

$\varepsilon_{G0}$	= $\varepsilon_G$ at $N=0$	[—]
$\varepsilon_{G,cal}$	= values of $\varepsilon_G$ calculated by Eq. (2) with $\varepsilon_{G0}$	[—]
$\varepsilon_{G,exp}$	= experimental gas holdup for wire gauzes with support plates	[—]
$\varepsilon'_G$	= modified gas holdup (=defined by Eq. (4))	[—]

#### Literature Cited

- 1) Patil, V. K., J. B. Joshi and M. M. Sharma: *Can. J. Chem. Eng.*, **62**, 228 (1984).
- 2) Yamashita, F.: *J. Chem. Eng. Japan*, **18**, 349 (1985).

(This paper was presented at the 19th Autumn Meeting (Nagoya, Oct., 1985) of The Society of Chemical Engineers, Japan.)

## EFFECTS OF VERTICAL PIPE AND ROD INTERNALS 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, Pipe, Rod, Internal Obstacle, Vertical Obstacle, Obstacle

### Introduction

Bubble columns are widely used as gas liquid reactors and bio-reactors. Gas holdup is very important in the design of bubble columns and has been widely studied.<sup>1-9)</sup> But there have been few reports about the effects of internal obstacles such as heat exchangers.<sup>4,7,8)</sup>

The effects of baffle plates and wire gauzes on gas holdup have been clarified in previous papers.<sup>7,8)</sup> But the effects of pipe and rod internals on gas holdup remain obscure.

In this work, the effects of single and multiple pipe and rod internals on gas holdup were experimentally determined using three kinds of bubble columns, and the results were studied and correlated.

### 1. Experimental

Bubble columns used were made of transparent acrylic resin. Gas spargers used were single nozzles. Details of the columns and gas spargers used are listed in **Table 1**. In the 8 cm and 16 cm i.d. bubble columns, single nozzles were set horizontally on the side wall and 4.2 cm and 10 cm above the bottom of the columns, respectively. In the 31 cm i.d. bubble column, a single nozzle ( $d_N = 60$  mm) was set downwards on the central axis, 10 cm above the bottom of the column.

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

When the effects of a pipe and rod internals ( $L = 250-280$  cm) made of vinyl chloride resin and iron on

gas holdup were measured, they were set vertically on the central axis of the bubble columns. In the 8 cm and 16 cm i.d. bubble columns, a pipe and a rod were set vertically on the bottom of the bubble columns. Bubbles could not rise through the pipe. In the 31 cm i.d. bubble column, a rod was set vertically on the two horizontal support pipes ( $d_o = 6$  mm) and 36.5 cm above the bottom of the column. The upper ends of pipes and rods were fixed vertically by using flanges and angle irons. Pipes whose both ends were sealed with vinyl chloride resin plates were used as rods.

When the effects of 250-270 cm-long multiple pipe and rod internals on gas holdup were measured, they were set vertically on the bottom of the bubble columns as shown in **Fig. 1**, and fixed by two support plates (b in **Fig. 1**). The support plates (b in **Fig. 1**) were set 50 cm and 150 cm above the bottom of the 31 cm i.d. bubble column, and 21 cm and 123 cm above the bottom of the 16 cm i.d. bubble column by use of flanges. The support plates were made of vinyl chloride resin ( $t = 5$  mm). Details of the support plates used are listed in **Table 2**. Average gas holdup with no pipe and rod internals ( $= \varepsilon_G$  at  $N=0$ ) was measured only with the two support plates.

Average gas holdup was obtained by the manometric method in the 8 cm and 31 cm i.d. bubble columns

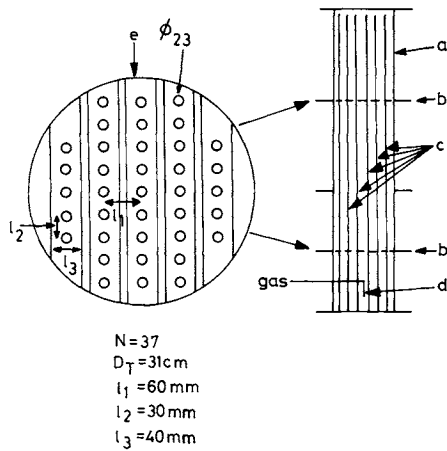
**Table 1.** Details of experimental apparatus and clear liquid height and ranges of parameters in Eqs. (1)-(3)

No.	$D_T$ [cm]	$H_T$ [cm]	$H_L$ [cm]	$S/S_T$ [—]	$V_G$ [cm/s]	$d_N$ [mm]
1	8	350	100-165	0-0.562	1.66 -66.3	10
2	16	270	130-140	0-0.517	1.66 -47.0	27.6
3	31	300	130-140	0-0.747	0.883-35.3	60

Received August 18, 1986. Correspondence concerning this article should be addressed to F. Yamashita.

