EFFECT OF LIQUID DEPTH, COLUMN INCLINATION AND BAFFLE PLATES ON GAS HOLDUP IN BUBBLE COLUMNS

FUKUJI YAMASHITA
Department of Chemical Process Engineering, Ikutoku Technical University, Atsugi 243–02

Key Words: Bubble Column, Gas Holdup, Liquid Depth, Inclination, Baffle Plate, Critical Liquid Depth, Semi Circular Column

The effects of liquid depth, inclination angle of the column from verticality and baffle plates on gas holdup in bubble columns were determined, using three bubble columns.

When liquid depth H_l was less than the critical liquid depth H_{lc}, gas holdup ε_g decreased with increasing H_l, but when H_l was larger than H_{lc}, ε_g was nearly constant.

ε_g decreased with increasing column inclination angle, and the effect on ε_g was correlated.

ε_g was independent of the cross-sectional shape of the column.

Baffle plates set in bubble columns increased ε_g, and the effects of the area and number of baffle plates on ε_g were correlated.

Introduction

Bubble columns are widely used as gas-liquid reactors. Gas holdup is a very important parameter in the bubble column and has been widely investigated. The effects of many parameters such as gas and liquid velocity, column diameter, conditions of gas distributors and liquid properties have been clarified.[1,2,4–7] But the effects of liquid depth, inclination of the column from verticality and baffle plates on gas holdup remain obscure.

The effect of liquid depth on gas holdup has been reported by the authors.[6] But the findings were not sufficient to estimate the effect quantitatively.

The effects of column inclination on the fluidized bed have been reported by Nishi[3] in relation to plants aboard ship, but for bubble columns there have been no reports about this effect.

In bubble column research, columns without obstacles inside have been used. But commercial bubble columns with internal obstacles such as heat exchangers are sometimes used. So it is useful to determine the effects of such obstacles.

In this work, the effects of liquid depth, column inclination and baffle plates on gas holdup were experimentally determined, using three kinds of bubble columns, and the results were discussed and correlated.

1. Experiments

Three kinds of bubble columns were used in this work. They were all made of transparent acrylic resin. Details of the columns used are listed in **Table 1**.

The gas distributors used were perforated plates made of vinyl chloride resin ($t=5$ mm), a porous plate (100–120 μm glass filter of 65 mm diameter) and a single nozzle (27.6 mm i.d.). The details of the perforated plates are listed in **Table 2**. The perforated plates and the porous plate were set 20 cm above the bottom of the column in the 16 cm i.d. column (No. 1 column in Table 1) and 50 cm above the bottom of the column in the 8 cm i.d. column (No. 3 column in Table 1). A single nozzle was installed 10 cm above the bottom of each column on the side wall.

The liquid used was tap water at room temperature. During a run, liquid was neither fed nor discharged. Air was used as gas.

The average gas holdup in bubble columns was obtained from the difference in height of the bubbling and clear liquid layer.

When the effects of inclination of the column from verticality on gas holdup were measured, the column was inclined by angle θ, as shown in **Fig. 1**.

When the effect of cross-sectional shape of the column on gas holdup was measured, the circular column (No. 1 column in Table 1) and the semi-circular column (No. 2 column in Table 1) with the single nozzle as gas distributor were used.

When the effect of baffle plates on gas holdup was measured, baffle plates made of vinyl chloride resin ($t=5$ mm) were set in No. 1 bubble column ($D_T=$ 16 cm) with the single nozzle as gas distributor, as shown in **Fig. 2**.

Two kinds of baffle plates were used, circular and

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Table 1. Details of bubble columns

No.	D_T [cm]	H_T [cm]	Shape of cross section
1	16	270	Circle
2	16	270	Semi-circle
3	8	350	Circle

Table 2. Details of perforated plates

Key	δ [mm]	n [—]	p [mm]	D_T [cm]	Arrangement of holes
A	1.0	193	10	16	Square pitch
B	0.7	49	7	8	Square pitch

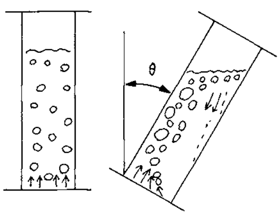

Fig. 1. Definition of θ and effect of θ.

