AIDIC *Conference Series*, Vol. 9, 2009
Editor Sauro Pierucci
DOI: 10.3303/ACOS0909043

ISBN 978-88-95608-10-5 ISSN 2036-5969

EFFECT OF KINDS OF GAS ON GAS HOLDUP IN BUBBLE COLUMNS

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The effect of kinds of gas on gas holdup E_G in bubble columns was studied. E_G increased with increasing density of gas. This reason was explained as follows: Small bubbles easily generate in a heavy gas according to breakup of bubbles, because the dynamic pressure $(\rho_G U^2/2)$ in bubbles is large in heavy gas. Therefore, the quantity, or number of small bubbles for heavy gas becomes much larger than that for light gas and E_G increases with increasing density of gas. Data of E_G by this work and Ozturk et al. (1987) were correlated.

1. INTRODUCTION

Bubble columns 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 have been many studies about gas holdup in bubble columns. It has been reported that gas holdup depends on many factors such as gas and liquid velocity, physical property of gas and liquid, type and arrangement of gas spargers, gas inlet height and inclination angle of bubble columns. However, the effect of kinds of gas on E_G is not yet clear. In this work, the effect of kinds of gas on E_G was experimentally studied and the results were discussed and analyzed.

2. PREVIOUS STUDY

Akita et al. (1973) have reported that E_G does not depend on kinds of gas in a 15cm square and 4 m high bubble column with a single 4.5 mm orifice as a gas sparger in the range of U_G = 0 - 25cm/s, although the gas holdup with He gas appears slightly lower at higher gas velocities. They used Air, O_2, He, CO_2 / water system. Hikita et al. (1980) studied the effect of gas and liquid properties on gas holdup in the bubble column of 10 cm inner

Please cite this article as: Yamashita F. and Fukaura T., (2009), Effect of kinds of gas on gas holdup in bubble columns, AIDIC Conference Series, 09, 373-382 DOI: 10.3303/ACOS0909043

diameter and 1.5 m height. They have reported that E_G depends on $\rho_G^{0.062}\rho_L^{0.069}\mu_G^{0.107}\mu_L^{-0.053}$ and presented the following correlation:

$$E_G = 0.672\,(U_G\mu_L/\gamma)^{0.578}[\mu_L^4 g/(\rho_L\gamma^3)]^{-0.131}\,(\rho_G/\rho_L)^{0.062}(\mu_G/\mu_L)^{0.107} \quad (1)$$

Koetsier et al. (1976) studied the effect of kinds of gas on E_G in a 5cm I.D. and 0.6m high bubble column with a porous gas sparger. In demineralised water system, E_G for Ar gas is much larger than that for He gas. However, in 0.4 mol / dm^3 NaCl aqueous solution, E_G for Ar gas is nearly equal to that for He gas. They have concluded that bubbles for He gas coalesced into larger ones much easier than those for Ar gas and rise faster in the demineralized water system and that E_G for He gas is much lower than that for Ar gas. Ozturk et al. (1987) have also studied the effect of kinds of gas on E_G in the 9.5 cm I.D. and 85 cm tall bubble column with organic liquids and reported that E_G depends on kinds of gas. They have concluded that the gas-specific effects are probably related to the bubble formation at the sparger rather than the hydrodynamics in the bulk of the dispersion. Therefore, E_G depends on kinds of gas in bubble columns with small height (H_T < 1 m), however, E_G does not depend on kinds of gas in tall bubble columns (H_T > 2 m). H_T means a bubbling height.

