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Gas Holdup in Bubble Columns

(Effect of Liquid Properties)

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Experimental data on the fractional gas holdup in bubble columns were obtained with air and various liquids, and the effect of the liquid physical properties on the gas holdup was studied. The gas holdup was found to vary with the viscosity and surface tension of the liquid, and the superficial gas velocity. A new correlation for gas holdup was presented and shown to correlate the experimental data with an average deviation of 1.4%.

1. Introduction

Bubble columns are widely used in chemical industry as absorbers, strippers, and gas-liquid reactors. In recent years a number of works have been made on the gas holdup in bubble columns. However there is very limited information^{1,2,3)} in the literature concerning the effect of the liquid physical properties on the gas holdup.

Hughmark²⁾ has presented a correlation of the gas holdup which takes into account the effect of the liquid properties. He showed that his own and other investigators' data on the fractional gas holdup ϵ_G can be correlated successfully by using the term $u_G[(1/\rho_L)(72/\sigma)]^{1/3}$, where u_G is the superficial gas velocity and ρ_L and σ are the density and surface tension of the liquid. The final correlation has been given as a curve on log-log coordinates, which can be represented by the following expression

$$\epsilon_G = \frac{1}{2 + (0.35/u_G)[(\rho_L/1)(\sigma/72)]^{1/3}} \quad (1)$$

over the range of the values of $u_G[(1/\rho_L)(72/\sigma)]^{1/3}$ from 0.003 to 0.045 m/sec.

Akita and Yoshida³⁾ have recently measured the gas holdup for various liquid-gas systems and analysed the experimental data by means of dimensional analysis. The equation representing the final correlation is

$$\frac{\epsilon_G}{(1-\epsilon_G)^4} = 0.20 \left(\frac{D_T^2 \rho_L g}{\sigma} \right)^{1/8} \left(\frac{D_T^3 \rho_L^2 g}{\mu_L^2} \right)^{1/12} \frac{u_G}{\sqrt{D_T g}} \quad (2)$$

where D_T is the column diameter, μ_L is the viscosity of the liquid, and g is the gravitational constant. This equation is valid in the range of the values of $(D_T^2 \rho_L g / \sigma)^{1/8} (D_T^3 \rho_L^2 g / \mu_L^2)^{1/12} (u_G / \sqrt{D_T g})$ from 0.1 to 5.0.

In the present work the values of fractional gas holdup in two bubble columns of different diameters were measured with air and various liquids, and the effect of the

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liquid properties on the gas holdup was studied.

2. Experimental

Fig. 1 shows a schematic diagram of the experimental apparatus. The bubble columns used were constructed of transparent vinyl chloride resin, and their inside diameters were 19.0cm and 10.0cm. The 19-cm column was 240cm in height and twelve pressure taps were drilled in the wall at 20cm intervals. The 10-cm column

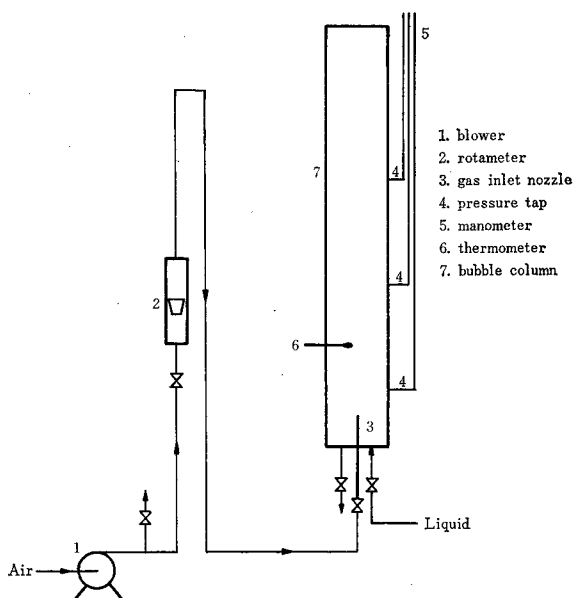


Fig. 1. Schematic diagram of experimental apparatus

was 100cm in height and three pressure taps were drilled in the wall at 25cm intervals.

The gas spargers used were of single gas nozzle type, and three nozzles of 1.31, 2.06 and 3.62cm I. D. were used for 19-cm column and two nozzles of 0.9 and 1.30cm I. D. were used for 10-cm column. The nozzle was located 5cm above the bottom plate of the column.