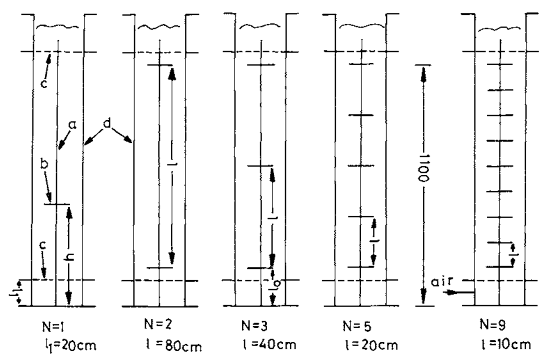

Fig. 2. Arrangement of circular baffle plates: a = center pole; b = baffle plate; c = support plate for center pole; d = bubble column; l = distance between baffle plates; $l_0 = 30$ cm; $l_1 = 20$ cm.

non-circular, as shown in **Fig. 3**. The circular baffle plates were supported by a center pole (a in Fig. 2) with rubber stoppers. The center pole was made of steel pipe (13 mm diameter and 130 cm long), and was fixed by acrylic resin plates (c in Fig. 2, $t = 10$ mm and $W = 30$ mm). The non-circular baffle plate (b in Fig. 3) was set 120 cm above the bottom of the column by use of flanges.

2. Experimental Results and Discussion

2.1 Effect of liquid depth H_l

No. 1 and No. 3 columns were used. **Figures 4 and 5** show the results. From these figures, it is found that when H_l is small, gas holdup decreases with H_l, and that when H_l is larger than 30–50 cm, gas holdup is nearly constant. Therefore, the critical depth H_{lc},

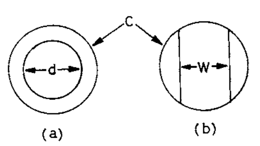

Fig. 3. Shape of baffle plates: (a) = circular baffle plate; (b) = non-circular baffle plate; c = bubble column; d = diameter of baffle plate; W = width of baffle plate.

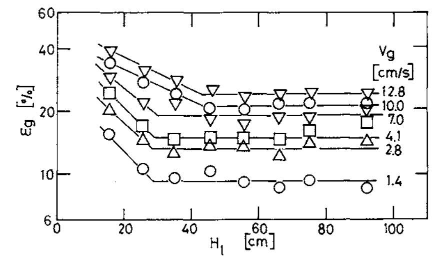

Fig. 4. ε_g vs. H_l for $D_T = 8$ cm column with glass filter as gas distributor.

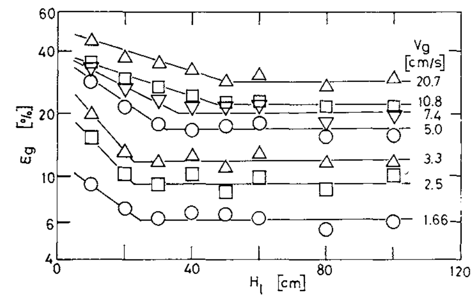

Fig. 5. ε_g vs. H_l for $D_T = 16$ cm bubble column with perforated plate as gas distributor: $\delta = 1$ mm, $n = 193$, $p = 1$ cm.

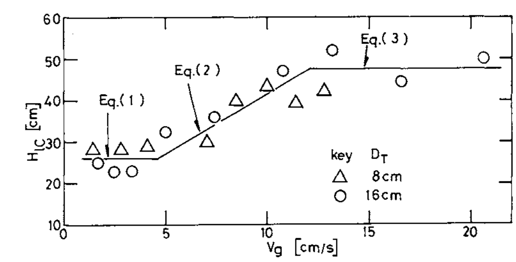

Fig. 6. H_{lc} vs. V_g.

above which gas holdup is independent of H_l, can be obtained from these figures.