3. EXPERIMENTAL

One circular and three rectangular bubble columns were used. They were all made of transparent acrylic resin. The cross sections of three rectangular bubble columns were 1cm x 30cm, 3cm x 20cm and 5cm x 10cm, in order. The circular bubble column has 8 cm inner diameter and 165 cm height. A single nozzle and perforated plates were used as a gas sparger. H_2, He, Ar, O_2 , CO_2 and HFC-134a gas from cylinders were used as a gas. Most of flow rate of gases were controlled by the mass flow controller made by Alicat, USA. Some flow rate of gases was measured by commercial flow meter (Omega, Japan). Tap water was used as a liquid. Liquid was used in a batch. All runs were conducted at room temperature. Average gas holdup E_G was measured visually, or by a photographic method. When the effect of kinds of gas on frequency and volume of bubbles which generated from a single nozzle was studied, single horizontal 7 and 10 mm I.D. glass tubes were used as a nozzle. The nozzles were set on a bottom of a rectangular water bath at room temperature. The water bath was 16 cm wide, 29 cm deep and 21 cm high. Water depth was 15 cm. Frequency of bubbles and gas flow rate were measured by the electric resistance probe and mass flow controller, respectively.

4. EXPERIMENTAL RESULTS AND DISCUSSIONS

4.1 Effect of kinds of gas on frequency N of bubbles generated from a single nozzle

Figs.1 and 2 show the effect of kinds of gas on frequency N of bubbles which generated from horizontal d = 7 mm and 10 mm single nozzle, respectively. It is clear from these figures that frequency N and volume V of bubbles which generate from single nozzles do not depend on kinds of gas. The reason why N and V did not depend on kinds of gas may be because of small gas velocity in the single nozzle. At small gas velocity bubbles were formed not by gas jetting and breakup, but by expansion and detachment at the outlet of the single nozzle.

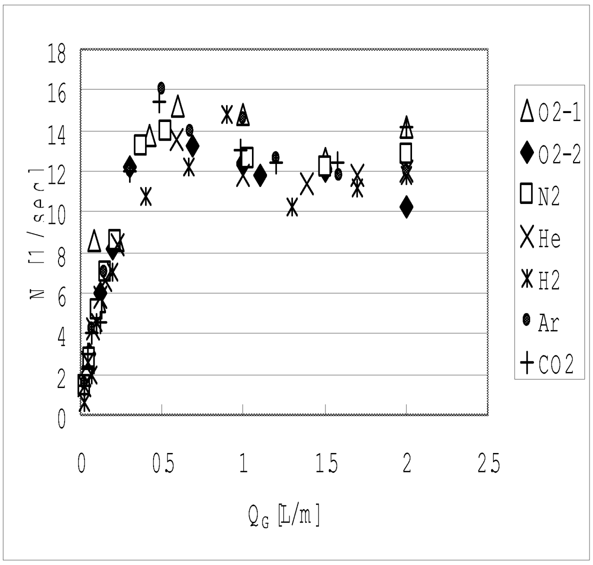

Fig.1 N vs. Q_G for 7 mm I.D. nozzle

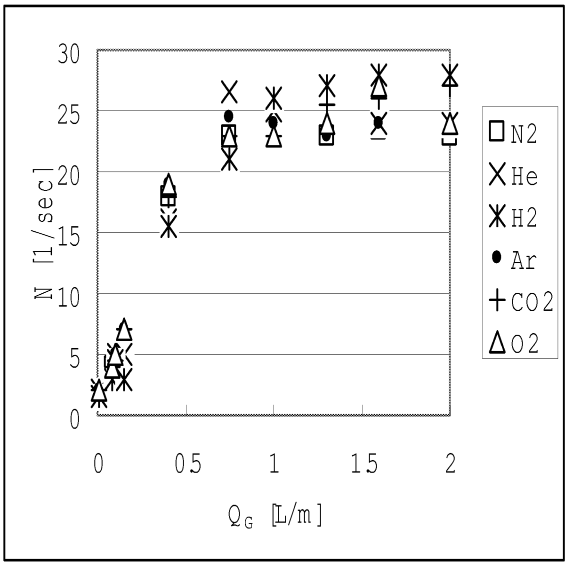

Fig.2 N vs. Q_G for 10 mm I.D. nozzle

4.2 E_G for tap water

Figs.3-5 show E_G for various bubble columns. Fig.3 shows E_G for the 5 x10 cm rectangular bubble column whose gas sparger was a perforated plate (d = 0.5mm, n=18, p = 10 mm). Fig.4 shows E_G for the 1cm x 30 cm rectangular bubble column whose gas sparger was a single orifice (d = 1 mm).Fig.5 shows E_G for the 8cm I.D. bubble column whose gas sparger was a single nozzle (d = 6 mm). It is clear from these figures that E_G increases with density of gas.

