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Simulation of gas holdup in a bubble column with a draft tube

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The effect of inner diameter and clearance on gas holdup in a bubble column with a draft tube was simulated by CFX software. Simulation was done by using three-dimensional two-phase Euler-Euler model. Shear Stress Transfer (SST) model was used as a turbulent model. Gas holdup by the simulation showed a fairly good agreement with the correlation of Yamashita (1999).

1. Introduction

Bubble columns with a draft tube are widely used as bioreactors and gas-liquid reactors. Gas holdup E_G is a very important parameter for design and scale-up of bubble columns. Therefore there are many studies about E_G. However, it is difficult to know exact flow conditions in the bubble columns because of two phase flow. Recently, CFD has developed remarkably because of development of cheap efficient PC and good software. Simulation by CFD is very useful for visualization of flow conditions, design and scale up of bubble columns. Therefore there have been many studies about simulation of bubble columns (Becker et al. (1994), Jakobsen et al. (2005) , Zhang et al. (2006)). However, flow conditions in the bubble column with a draft tube were not clear. In this work, the effects of clearance C and inner diameter D_i of draft tube on E_G in the bubble column were simulated by CFX. The results were compared with the experimental results of Yamashita (1999).

2. Previous study

Yamashita (1999) have studied the effect of geometric parameters of draft tubes and clear liquid height on gas holdup in a 16 cm I.D. bubble column for gas dispersion into tubes and presented the following equations:

$$E_G / E_s = Z_1 Z_2 \tag{1}$$
$$Z_1 = 1 - (1 - F_{ai})^M \tag{2}$$
$$Z_2 = 1 + 70\,(L_d/D)^{-2}\,(L_d / H_L)^q \{F_{ai}(1 - F_{ai})\}^2 \tag{3}$$
$$M = 18\,(F_r)^{0.41} \tag{4}$$
$$q = 35.3(F_r)^{0.83} \tag{5}$$

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These equations are applicable in the range of D_i = 0.05-0.13m, L_d = 0.5-1.40m, H_L = 0.60-1.55m and C = 0.03-0.182 m.

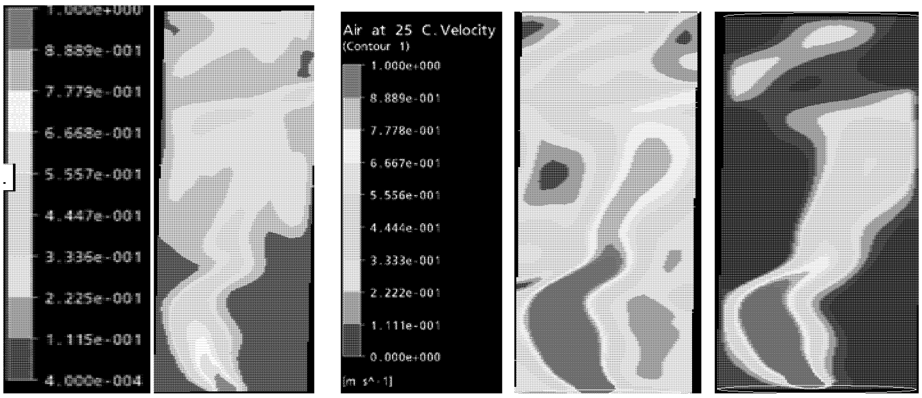
3. Simulation by CFX software

The simulation was done by using CFX software. The conditions of the simulation are as follows: diameter of bubbles = 5 mm, unsteady simulation, 3D model (column diameter D = 16 cm and height H = 100 cm), Euler-Euler method, turbulent model = SST (Shear Stress Transfer) model and 5 mm mesh. Length and thickness of draft tube were 50 cm and 5 mm, respectively. D_i and C were in the range of 2- 12 cm and 1-10 cm, respectively. Superficial gas velocity U_G was 7 cm/s. Air at 25℃ was used as a gas and water at 25℃ was used as a liquid. Liquid was fed in a batch. Air was fed into the draft tube. The gas inlet was set as a source point (1cm diameter) in the center of the bottom of the bubble column.

