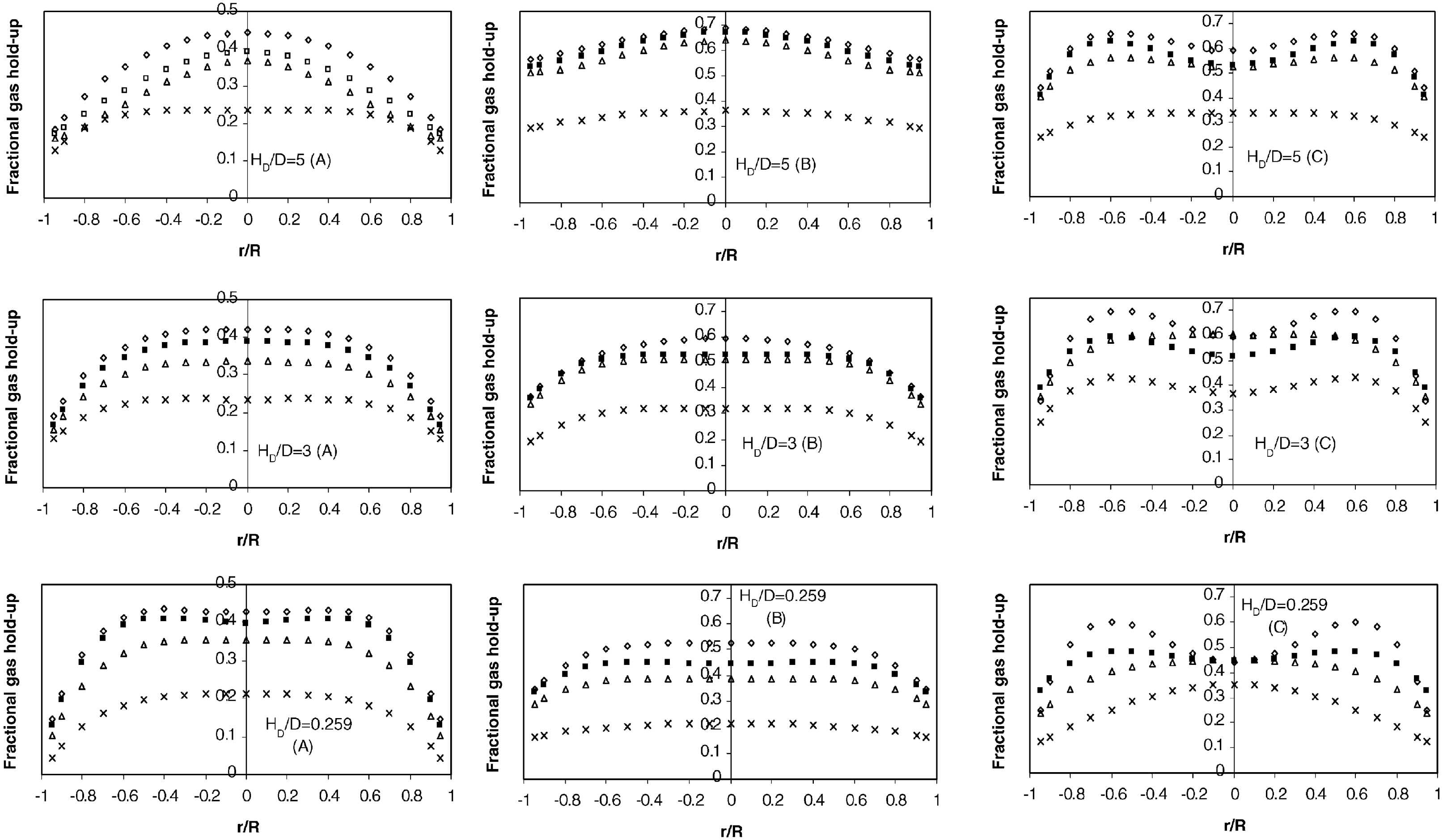

Fig. 1. Effect of *n*-butanol concentration and column height on hold-up profiles for the multipoint sparger: $d_0 = 1$ mm, FA = 0.42%, $H_D/D = 7$; (A) conc. 0.02%, (B) conc. 0.2%, (C) conc. 0.5%; (◇) 0.24 m/s; (■) 0.18 m/s; (△) 0.12 m/s; (×) 0.06 m/s.