Fig.6 shows the cross sectional area of maximum bubbles for the 1 x 30cm bubble column whose gas sparger was a single orifice (d = 1mm). The cross sectional area of bubbles was measured by a photographic method. It is clear from this figure that the cross sectional area of maximum bubbles do not depend on kinds of gas.

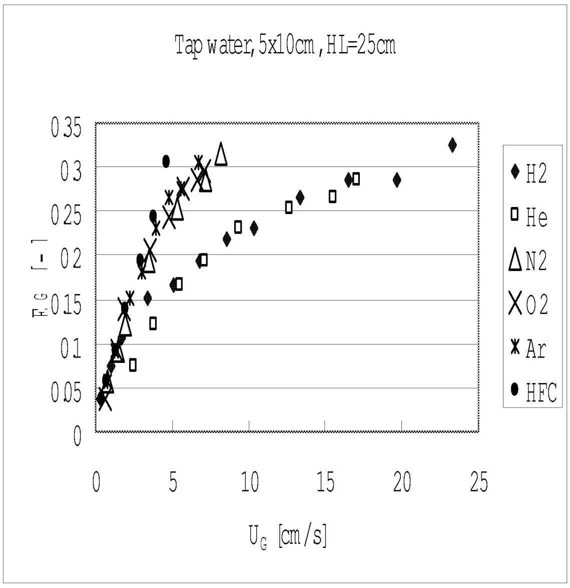

Fig.3 E_G vs. U_G for the 5 x 10 cm column

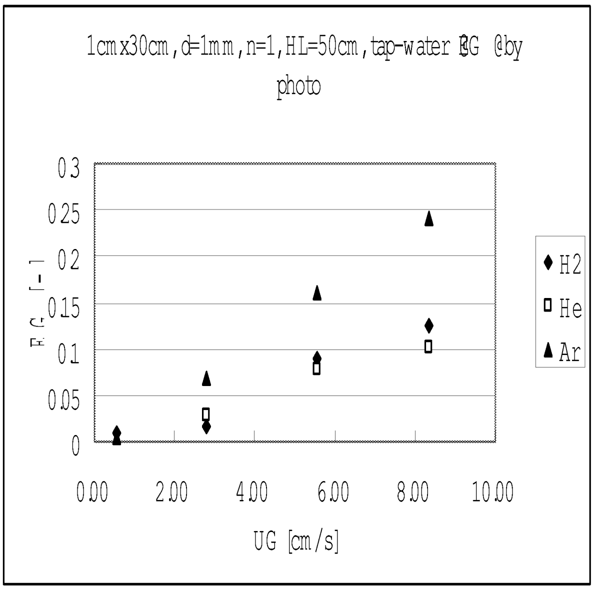

Fig.4 E_G vs. U_G for the 1 x 30 cm column

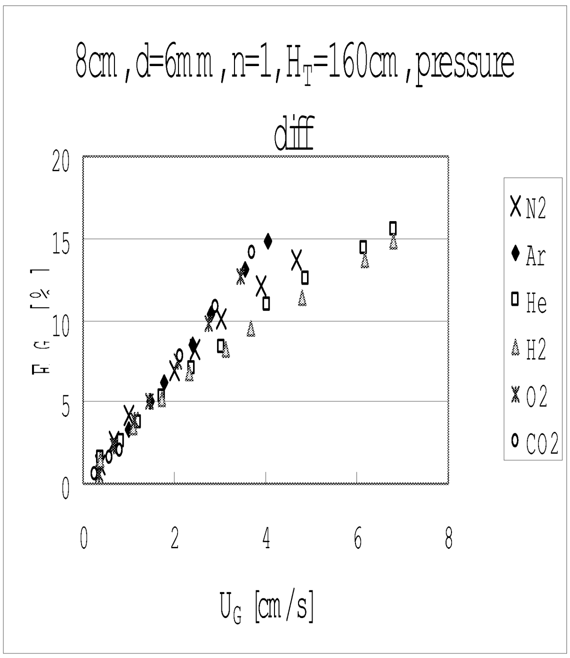

Fig.5 E_G vs. U_G for 8 cm I.D. column