4. Simulation results

4.1 Flow conditions in the bubble column without a draft tube

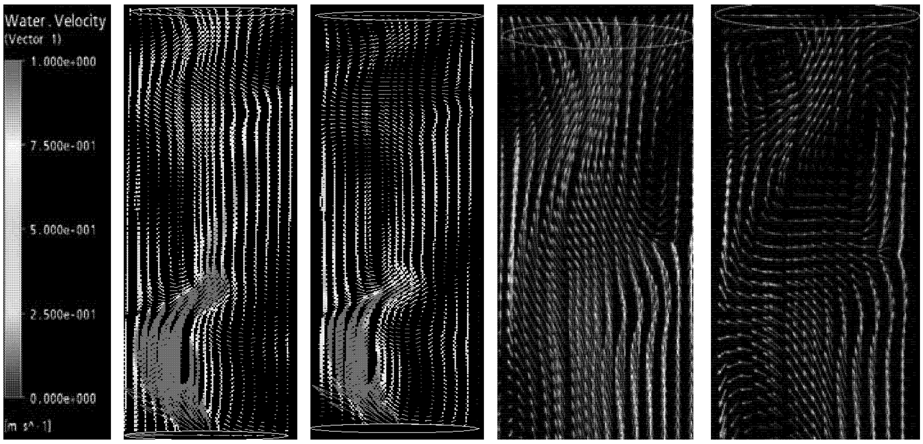
Fig.1 shows a contour of E_G, V_G and V_L at U_G =7 cm/s in the bubble column without a draft tube. Fig.1(b) shows radial dispersion of bubbles as they rise. Fig.1(d) and (e) show that V_G and V_L are large just above the gas inlet and that V_L is large where V_G is large.



(a) legend (b) E_G (c) legend (d) V_G (e) V_L

Fig.1 Contours of E_G, V_G and V_L in the bubble column with no draft tube
(a) legend of E_G (b) contour of E_G (c) legend of V_G and V_L (d) contour of V_G
(e) contour of V_L

Fig.2 shows vectors of V_G and V_L in the bubble column with no draft tube. Though vectors of V_G and V_L resemble each other in the whole bubble column, the vectors of V_L above the draft tube are different from those of V_G above the draft tube, because no flow of the liquid. There were vortexes near the top and bottom of the bubble column.



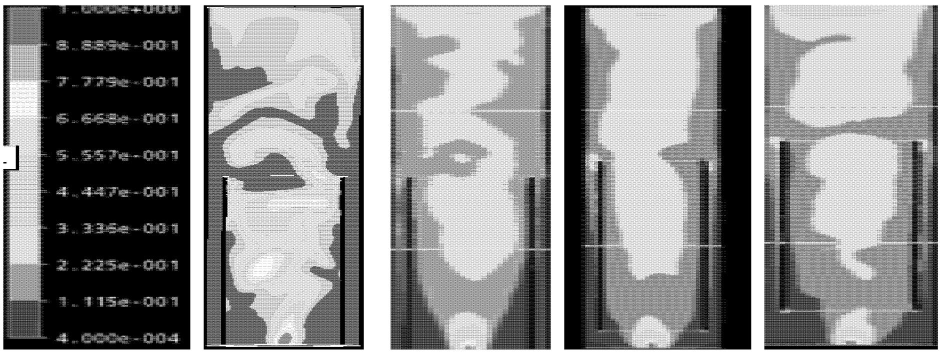
(a) (b) V_G (c) V_L (d) V_G (e) V_L

Fig.2 Vectors of V_G and V_L in the bubble column with no draft tube
(a) legend (b) V_G in the whole column (c) V_L in the whole column
(d) V_G near the top of the column (e) V_L near the top of the column

4.2 Flow conditions in the bubble column with a draft tube

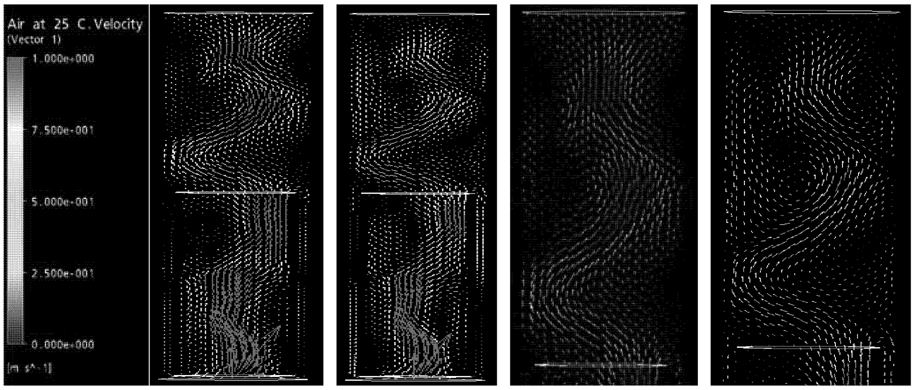
Fig.3 shows contours of E_G at U_G = 7cm/s in the bubble column with a 12cm I.D. draft tube. Though there were no bubbles in the annular region at C = 0 cm, bubbles in the annular region increased with increasing C, because the circulation of liquid increased. E_G at C = 5cm was the lowest. At C = 10cm some bubbles rose outside the draft tube and E_G increased. At C = 1cm, the circulation rate of liquid is small and the rising velocity of bubbles in the draft tube is slow. So, E_G becomes large. However, At C = 5cm, the circulation rate of liquid is large and the rising velocity of bubbles in the draft tube is fast. Therefore E_G becomes small.