**Table 2.** Details of support plates used

Key	$D_T$ [cm]	$N_h$ [—]	$d_h$ [mm]	$l_1$ [mm]	$l_2$ [mm]	$l_3$ [mm]	$d_{o,max}$ [mm]	$l_2 - d_{o,max}$ [mm]
A	31	85	15	40	20	20	14	6
B	31	37	23	60	30	40	22	8
C	31	9	62	85	85	70	60	25
D	16	11	24	55	30	30	22	8
E	16	2	63	—	80	80	60	20



**Fig. 1.** 31 cm i.d. bubble column and support plate B for multiple pipe and rod internals. a, bubble column; b, support plate for internals; c, pipe or rod internals; d, gas sparger (downward single nozzle); e, support plate B for internals.

and from the difference in height of the bubbling and clear liquid layer in the 16 cm i.d. bubble column. Pressure taps were set on the side wall, 4.2 cm and 145.7 cm above the bottom of the 8 cm i.d. bubble column, and 21.5 cm and 127.5 cm above the bottom of the 31 cm i.d. bubble column.

## 2. Experimental Results and Discussion

### 2.1 Effects of single pipe and rod internals in the 8 cm and 16 cm i.d. bubble columns and single-rod internals in the 31 cm i.d. bubble column on gas holdup

Gas holdup increased with the outer diameter of pipe and rod. The effects of pipe internals were equal to those of rod internals, because bubbles could not rise through the internals. The effects were correlated by the following equations, using the modified superficial gas velocity  $V_{Gm}$  defined by Eq. (3):

For  $D_T = 8$  cm,

$$\varepsilon_G(1 - \varepsilon_G)^{-1} = 0.03 V_{Gm}^{0.773} \quad (1)$$

For  $D_T = 16$  cm and 31 cm,

$$\varepsilon_G(1 - \varepsilon_G)^{-1} = 0.025 V_{Gm}^{0.773} \quad (2)$$

$$V_{Gm} = V_G [1 - (S/S_T)]^{-1} \quad (3)$$

where  $\varepsilon_G$  is the average gas holdup,  $V_G$  the superficial gas velocity,  $S$  the cross-sectional area of the pipe and rod and  $S_T$  the cross-sectional area of the bubble

column. The ranges of parameters in Eqs. (1)–(3) are listed in Table 1.  $\varepsilon_G(1 - \varepsilon_G)^{-1}$  in the 8 cm i.d. bubble column was 20% higher than that of the 16 cm and 31 cm i.d. bubble columns. This result agrees with those of Fair *et al.*<sup>2)</sup> and Yoshida *et al.*<sup>9)</sup>

The reason why gas holdup increased with the outer diameter of pipe and rod internals is that the pipe and rod internals decrease the cross-sectional area of the bubble column where bubbles can rise and make the gas velocity increase.

### 2.2 Effects of multiple pipe and rod internals on gas holdup

Pipes and rods were set in various arrangements by changing the number  $N$  and column positions on the support plates of multiple pipes and rods in the 16 cm and 31 cm i.d. bubble columns.

1) Large separation distance between internals ( $L_s \geq 8$  mm)  $L_s$  is the separation distance between internals defined by the following equation:

$$L_s = l_2 - d_o \quad (4)$$

where  $l_2$  is the distance between holes on the support plates as shown in Fig. 1 and  $d_o$  the outer diameter of pipes and rods. Gas holdup  $\varepsilon_G$  increased with the number  $N$  and the outer diameter of pipes and rods. Gas holdup for pipes was the same as that for rods, because bubbles could not rise through pipes. The effects of multiple pipe and rod internals at  $L_s \geq 8$  mm on gas holdup are expressed by Eq. (2), which was applicable to single pipe and rod internals, as shown in Fig. 2. The ranges of parameters in Eq. (2) were  $0 \leq S/S_T \leq 0.337$  and  $0 \text{ cm/s} \leq V_G \leq 47 \text{ cm/s}$ .

Pipes and rods decrease the cross-sectional area of the column where bubbles can rise, and make the gas velocity increase like single pipe and rod internals. Moreover, bubble motions are very vigorous and can move radially well in spite of prevention by internals. These are the reasons why gas holdup increased with the cross-sectional area of vertical internals at large separation distance.

2) Small separation distance between internals ( $L_s = 6$  mm) In this run, support plate A shown in Fig. 3 was used. Gas holdup decreased with  $N$  and showed minimum at  $N = 70$  as shown in Fig. 3. Gas holdup for pipes was the same as that for rod

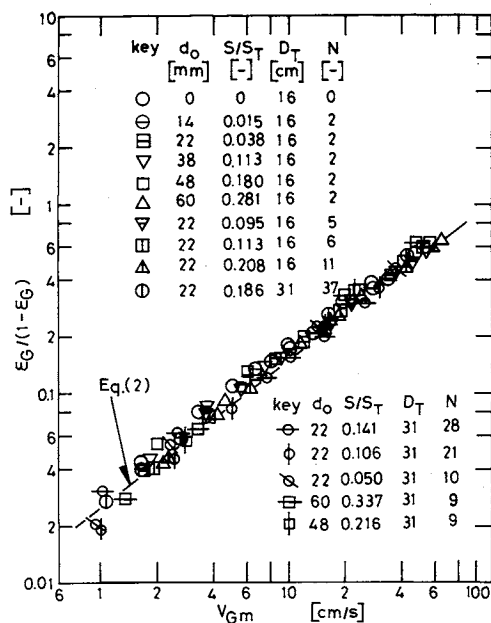


Fig. 2.  $\varepsilon_G/(1-\varepsilon_G)$  vs.  $V_{Gm}$  for multiple pipe and rod internals at large separation distance ( $L_s \geq 8$  mm) in the 16 cm and 31 cm i.d. bubble columns.