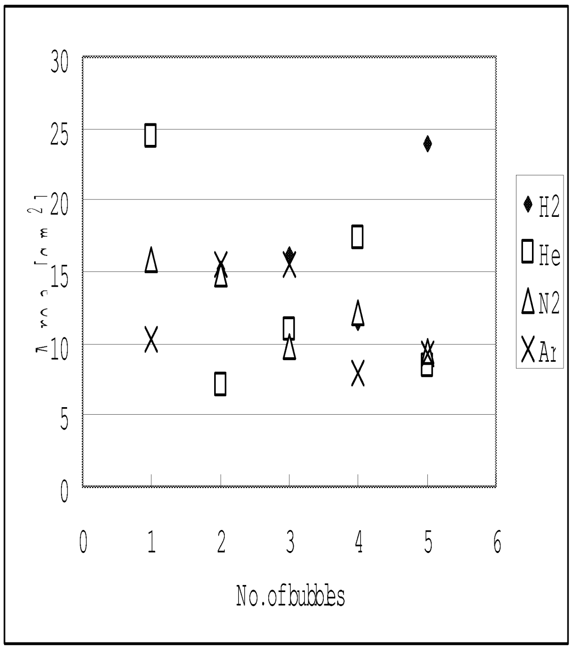

Fig.6 Area of maximum bubbles

Fig.7 Photos of bubbles in the 5 x 10 cm rectangular bubble column in the range of h = 20-30cm.
Left: oxygen – tap water at U_G =4.47 cm/s. Right: He-tap water at U_G = 4.80 cm/s.

Fig.7 shows the flow conditions of bubbles in the 5cm x 10cm rectangular bubble column. It is clear that the number, or quantity of bubbles for oxygen – tap water are much larger than that for He – tap water system at nearly the same U_G.

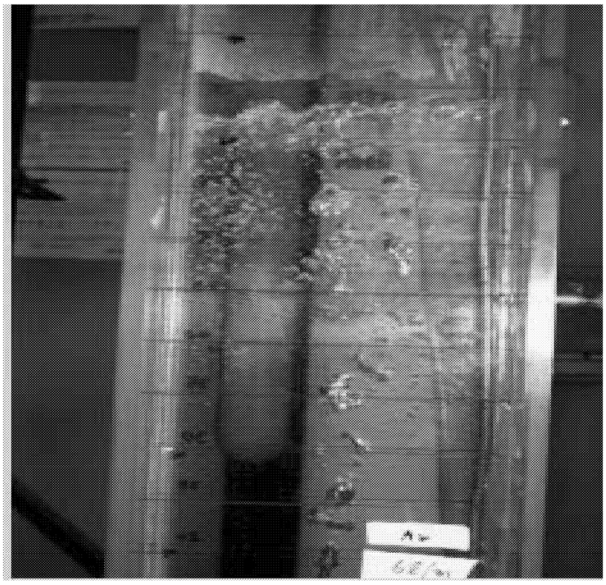

Fig.8 Flow conditions of Ar bubbles at U_G=2.8cm/s and h = 20-60 cm.