Figure 6 shows H_{lc} obtained from Figs. 4 and 5. From Fig. 6, the following equation can be obtained:

$$V_g \leq 4.6\,\text{cm/s} \qquad H_{lc} = 26 \tag{1}$$

$$12.0\,\text{cm/s} \geq V_g > 4.6\,\text{cm/s} \qquad H_{lc} = 2.91\,V_g + 12.6 \tag{2}$$

$$V_g > 12.0\,\text{cm/s} \qquad H_{lc} = 47.5 \tag{3}$$

where H_{lc} and V_g are expressed in cm and cm·s^{-1}, respectively.

2.2 Effect of column inclination

No. 3 column ($D_T = 8$ cm) was used. **Figure 7** shows an example of the results. It is clear from this figure that gas holdup decreases with increasing angle θ. The

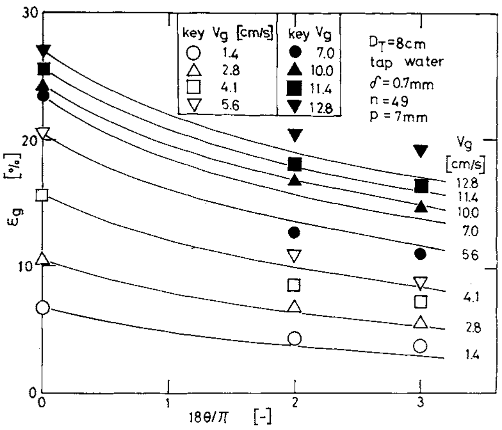

Fig. 7. ε_g vs. $18\theta/\pi$: Solid line, calculated by Eqs. (4) and (5).

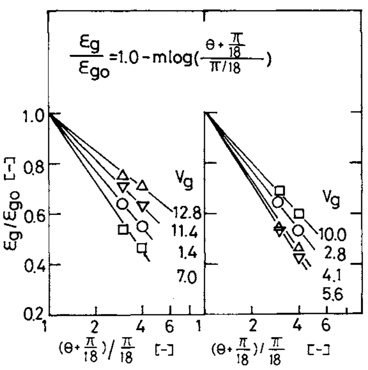

Fig. 8. $(\varepsilon_g/\varepsilon_{g_0})$ vs. $(\theta+(\pi/18))/(\pi/18)$.

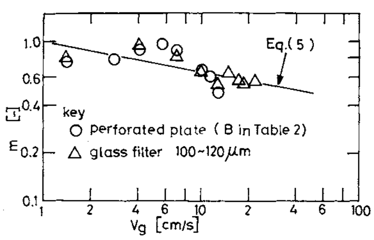

Fig. 9. m vs. V_g.

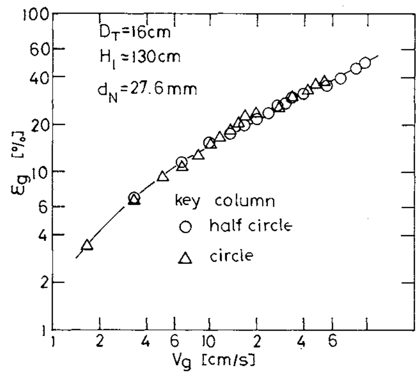

Fig. 10. Effect of cross-sectional shape of bubble column.