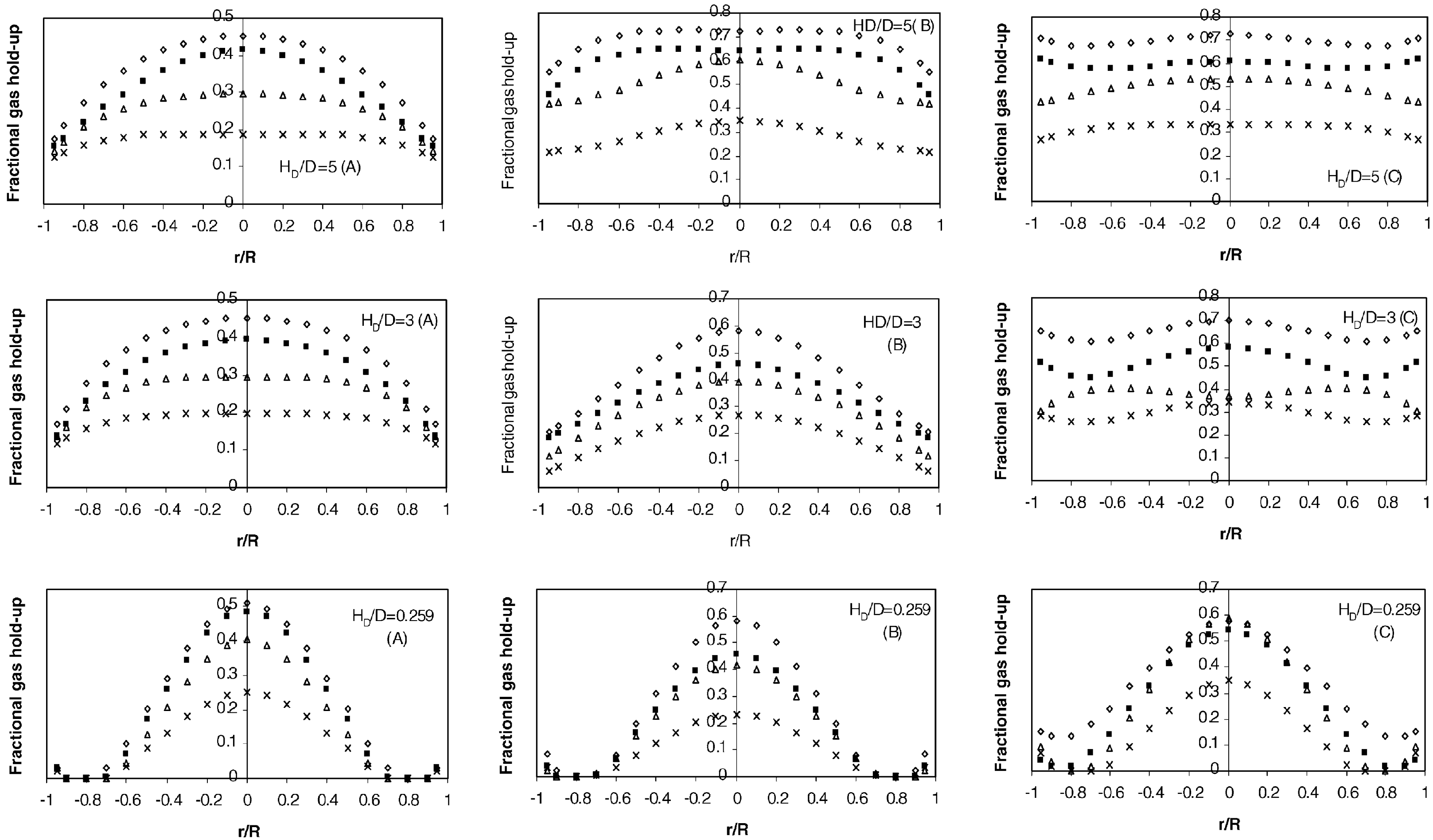

Fig. 2. Effect of *n*-butanol concentration and column height on hold-up profiles for the single point sparger: $d_0 = 25$ mm, FA = 0.42%, $H_D/D = 7$; (A) conc. 0.02%, (B) conc. 0.2%, (C) conc. 0.5%; (◇) 0.24 m/s; (■) 0.18 m/s; (△) 0.12 m/s; (×) 0.06 m/s.