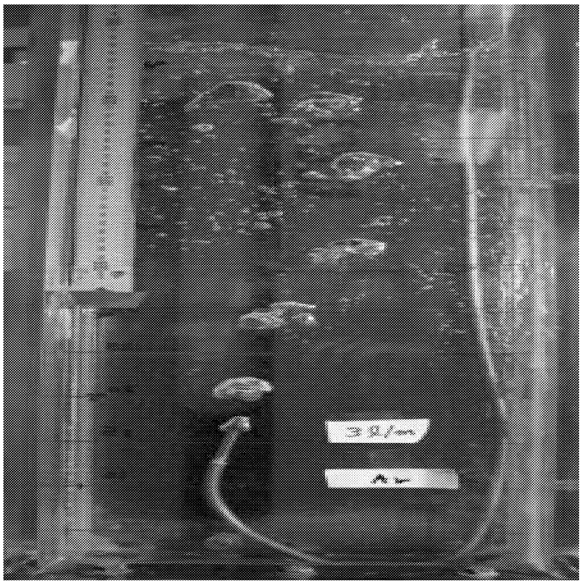

Fig.9 Flow conditions of Ar bubbles at U_G = 1.4 cm/s and h = 0-60 cm.

Figs.8 and 9 show rising bubbles of Ar gas which generated from a 3mm I.D. single nozzle at U_G= 1.4 and 2.8 cm/s in the 1cm x 30cm bubble column, respectively. The number, or quantity of small bubbles increases with height from the nozzle according to bubble breakup.

From these findings, it is concluded that the effects of kinds of gas on E_G are caused by the difference of number, or quantity of small bubbles. It is known that bubbles tend to break when dynamic pressure ($\rho_G U^2/2$) in a bubble is large (Levich, 1962). Therefore, the number, or quantity of small bubbles increases with increasing density of gas.

4.3 Correlation of E_G for tap water

Fig.10 shows the effect of U_G on E_G in the circular bubble column. E_G increased with U_G and was expressed by the following equation:

$$E_G = AU_G^{\,B} \tag{2}$$

Where A and B are constants. Table 1 shows the effect of kinds of gas on values of A and B. Figs.11 and 12 show the effect of gas density ρ_G on A and B, respectively. A and B were expressed by the following equations, respectively.

$$A = 3.23\rho_G^{-0.0121} \tag{3}$$

$$B = 1.05\rho_G^{0.122} \tag{4}$$

Eqs. (3) and (4) are applicable in the range of ρ_G = 0.083-1.83 kg/m^3.

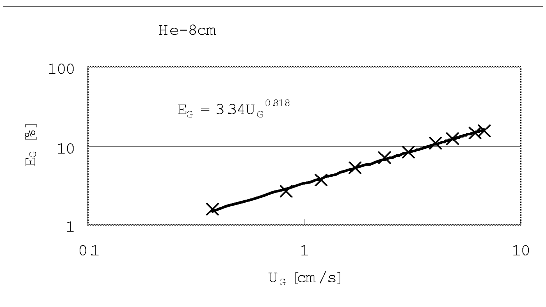

Fig.10 E_G vs. U_G for He- tap water system in the circular bubble column

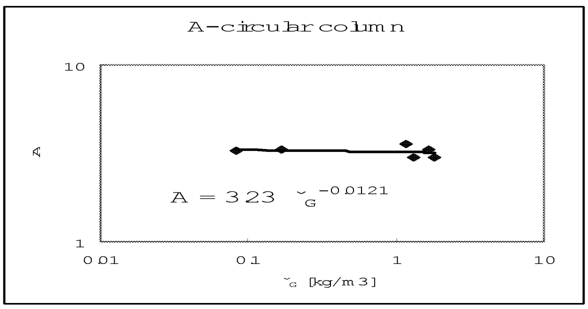

Fig.11 A vs. ρ_G for the circular column.