The bubble columns were operated continuously with respect to the gas flow and batch-to-batch with respect to liquids. The gas used was always air, which was fed from the gas nozzle to the bottom of the column after being metered with rotameters. The superficial gas velocity u_G ranged from 0.07 to 0.338 m/sec. Liquids used were water and various kinds of aqueous solutions, and are listed in Table 1.

Values of the gas holdup were calculated from

$$\varepsilon_G = 1 - \frac{g_c}{\rho_L g} \left(\frac{dP}{dZ} \right) \quad (3)$$

where g_c is the gravitational conversion factor and dP/dZ is the slope of the curve representing the axial distribution of the static pressure in the column. Fig. 2 is an example of the static pressure distribution curves obtained at several gas velocities

Table 1. Liquids used and their physical properties

Liquid	Temp. °C	Density g/cm ³	Viscosity c. P.	Surface tension dyne/cm
Water	20	1.000	1.00	72.0
Water	35	0.994	0.70	69.2
8.0 wt% aq. methanol sol.	16	0.985	1.50	59.5
15.0 wt% aq. methanol sol.	16	0.974	1.63	51.0
53.0 wt% aq. methanol sol.	15	0.911	1.70	37.5
28.6 wt% aq. cane sugar sol.	35	1.116	2.06	70.6
30.6 wt% aq. cane sugar sol.	16	1.137	3.65	73.5
44.5 wt% aq. cane sugar sol.	16	1.221	13.80	74.8
50.0 wt% aq. cane sugar sol.	35	1.235	10.90	71.8
14.5 wt% aq. NaCl sol.	16	1.114	1.48	77.2
24.2 wt% aq. NaCl sol.	16	1.186	1.93	79.5
29.1 wt% aq. CaCl ₂ sol.	16	1.277	3.67	86.0
36.5 wt% aq. CaCl ₂ sol.	16	1.362	7.11	91.5

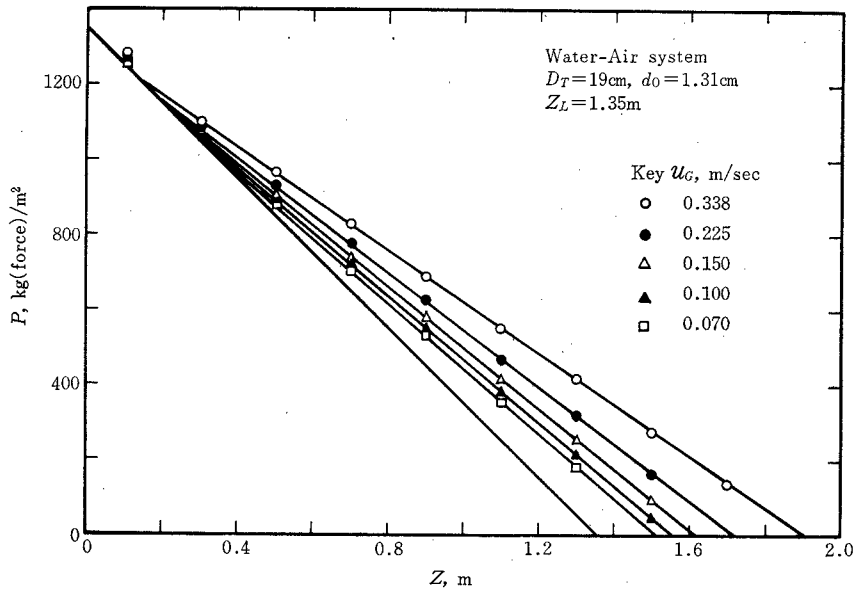


Fig. 2. Axial distribution of static pressure

with the water-air system. The data points fall on the straight lines, indicating that the gas holdup is constant throughout the column except for the lower section close to the gas nozzle, where the gas holdup is low because of the large gas bubbles and the jetting gas stream.

3. Results and Discussion

Experimental results obtained in the present work are shown in Figs. 3, 4, 6 and 8, where the values of fractional gas holdup ϵ_G are plotted on log-log coordinates

against the superficial gas velocity u_G . It can be seen from these figures that the gas holdup is proportional to the 0.47 power of the superficial gas velocity.