Fig.4 shows vectors of V_G and V_L at U_G = 7cm/s in the bubble column with a D_i=12 cm draft tube. Though vectors of V_G and V_L resemble each other in the whole bubble column, the vectors of V_G are larger than V_L .



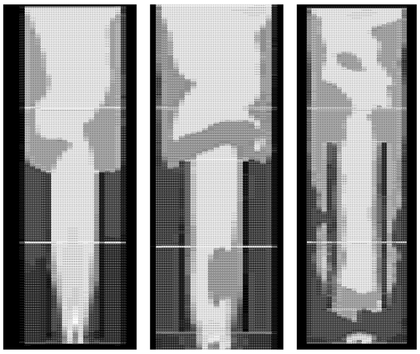
C:	0cm	1cm	5cm	10cm
E_G:	16.26%	16.22%	15.05%	16.26%

Fig.3 Contour of E_G at U_G = 7cm/s in the bubble column with a 12cm I.D. draft tube.



(a) V_G (b) V_L (c) V_G (d) V_L

Fig.4 Vectors of V_G and V_L at U_G = 7cm/s in the bubble column with a 12cm I.D. draft tube.
(a) V_G in the whole column (b) V_L in the whole column (c) V_G above the draft tube
(d) V_L above the draft tube



C: 1cm 5cm 10cm
E_G: 12.9% 13.2% 15.4%

Fig.5 Contours of E_G for D_i = 8cm

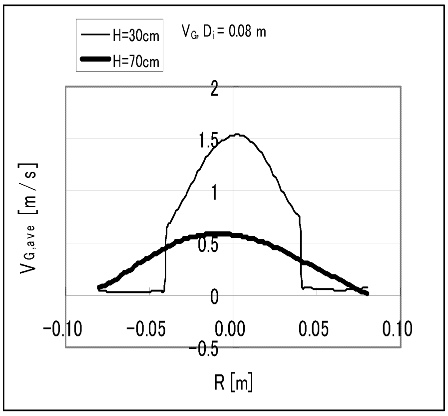


Fig.6 Profile of $V_{G,ave}$ at D_i = 8 cm.

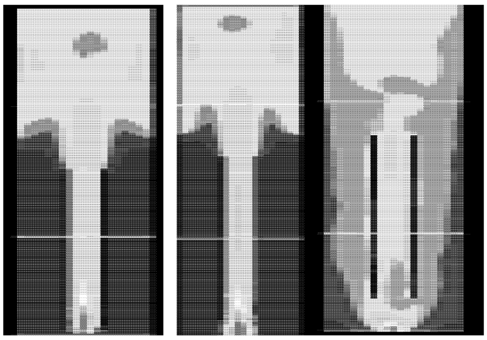
Fig.5 shows contours of E_G at U_G = 7cm/s in the bubble column with a 8cm I.D. draft tube. E_G increased with C. Though at C = 5cm the circulation rate of liquid becomes larger than that at C = 1cm, the quantity of bubbles which fall down in the annular region becomes larger. Therefore E_G becomes larger at C = 5cm than that at C = 1cm. At C = 10cm some bubbles rose in the annular region. So, E_G became the largest.

Fig.6 shows profiles of $V_{G,ave}$ at H = 30 and 70 cm in the bubble column with a 8cm I.D. draft tube. $V_{G,ave}$ at H = 30cm in the draft tube is larger than that at H = 70cm.

Fig.7 shows contours of E_G at U_G = 7cm/s in the bubble column with a 4cm I.D. draft tube. E_G also increased with C. The reason why E_G increased with C is the same as in Fig.5.

Fig.8 shows profile of $V_{G,ave}$ at H = 30 and 70cm in the bubble column with a D_i=4 cm draft tube. It is clear from Fig.6 and 8 that $V_{G,ave}$ at H= 30 and 70cm is larger than that for D_i = 8cm.

Fig.9 shows contours of E_G at U_G = 7cm/s in the bubble column with a 2cm I.D. draft tube. E_G also increased with C. Some bubbles rose outside the draft tube even at C = 1cm because the diameter of the draft tube was too small.