Fig.13 shows the comparison between $E_{G,exp}$ and $E_{G,cal}$. $E_{G,exp}$ means experimental values of E_G. $E_{G,cal}$ means values of E_G calculated by Eqs.(2)-(4). It is clear from Fig.13 that $E_{G,cal}$ shows a good agreement with $E_{G,exp}$.

Fig.14 shows the the effects of U_G on E_G in the rectangular bubble column. E_G increased with U_G and was expressed by the following equation:

$$E_G = CU_G^{\ D} \qquad (5)$$

Where C and D are constants. Table 2 shows values of C and D. Figs.15 and 16 show the effect of gas density ρ_G on C and D, respectively. C and D were expressed by the following equations, respectively.

$$C = 5.7\rho_G^{\ 0.042} \qquad (6)$$

$$D = 0.96\rho_G^{\ 0.114} \qquad (7)$$

Eqs.(6) and (7) are applicable in the range of ρ_G = 0.083-1.83 kg/m^3.

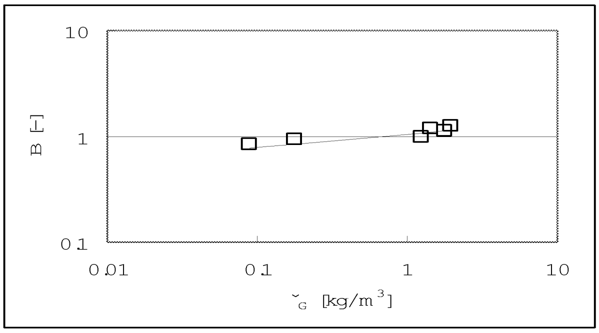

Fig.12 B vs. ρ_G for the circular column.

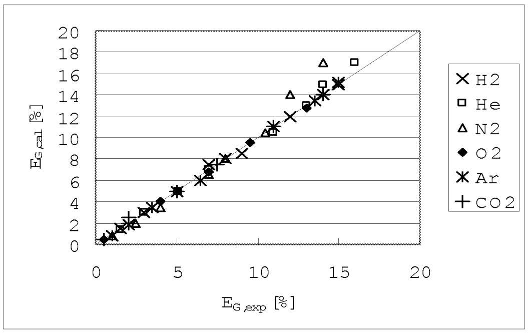

Fig.13 $E_{G,exp}$ vs. $E_{G,cal}$ for the circular column

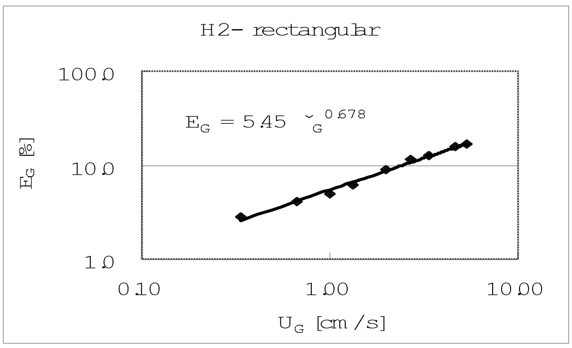

Fig.14 E_G vs. U_G for H_2 in the rectangular column

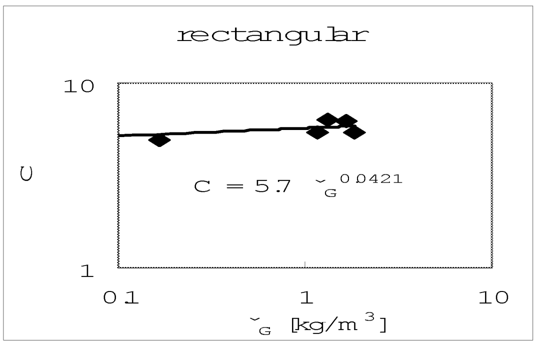

Fig.15 C vs. ρ_G for the rectangular column.