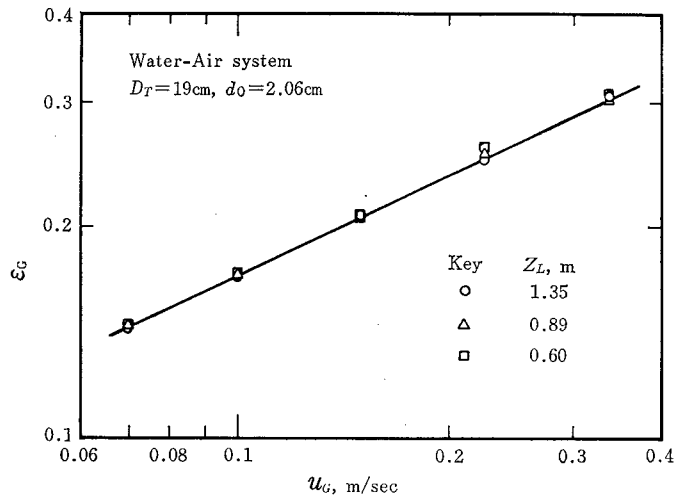


Fig. 3. Gas holdup for water-air system in 19-cm column (Effect of liquid height)

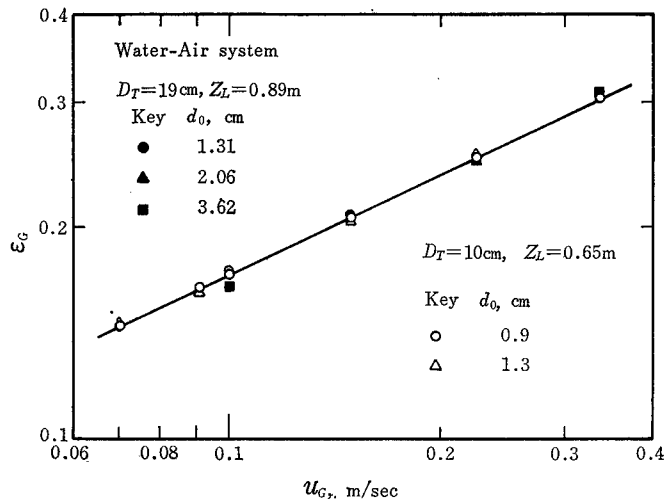


Fig. 4. Gas holdup for water-air system in 10-cm and 19-cm columns (Effects of column and nozzle diameters)

Fig. 3 presents the values of the gas holdup for the water-air system obtained with three different liquid heights in 19-cm column. As shown in this figure, the gas holdup ϵ_G is independent of the liquid height Z_L . The straight line through the data points is represented by the equation:

$$\epsilon_G = 0.505 u_G^{0.47} \quad (4)$$

Fig. 4 presents the values of ϵ_G for the water-air system obtained with the gas

nozzles of various diameters in 10-cm and 19-cm columns. The solid line represents Eq. (4). Fig. 4 shows that neither the nozzle diameter nor the column diameter affects the gas holdup.

In Fig. 5, the present data on the gas holdup for the water-air system are compared with the previous data^{1,3,4}) obtained by using the single nozzle as gas sparger. Data of Yoshida and Akita¹⁾ are about 20% lower than the data obtained in this work. However the data of Akita and Yoshida³⁾ and of Miyauchi and Shyu⁴⁾ agree well with the present data.

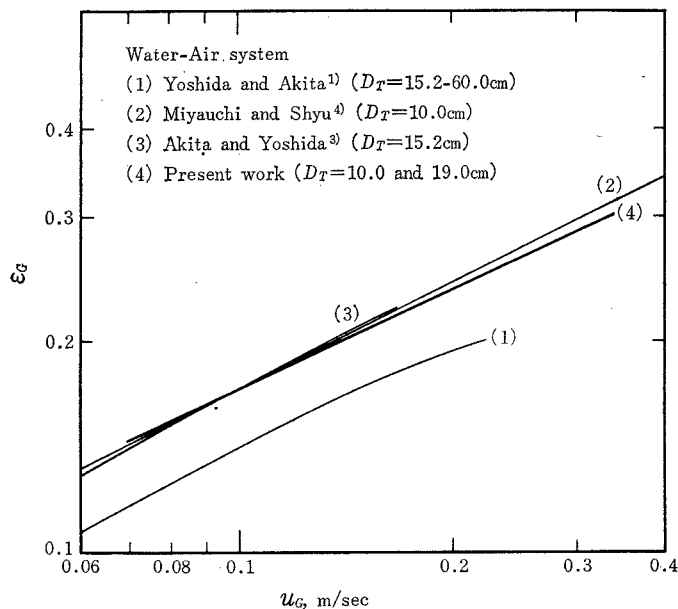


Fig. 5. Comparison of present and previous data on gas holdup for water-air system