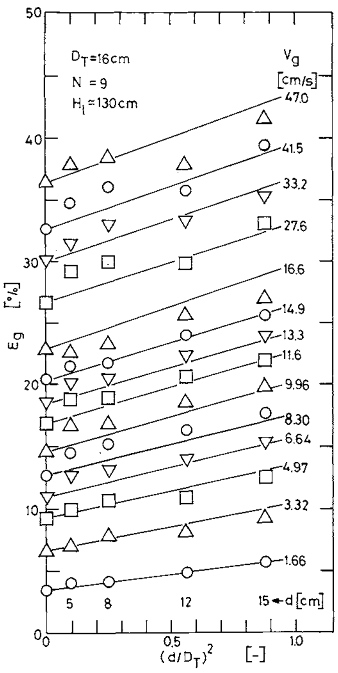

Fig. 11. ε_g vs. $(d/D_T)^2$ for circular baffle plates: Solid line, values calculated by Eq. (9) with ε_{g_0}.

reason is that bubbles rise along the upper wall of the column and tend to coalese more easily into large bubbles with increasing angle θ, as shown in Fig. 1. Nishi has reported the same results in the fluidized bed.[3)]

Figure 8 shows $(\varepsilon_g/\varepsilon_{g_0})$ vs. $(\theta+\pi/18)/(\pi/18)$. From Fig. 8, the following equation can be obtained:

$$(\varepsilon_{g_0}-\varepsilon_g)/\varepsilon_{g_0}=m\log\left[\left(\theta+\frac{\pi}{18}\right)\Big/\frac{\pi}{18}\right] \qquad (4)$$

where m is constant and ε_{g_0} is gas holdup in the case of $\theta=0$. $\theta=0$ means that the column is vertical.

Figure 9 shows m vs. V_g. From Fig. 9, it is clear that m decreases with increasing superficial gas velocity V_g and that m can be fairly well expressed by the following equation:

$$m=V_g^{-0.19} \qquad (5)$$

2.3 Effect of cross-sectional shape of the column

Gas holdup was determined using No. 1 circular column and No. 2 semi-circular column. In both columns, the gas distributor was the single nozzle.

Figure 10 shows the results. From Fig. 10, it is clear that there are no differences of gas holdup between the circular column and the semi-circular column.

2.4 Effect of circular baffle plates

No. 1 column with the single nozzle as gas distributor was used. The arrangements of baffle plates are shown in Fig. 2.

2.4.1 Effect of diameter d of baffle plate **Figure 11** shows the results. From this figure, it is clear that gas holdup increases with $(d/D_T)^2$. The reason is that the quantity of gas bubbles trapped under the baffle plates increases with $(d/D_T)^2$. From Fig. 11, the following relation can be obtained:

$$(\varepsilon_g-\varepsilon_{g_0})/\varepsilon_{g_0}\propto(d/D_T)^2 \qquad (6)$$

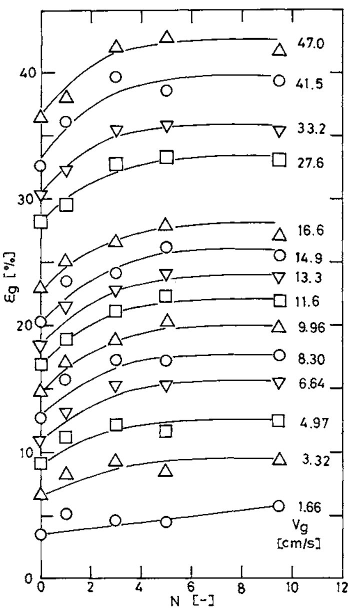

Fig. 12. ε_g vs. N. Experimental conditions: $D_T = 16$ cm; $d = 15$ cm; for $N = 1$, $h = 60$ cm.

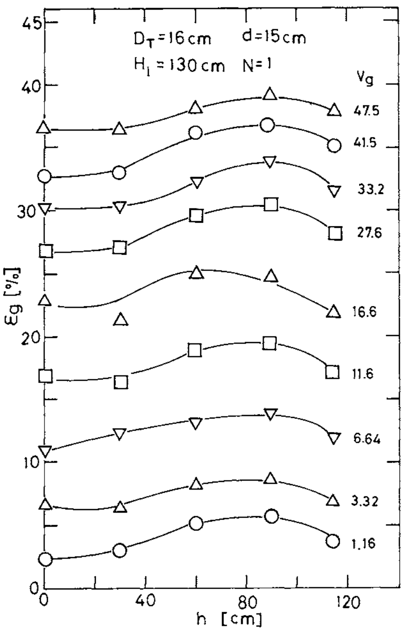

Fig. 14. ε_g vs. h.