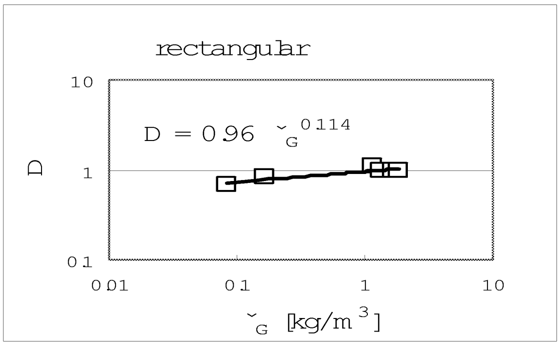

Fig.16 D vs. ρ_G for the rectangular column.

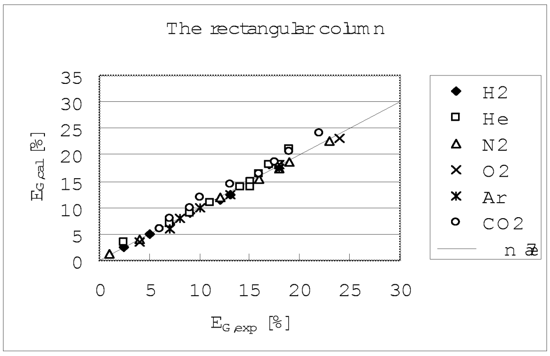

Fig.17 $E_{G,cal}$ vs. $E_{G,exp}$ for the rectangular column

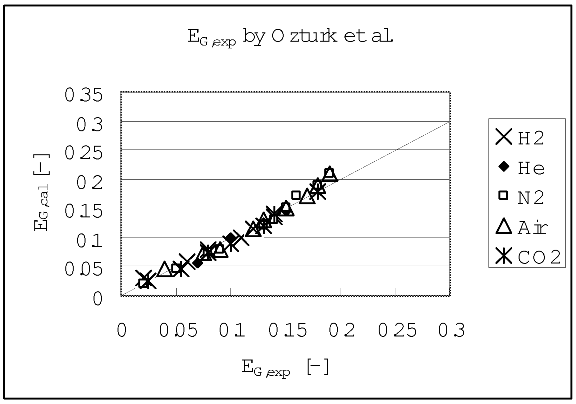

Fig18 $E_{G,cal}$ vs. $E_{G,exp}$ for Ozuturk et al.

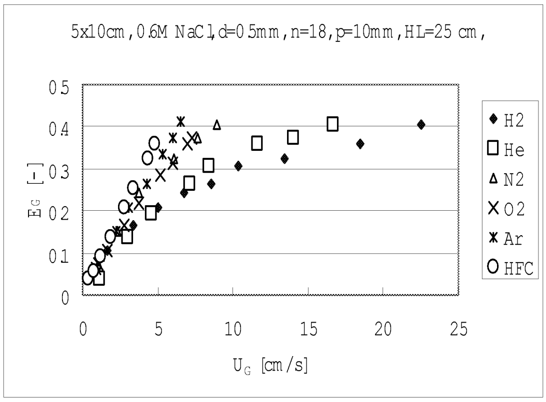

Fig.19 E_G vs. U_G for 0.6M NaCl solution in the 5 x 10 cm bubble column with a perforated plate.

Fig.17 shows the comparison between $E_{G,exp}$ and $E_{G,cal}$. $E_{G,cal}$ means E_G calculated by Eqs.(5)-(7). It is clear from Fig.11 that $E_{G,cal}$ shows a good agreement with $E_{G,exp}$.