Nomenclature

C_0, C_1	drift flux constants
D	diameter of the column (m)
H_D	height of dispersion (m)
H_D/D	ratio of axial measurement location to diameter of the column (dimensionless)
r	radial location (mm)
r/R	ratio of radial location to radius of the column (dimensionless)
R	radius of the column (m)
V_G	superficial gas velocity (m/s)
V_S	slip velocity (m/s)
ε_G	fractional gas hold-up
$\bar{\varepsilon}_G$	average radial gas hold-up

3. Fig. 1 shows the effect of multipoint sparger together with H_D/D ratio, butanol concentration and V_G. It can be seen that in all the cases (except 0.06 m/s), ε_G increases with an increase in the butanol concentration. However, the extent strongly depends upon H_D/D ratio. From Fig. 1A–C it can be seen that when the butanol concentration is increased from 0 to 0.2%, the increase in ε_G is fairly good at H_D/D of 0.259 (38% increase with respect to water), appreciable (50%) at H_D/D at 3 and substantial at $H_D/D = 5$ (62%). More important observation is that all the possible increase occurs up to 0.2% concentration for the case of $H_D/D = 5$. However, at 0.259 and 3, ε_G increases continuously up to butanol concentration 0.5%.
4. Fig. 4 shows the observations for single point sparger, which are practically the same as Fig. 3, though the values of ε_G are generally low as compared to multipoint sparger except at H_D/D of 5.
5. It was thought desirable to capture all the above effects with the help of drift flux model. The values of C_0 and C_1 have been given in Tables 1 and 2 for multipoint and single point sparger, respectively. According to Zuber and Findley [3] the drift flux constant C_0 indicates the shape of hold-up profile. For $C_0 = 1$ the profile is flat ($\bar{\varepsilon}_G$ is same at all the radial locations). As the profiles becomes steeper the values of C_0 increases. The other drift flux constant (C_1) corresponds to bubble slip velocity (V_S). From Table 1, it can be seen that the values of C_0 and C_1 decrease with an increase in H_D/D ratio and butanol concentration. In other words the hold-up profiles become flatter with an increase in H_D/D, and for a given H_D/D, with an increase in butanol concentration.

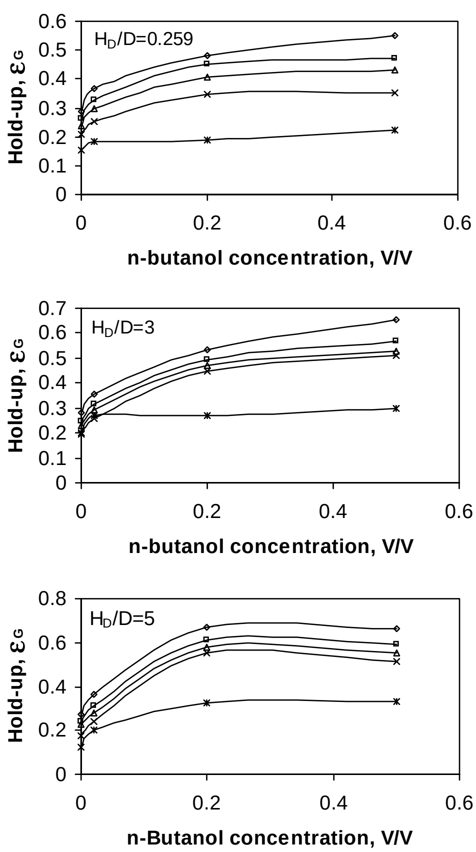

Fig. 3. Effect of *n*-butanol concentration and column height on cross-sectional average hold-up with; (◇) 0.29 m/s; (■) 0.24 m/s; (△) 0.18 m/s; (×) 0.12 m/s; (*) 0.06 m/s (sparger: multipoint).