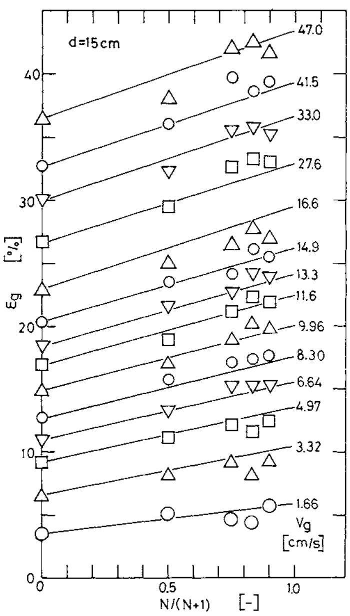

Fig. 13. ε_g vs. $N/(N+1)$. Experimental conditions are the same as those in Fig. 12. Solid line, values calculated by Eq. (9) with ε_{go}.

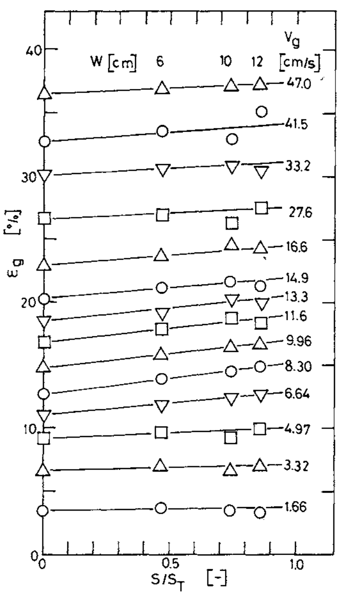

Fig. 15. ε_g vs. S/S_T for a non-circular baffle plate: $h = 120$ cm.

where ε_{go} is gas holdup in the case of $d = 0$.

2.4.2 Effect of number of baffle plates N **Figure 12** shows the results. From this figure, it is found that when N is small, gas holdup increases rapidly with N, but that when N is larger than 4, gas holdup increases gradually with N. This is because it becomes more difficult for gas bubbles to enter the spaces between baffle plates with decreasing distance between baffle plates.

Figure 13 shows ε_g vs. $N/(N+1)$. From Fig. 13, the following relation can be obtained:

$$(\varepsilon_g - \varepsilon_{go})/\varepsilon_{go} \propto N/(N+1) \qquad (7)$$

where ε_{go} is gas holdup in the case of $N = 0$.

2.4.3 Effect of height of baffle plate The effect of height of a baffle plate from the bottom of the column was determined. Experimental conditions were as follows: $d = 15$ cm, $N = 1$ and $H_l \simeq 130$ cm.

Figure 14 shows the results. From Fig. 14, it is found that ε_g is maximum at $h = 60$–90 cm.

2.5 Effect of width of non-circular baffle plate

No. 1 column with the single nozzle as gas distributor was used. The non-circular baffle plate (b in Fig. 3) was used. Experimental conditions were as follows: $N = 1$, $h = 120$ cm, $t = 5$ mm, $H_l \simeq 130$ cm.

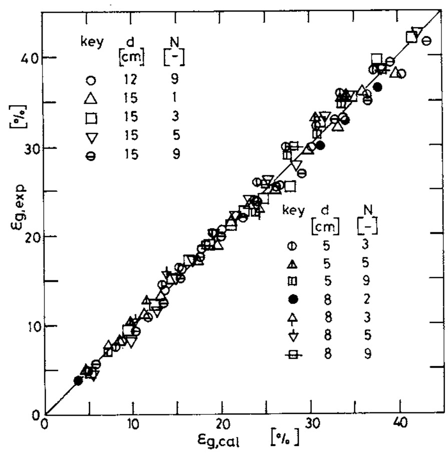

Fig. 16. $\varepsilon_{g,\exp}$ vs. $\varepsilon_{g,\mathrm{cal}}$ for circular baffle plates. $\varepsilon_{g,\mathrm{cal}}$, values calculated by Eq. (9) with ε_{go}; for $N=1$, $h=60\,\mathrm{cm}$.