C:1cm 5cm 10 cm

E_G:11.68% 11.82% 15.12%

Fig.7 Contours of E_G for D_i = 4 cm

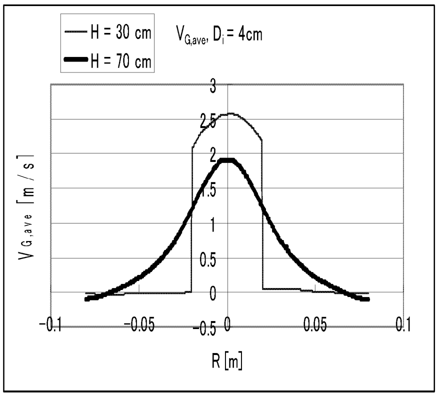
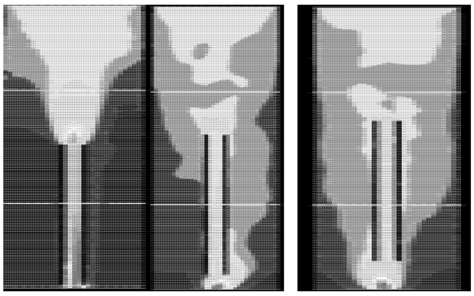


Fig.8 Profile of $V_{G,ave}$ for D_i = 4 cm and C = 1 cm



C: 1cm 5cm 10 cm

E_G: 9.33 % 12.54 % 14.12 %

Fig.9 Contours of E_G for D_i = 2 cm

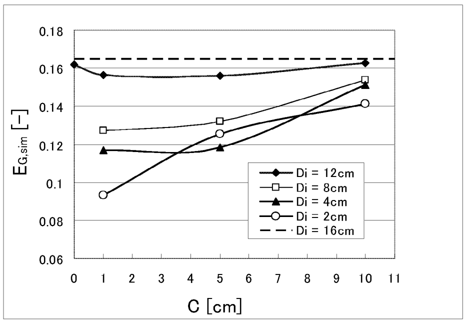


Fig.10 Effct of C and D_i on $E_{G,sim}$. Broken line means $E_{G,sim}$ in the bubble column with no draft tube.

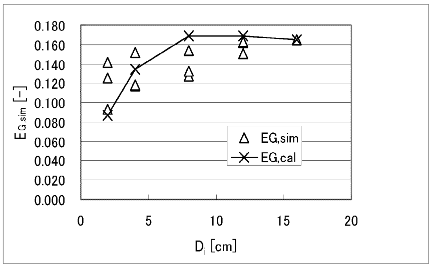


Fig.11 $E_{G,sim}$ vs. D_i

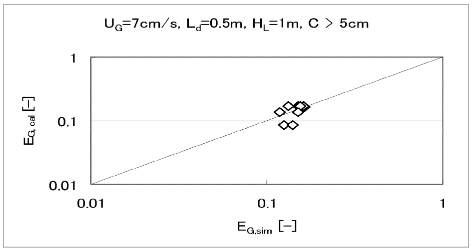


Fig.12 $E_{G,cal}$ vs. $E_{G,sim}$

4.3 Comparison between $E_{G,sim}$ and $E_{G,cal}$

Fig.10 shows the effect of C and D_i on $E_{G,sim}$. $E_{G,sim}$ depended upon C and D_i. The reason why $E_{G,sim}$ depended upon C and D_i is already explained in 4.2. Broken line in Fig.10 shows $E_{G,sim}$ in the bubble column with no draft tube. It is clear from Fig.10 that gas holdup in the bubble column with a draft tube is smaller than that in the bubble column with no draft tube because of the circulation of liquid.
Fig.11 shows the effect of D_i on $E_{G,sim}$. Fig.11 also shows $E_{G,cal}$ calculated by Eqs.(1)-(5) with $E_{s.sim}$. as E_s. $E_{G,ca}l$ was nearly equal to $E_{G,sim}$.
Fig.12 shows comparison between $E_{G,sim}$ and $E_{G,cal.}$ It is clear that from Fig.12 that $E_{G,cal.}$ is nearly equal to $E_{G,sim}$.

Conclusion

The effect of D_i and C on gas holdup in a 16 cm I.D. bubble column with a draft tube was simulated by CFX software. The results were compared with the correlation of Yamashita (1999).
1) $E_{G,sim}$ was nearly equal to $E_{G,cal}$ with $E_{S,sim}$ as E_s.
2) Bubbles rose outside the draft tube for small D_i and large C.

Nomenclature
C = clearance between lower end of draft tube and bottom of bubble column [m]
D = diameter of bubble column [m], D_i = inner diameter of draft tube [m], E_G = average gas holdup [-], $E_{G,cal}$ = E_G calculated by Eqs.(1) – (5) with E_s [-], $E_{G,sim}$ = E_G obtained by simulation, E_s = E_G in the bubble column with no draft tube [-],$E_{s,sim}$ = E_s obtained by simulation F_{ai} = D_i / D [-], F_r = Froude number (= $U_G(gD)^{-0.5}$), g = gravitational acceleration [m/s^2], H = height [m], H_L = clear liquid height [m], L_d = length of draft tube [m], M = parameter defined by Eq.(4), q = parameter defined by Eq.(5), R = radial distance [m], U_G = superficial gas velocity [m/s], V_G = velocity of gas [m/s], $V_{G,\ ave}$ = average of V_G, V_L = velocity of liquid [m/s], Z_1 = parameter defined by Eq.(2), Z_2 = parameter defined by Eq.(3)

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