internals. The separation distance  $L_s$  between pipe or rod internals was narrow and the number of pipes and rods in one column of the support plate was large. So radial motions of bubbles were much retarded by the existence of internals. This is the reason why gas holdup decreased. Especially at  $N=70$ , where rods were set at a, b, c, e, f and g columns on the support plate (see Fig. 3), the central region of the bubble column was free. So bubbles rose mainly in the central region of the bubble column and gas holdup showed minimum.

#### Acknowledgment

The author wishes to thank Messrs. K. Uchida, M. Oka, Y. Kanmuri and K. Namiki, former students at Department of Chemical Process Engineering, Ikutoku Technical University for their experimental work.

#### Nomenclature

$D_T$	= diameter of bubble column	[cm]
$d_h$	= diameter of hole on support plate	[mm]
$d_N$	= inner diameter of nozzle	[mm]
$d_o$	= outer diameter of pipe and rod	[cm]
$d_{o,max}$	= maximum outer diameter of pipe and rod used in support plate	[mm]
$H_L$	= height of clear liquid	[cm]
$H_T$	= height of bubble column	[cm]
$L$	= length of pipe and rod	[cm]
$L_s$	= separation distance between internals	[mm]
$l_1$	= distance between centers of holes (see Fig. 1)	[mm]
$l_2$	= distance between centers of holes (see Fig. 1)	[mm]
$l_3$	= width of one column of support plate (see Fig. 1)	[mm]

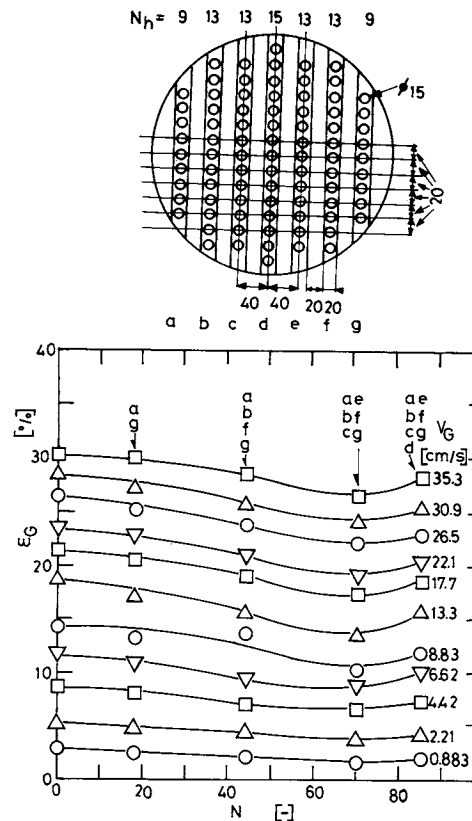


Fig. 3. Effect of number  $N$  of  $d_o=14$  mm rod internals at small separation distance ( $L_s=6$  mm) on gas holdup in the 31 cm i.d. bubble column and details of support plate A. a-g mean the column position of rods on the support plate A.

$N$	= number of pipes and rods	[-]
$N_h$	= number of holes on support plate	[-]
$S$	= total cross-sectional area of pipe and rod internals	[cm <sup>2</sup> ]
$S_T$	= cross-sectional area of bubble column	[cm <sup>2</sup> ]
$V_G$	= superficial gas velocity	[cm/s]
$V_{Gm}$	= modified superficial gas velocity defined by Eq. (3)	[cm/s]
$\varepsilon_G$	= average gas holdup	[-]

#### Literature Cited

- 1) Akita, K. and F. Yoshida: *Ind. Eng. Chem., Process Des. Dev.*, **12**, 76 (1973).
- 2) Fair, J. R., A. J. Lambright and J. M. Anderson: *Ind. Eng. Chem., Process Des. Dev.*, **1**, 33 (1962).
- 3) Koide, K.: "Kagaku Kōgaku no Shinpo 16 Kihō Ekiteki Bunsan Kōgaku," p. 58, The Soc. of Chem. Engrs., Japan (1982).
- 4) Patil, V. K., J. B. Joshi and M. M. Sharma: *Can. J. Chem. Eng.*, **62**, 228 (1984).
- 5) Yamashita, F. and H. Inoue: *J. Chem. Eng. Japan*, **8**, 334 (1975).
- 6) Yamashita, F. and H. Inoue: *Kagaku Kogaku Ronbunshu*, **2**, 250 (1976).
- 7) Yamashita, F.: *J. Chem. Eng. Japan*, **18**, 349 (1985).
- 8) Yamashita, F.: *J. Chem. Eng. Japan*, **20**, 201 (1987).
- 9) Yoshida, F. and K. Akita: *AIChE J.*, **11**, 9 (1965).