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:

\[
E_g / E = Z_1 Z_2
\]

\[
Z_1 = 1 + (1 - F_{sl})^{0.41}
\]

\[
Z_2 = 1 + 70 (L_d / D)^{0.5} (L_d / H)^{0.4} \left( F_{sl} (1 - F_{sl}) \right)^{0.83}
\]

\[ M = 18 (F_r)^{0.41} \]

\[ q = 35.3 (F_r)^{0.83} \]
These equations are applicable in the range of $D_t = 0.05-0.13\text{m}$, $L_d = 0.5-1.40\text{m}$, $H_L = 0.60-1.55\text{m}$ and $C = 0.03-0.182\text{m}$.

### 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 $D = 16\text{ cm}$ and height $H = 100\text{ cm}$), 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. $D_t$ 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°C was used as a gas and water at 25°C 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.

![Fig.1](attachment:image1.png)

(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.
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 $U_G = 7\text{cm/s}$ in the bubble column with a 12cm I.D. draft tube. Though there were no bubbles in the annular region at $C = 0\text{ cm}$, bubbles in the annular region increased with increasing $C$, because the circulation of liquid increased. $E_G$ at $C = 5\text{ cm}$ was the lowest. At $C = 10\text{ cm}$ some bubbles rose outside the draft tube and $E_G$ increased. At $C = 1\text{ cm}$, 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 $C = 5\text{ cm}$, 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 $U_G = 7\text{cm/s}$ in the bubble column with a $D_r = 12$ 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 $V_L$.

Fig. 3 Contour of $E_G$ at $U_G = 7\text{cm/s}$ in the bubble column with a 12cm I.D. draft tube.
Fig. 4 Vectors of $V_G$ and $V_L$ at $U_G = 7\text{cm/s}$ 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

Fig. 5 Contours of $E_G$ for $D_t = 8\text{cm}$

$E_G$: 12.9% 13.2% 15.4%

Fig. 6 Profile of $V_{G,avg}$ at $D_t = 8\text{cm}$

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

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

Fig. 7 shows contours of $E_G$ at $U_G = 7\text{cm/s}$ 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 $V_{G,\text{ave}}$ at $H = 30$ and $70 \text{cm}$ in the bubble column with a $D_t = 4 \text{ cm}$ draft tube. It is clear from Fig. 6 and 8 that $V_{G,\text{ave}}$ at $H = 30$ and $70 \text{cm}$ is larger than that for $D_t = 8 \text{ cm}$.

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

Fig. 7 Contours of $E_G$ for $D_t = 4 \text{ cm}$

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

Fig. 9 Contours of $E_G$ for $D_t = 2 \text{ cm}$

Fig. 10 Effect of $C$ and $D_t$ on $E_{G,\text{sim}}$.

Broken line means $E_{G,\text{sim}}$ in the bubble column with no draft tube.

Fig. 11 $E_{G,\text{sim}}$ vs. $D_t$

Fig. 12 $E_{G,\text{cal}}$ vs. $E_{G,\text{sim}}$
4.3 Comparison between $E_{G,sim}$ and $E_{G,cal}$

Fig.10 shows the effect of C and $D_t$ on $E_{G,sim}$. $E_{G,sim}$ depended upon C and $D_t$. The reason why $E_{G,sim}$ depended upon C and $D_t$ 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 $D_t$ on $E_{G,sim}$. Fig.11 also shows $E_{G,cal}$ calculated by Eqs.(1)-(5) with $E_{s,sim}$ as $E_s$, $E_{G,cal}$ 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 $D_t$ 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 $D_t$ and large C.

Nomenclature

$C$ = clearance between lower end of draft tube and bottom of bubble column [m]

$D$ = diameter of bubble column [m], $D_t$ = 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 [-], $F_{Fr}$ = 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], $Z$ = parameter defined by Eq.(2), $Z_2$ = parameter defined by Eq.(3)

References