Figure 15 shows the results. From this figure, ε_g increases gradually with dimensionless area S/S_T. The reason is that gas bubbles are more held with increasing area S under the baffle plate. From Fig. 15, the following relation can be obtained:

$$(\varepsilon_g-\varepsilon_{go})/\varepsilon_{go}\propto S/S_T \tag{8}$$

where ε_{go} is gas holdup without baffle plate.

2.6 Correlation of experimental results

To correlate the effects of area and number of baffle plates on gas holdup, the following equation is derived from Eqs. (6)–(8).

$$\varepsilon_g=\varepsilon_{go}\left[1+V_g^{-0.4}\left(\frac{S}{S_T}\right)\left(\frac{N}{N+1}\right)\right] \tag{9}$$

where the ranges of parameters are $0\leq N/(N+1)\leq 0.9$, $0\leq S/S_T\leq 0.879$ and $1.66\ \mathrm{cm/s}\leq V_g\leq 47.0\ \mathrm{cm/s}$, respectively. Figures 11, 13 and **16** compare $\varepsilon_{g,exp}$, experimental values of gas holdup, and $\varepsilon_{g,cal}$ values calculated by Eq. (9), using experimental values of ε_{go}. It is clear from these figures that Eq. (9) shows good agreement with the experimental results.

Conclusions

The effects of liquid depth, inclination angle of the column and baffle plates on gas holdup in bubble columns were studied, using three kinds of bubble columns, and the following information was obtained.

1) When liquid depth H_l is less than the critical liquid depth H_{lc}, gas holdup decreases with increasing H_l, but when H_l is larger than H_{lc}, gas holdup is nearly constant. H_{lc} was correlated by Eqs. (1)–(3).

2) Gas holdup decreases with increasing inclination angle θ of the column, and the effect was correlated by Eqs. (4) and (5).

3) Gas holdup is independent of cross-sectional shape of a bubble column.

4) Gas holdup increases with the area of the baffle plates and the number of circular baffle plates, and the effects were correlated by Eq. (9).

5) Gas holdup increases with height h and becomes maximum at $h=60$–$90\,\mathrm{cm}$. After that, ε_g decreases with increasing height h.

Acknowledgment

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Nomenclature

d	=	diameter of circular baffle plate	[cm]
d_N	=	diameter of nozzle	[mm]
D_T	=	diameter of bubble column	[cm]
h	=	height of a baffle plate from bottom of bubble column	[cm]
H_l	=	clear liquid depth	[cm]
H_{lc}	=	critical liquid depth	[cm]
H_T	=	height of bubble column	[cm]
m	=	constant	[—]
n	=	number of holes	[—]
N	=	number of baffle plates	[—]
p	=	pitch	[mm]
S	=	cross-sectional area of baffle plate	[cm^2]
S_T	=	cross-sectional area of bubble column	[cm^2]
V_g	=	superficial gas velocity	[cm·s^{-1}]
W	=	width of baffle plate (see Fig. 3)	[cm]
δ	=	hole diameter of perforated plate	[mm]
ε_g	=	average gas holdup	[—]
ε_{go}	=	average gas holdup without baffle plate and when $\theta=0$	[—]
$\varepsilon_{g,cal}$	=	value of ε_g calculated by Eq. (9)	[—]
$\varepsilon_{g,exp}$	=	experimental value of ε_g	[—]
θ	=	vertical angle of bubble column (see Fig. 1)	[rad]

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