Fig. 6 presents the data for the aqueous methanol solution-air system. This figure shows that the gas holdup increases considerably with increasing methanol concentration of the solution. The surface tension and viscosity of the solution including water ranged from 72.0 to 37.5 dyne/cm and from 1.0 to 1.7 c. P., respectively. As will be shown later, the effect of the liquid viscosity on the gas holdup is very little, then this effect is masked by experimental errors in the range of viscosities covered in these runs. Therefore, the variation in ϵ_g with methanol concentration seen in Fig. 6 may be attributed to the change in surface tension of the solution. Fig. 7 shows the values of ϵ_g read from Fig. 6 at a constant superficial gas velocity of 0.08 m/sec on log-log coordinates as a function of the surface tension σ . This indicates that the value of ϵ_g varies inversely as the $2/3$ power of the surface tension. This effect of surface tension is somewhat different from those found in the works of Hughmark²⁾ and of Akita and Yoshida³⁾. In the range of superficial gas velocities covered in the present work, Hughmark's correlation shows that the gas holdup is proportional to the surface

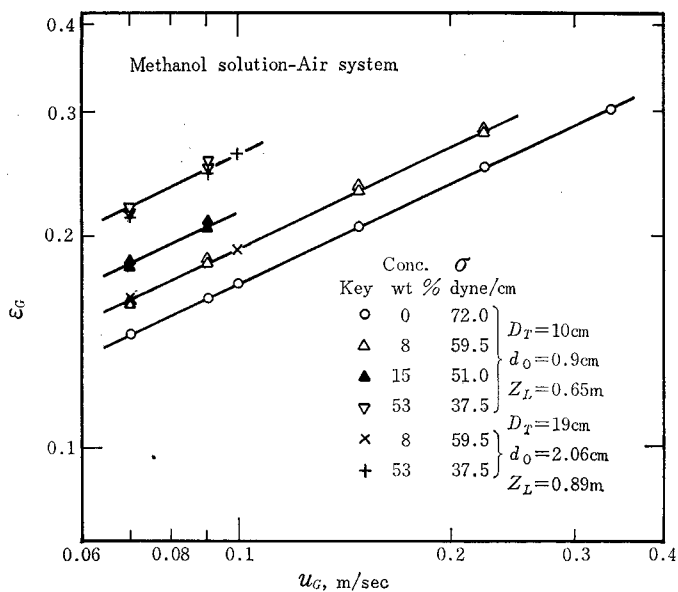


Fig. 6. Gas holdup for aqueous methanol solution-air system

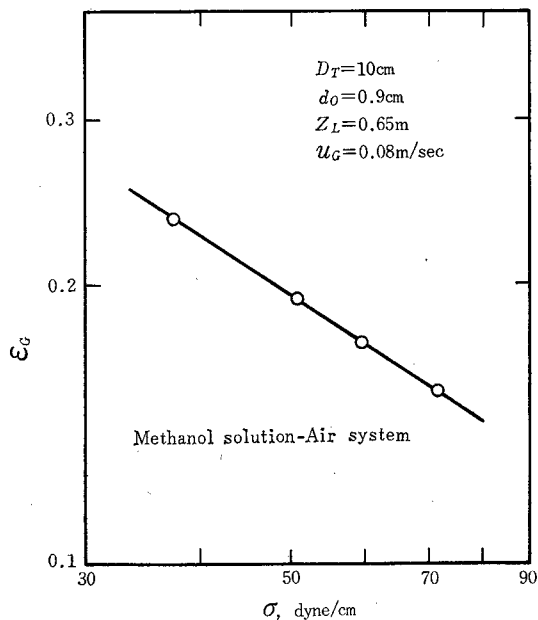


Fig. 7. Effect of surface tension on gas holdup

tension to a power which varies from -0.24 to -0.11 with an increase in the superficial gas velocity, while Akita and Yoshida have reported that the gas holdup varies as the surface tension to a power ranging between -0.08 and -0.05 .

In Fig. 8, data obtained with the aqueous cane sugar solution-air system are shown. As can be seen in this figure, the gas holdup decreases with increasing cane

sugar concentration. The viscosity of the solution including water varies from 0.07 to 13.8 c. P. covering about a 20-fold range, but the surface tension changes slightly from 69.2 to 74.8 dyne/cm, the variation in surface tension being less than 8%.