E_G data for H_2, He, N_2, Air, CO_2 gas -xylene system by Ozturk et al. (1987) in a 9.5cm I.D. and 85 cm tall bubble column were correlated by the following equations:

$$E_G = EU_G^{\ F} \tag{8}$$

$$E=3.22\rho_G^{-0.0122} \tag{9}$$

$$F=0.91\rho_G^{0.122} \tag{10}$$

Fig.18 shows the comparison between Eqs.(8)-(10) and the experimental data of Ozturk et al. (1987). $E_{G,cal}$ obtained from Eqs.(8)-(10) shows a good agreement with $E_{G,exp}$. Eqs. (8)-(10) remarkably resemble Eqs. (2)-(4).

Table1 Values of A - D

Gas	ρ_G[kg/m^3]	A	B	C	D
H_2	0.083	3.26	0.805	5.45	0.678
He	0.166	3.34	0.818	4.88	0.935
N_2	1.16	3.57	0.922	5.39	1.089
O_2	1.33	3.02	1.230	6.32	0.963
Ar	1.66	3.32	1.084	6.24	0.986
CO_2	1.83	2.99	1.20	5.42	0.973

4.3 E_G for NaCl aqueous solution

Fig. 19 shows the effect of kinds of gas on E_G for 0.6M NaCl aqueous solution in the 5 cm x 10 cm bubble column at H_L = 25 cm. The experimental conditions are the same as those in Fig.3 except NaCl aqueous solution. E_G in 0.6 M NaCl aqueous solution increased about 20% than that in tap water (see Fig.3) because of addition of NaCl. E_G depended remarkably on kinds of gas. However, Koetsier et al. (1976) have reported that E_G does not depend on kinds of gas in 0.4 M NaCl aqueous solution, because coalescence of bubbles at the porous gas sparger is prohibited by 0.4 M NaCl aqueous solution. The reason why their results are different from those in this work may be because they used a porous plate as a gas sparger and E_G depended mainly upon bubble coalescence at the porous gas sparger. However, it is thought that in this work E_G depended mainly upon bubble breakups in the bubble column because the gas spargers were a single nozzle or perforated plates in this work. Ozturk et al. (1987) have concluded that the gas-specific effects are probably related to the bubble formation at the sparger rather than the hydrodynamics in the bulk of the dispersion. Therefore, E_G depends on kinds of gas in bubble columns with small height (H_T < 1 m), however, E_G does not depend on kinds of gas in tall bubble columns (H_T > 2 m). Their conclusion cannot be verified because H_T was less than 2 m in this work.

5. Conclusion

1) E_G increased with increasing density of gas. This reason was explained as follows: Small bubbles easily generate in a heavy gas according to breakup of bubbles because the dynamic pressure ($\rho_G U^2 / 2$) in bubbles is large in heavy gas. Therefore, the quantity, or number of small bubbles for heavy gas becomes much larger than that for light gas and E_G increases with increasing density of gas. E_G for this work was correlated by Eqs. (2)-(7). E_G for Ozturk et al. (1987) was correlated by nearly the same equations (Eqs.(8)-(10)).

2) The number of bubbles which generated from single nozzles did not depend on density of gas because of small gas velocity.

3) The cross sectional area of maximum bubbles did not depend on kinds of gas in the 1cm x 30 cm bubble column.

4) E_G for 0.6M NaCl aqueous solution increased with increasing density of gas.

5) The quantity or number of small bubbles increased with height from the single nozzle.

6. NOMENCLATURE

A = constant [-]	H_L = height of clear liquid [m]	U_G = velocity of gas [m/s]
B = constant [-]	H_T = height of bubbling layer [m]	ρ_G = density of gas [kg/m^3]
C = constant [-]	n = number of holes [-]	ρ_L = density of liquid [kg/m^3]
D = constant [-]	N = number of bubbles [-]	μ_G = viscosity of gas [Pa·s]
d = diameter of hole [m]	p = pitch of holes [m]	μ_L = viscosity of liquid [Pa·s]
E_G = gas holdup [-]	Q_G = gas flow rate [m^3/min]	γ = suface tension of liquid [N/m]
h = height above gas sparger [m]	U = velocity [m/s]	

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