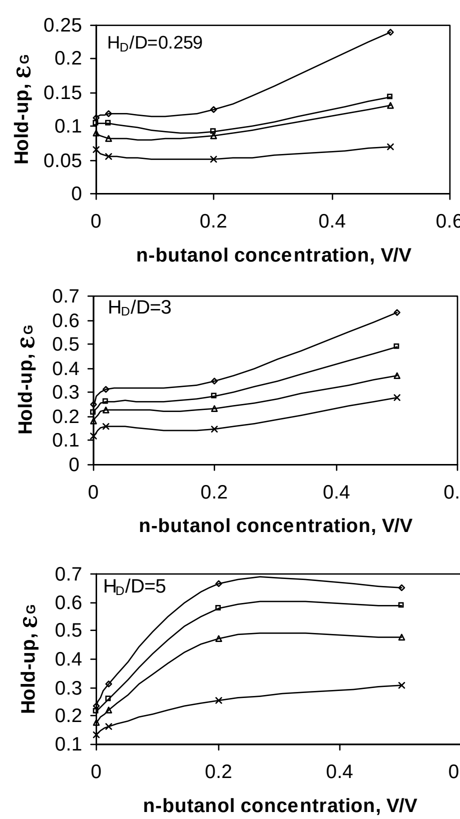

Fig. 4. Effect of *n*-butanol concentration and column height on cross-sectional average hold-up with; (◇) 0.24 m/s; (■) 0.18 m/s; (△) 0.12 m/s; (×) 0.06 m/s (sparger: single point).

Table 1
Values of C_0 and C_1 at different axial locations for multipoint sparger

n-Butanol conc., v/v	$H_D/D = 5$		$H_D/D = 3$		$H_D/D = 0.259$	
	C_0	C_1	C_0	C_1	C_0	C_1
0.5	1.179	0.1073	1.1701	0.1202	1.191	0.1998
0.2	1.161	0.1013	1.4853	0.1166	1.299	0.2149
0.02	2.215	0.2073	2.568	0.1166	2.033	0.2243
0	2.517	0.3524	3.158	0.1785	2.734	0.24

Table 2
Values of C_0 and C_1 at different axial locations for single point sparger

n-Butanol conc., v/v	$H_D/D = 5$		$H_D/D = 3$		$H_D/D = 0.259$	
	C_0	C_1	C_0	C_1	C_0	C_1
0.5	0.964	0.135	0.8914	0.1876	–	–
0.2	0.726	0.182	1.6358	0.3157	–	–
0.02	2.251	0.254	2.2632	0.2512	5.183	0.803
0	3.16	0.269	2.623	0.3476	4.652	0.9124

6. The major effect of the presence of butanol seems to be on the bubble slip velocity (V_S). The value of C_1 can be seen to decrease with an increase in H_D/D ratio and butanol concentration, the later being more dominant. For multipoint sparger, for instance, at $H_D/D = 0.259$ a nominal decrease in C_1 can be observed whereas at H_D/D ratio of 5 the decrease is substantial. Though similar observations can be seen (in Table 2) for single point sparger, the values of C_1 are much higher. Only at $H_D/D = 0.259$ no trend was observed.
7. From Tables 1 and 2, it can be seen that at $H_D/D = 0.259$ the values of C_0 for single point sparger are much higher than the multipoint sparger. This is of course obvious as the single point sparger produces very high hold-up in the central region. As a result the radial non-uniformity is maximum near the sparger.
8. We wish to bring out two qualitative observations:
   (a) From Fig. 1A and B, it can be seen that the hold-up profiles has central maxima whereas in Fig. 1C which shows the profiles at 0.5% butanol concentration, the hold-up profiles seem to take M-shape. This is probably because of reduction in bubble size with an increase in butanol concentration. Tomiyama et al. [4] have shown that for bubbles smaller than 3 mm the hold-up maxima shifts away from the centre. These observations have been based on the balance of radial lift, drag and pressure forces.
   (b) For single point sparging, at $H_D/D = 0.259$ the hold-up profiles have a central maxima obviously because of the central sparging. Further, the single point sparger generates strong liquid circulation and transports the gas bubbles near the wall and therefore the hold-up profiles take W-shape. Such a shape is retained only at the highest concentration (0.5%) whereas at lower concentration profiles take parabolic shape when the H_D/D ratio is increased.

4. Conclusions

1. Superficial gas velocity seems to have large influence on radial hold-up profile especially at high concentration of foaming agent and influence seems to be different for different sparger designs.
2. For multipoint sparger, ε_G depends on the butanol concentration and H_D/D ratio. Also, the hold-up profile takes flat shape with increase in H_D/D and for a given H_D/D with increase in butanol concentration (drift flux plots support the above observation).
3. For single point sparger, similar observations were made, however, the levels of ε_G were low as compared to multipoint sparger. Further, the comparisons of slip velocity (V_S) using drift flux plots shows that the values for single point sparger are higher than the multipoint sparger (except $H_D/D = 0.259$).
4. At highest concentration (0.5%), for the multipoint sparger, M-shaped profiles were observed that might be probably due to reduction in bubble size shifting the central maxima away from the centre. On the contrary, for single point sparger, W-shaped profiles were observed near the sparger because of carriage of bubbles toward wall by liquid circulatory motion.

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