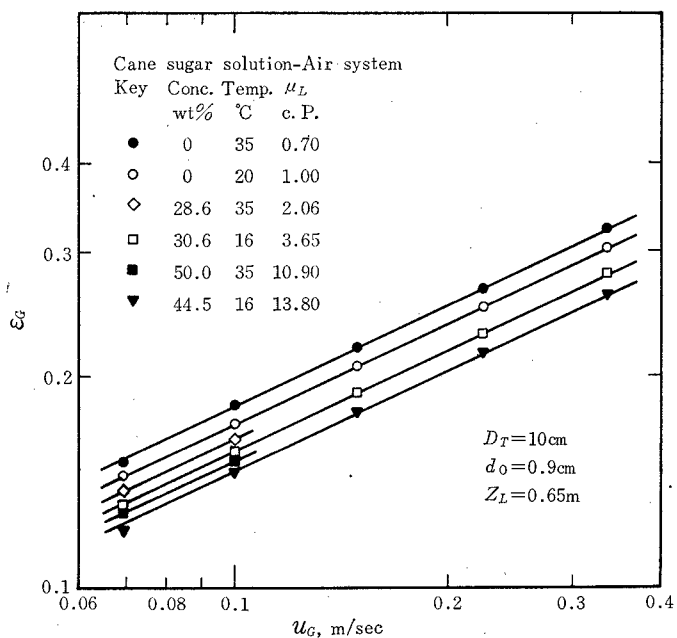


Fig. 8. Gas holdup for aqueous cane sugar solution-air system

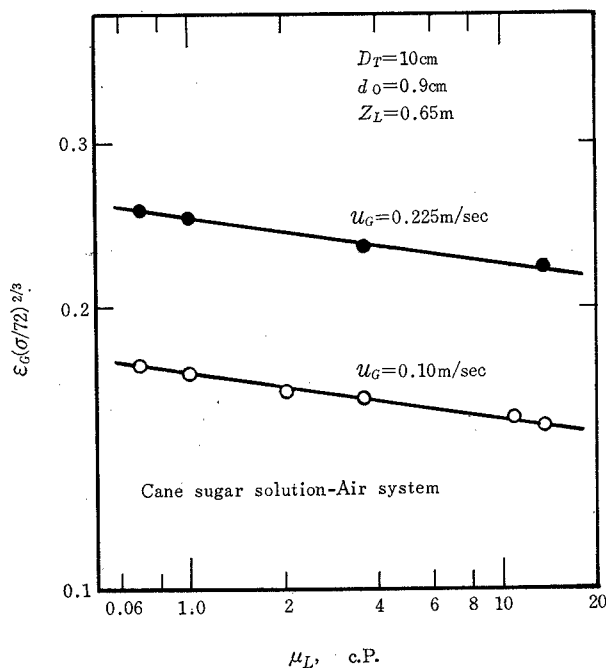


Fig. 9. Effect of liquid viscosity on gas holdup

Therefore, the vertical difference among the straight lines in Fig. 8 may be mainly due to the difference in the viscosity of the solution. Fig. 9 shows the values of the product $\epsilon_G(\sigma/72)^{2/3}$ at two superficial gas velocities of 0.10 and 0.225 m/sec plotted against liquid viscosity μ_L on log-log coordinates. Data points for each gas velocity fall on a straight line with a slope of -0.05 . This indicates that the value of ϵ_G is proportional to the -0.05 power of the liquid viscosity. Akita and Yoshida³⁾ found that the gas holdup varies as the viscosity to a power ranging from -0.10 to -0.06 in the range of superficial gas velocities covered in this work. Hughmark²⁾ has reported that the gas holdup is independent of the liquid viscosity.

From the results described above, the following equation correlating the experimental data was obtained:

$$\epsilon_G = 0.505u_G^{0.47}(72/\sigma)^{2/3}(1/\mu_L)^{0.05} \quad (5)$$

This equation reduces to Eq. (4) obtained for the water-air system at 20°C, when the viscosity and surface tension of the liquid are equal to 1.0 c. P. and 72.0 dyne/cm, respectively. Fig. 10 shows the comparison of the values of ϵ_G obtained in the present work with those calculated from Eq. (5). The observed values are in good agreement with the calculated values with an average deviation of 1.4% and a maximum deviation of 3.6%.

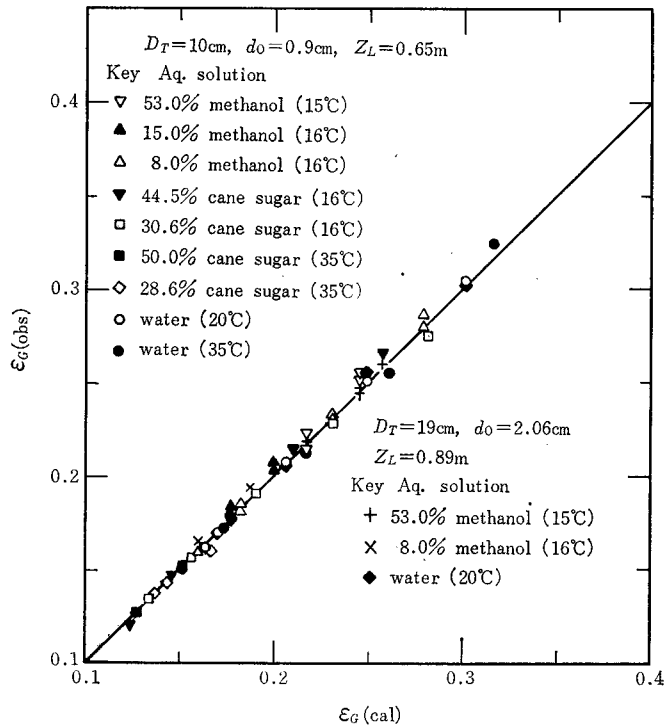


Fig. 10. Comparison of experimental and calculated gas holdup

In Figs. 11 and 12, the present data are plotted according to the methods of correlation proposed by Hughmark and by Akita and Yoshida, respectively. As can be

seen in these figures, the agreement between the experimental data and the proposed correlations is poor, the average deviations being 11.7% for Hughmark's correlation and 20.4% for Akita and Yoshida's correlation.

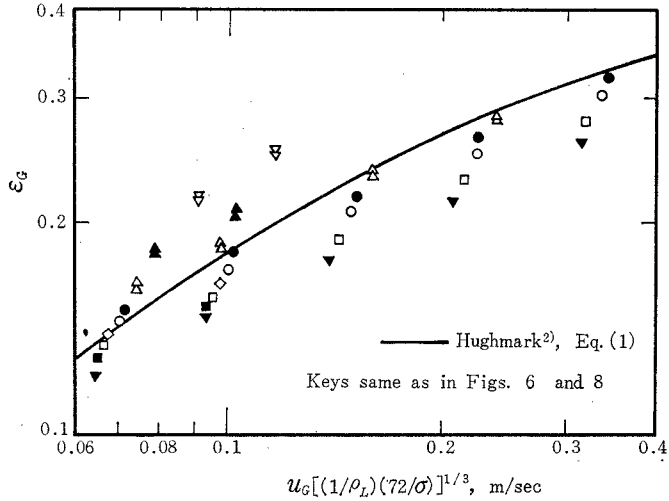


Fig. 11. Hughmark's correlation of the present data on gas holdup

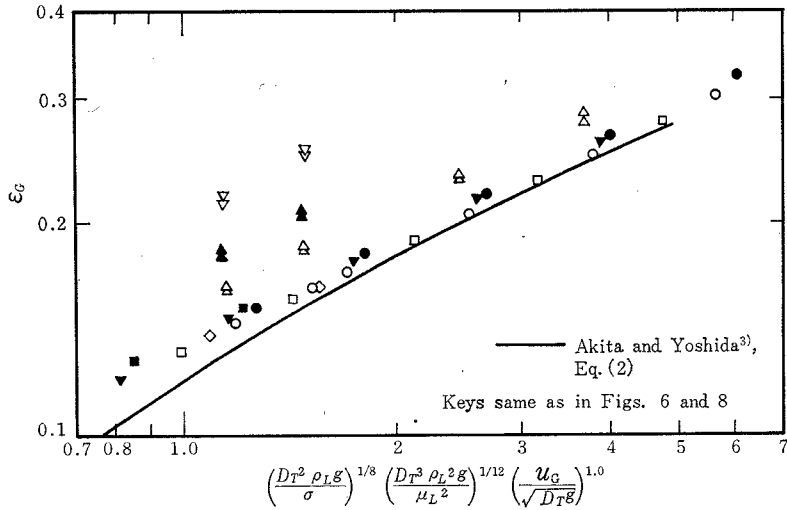


Fig. 12. Akita and Yoshida's correlation of the present data on gas holdup

Fig. 13 presents the data on the gas holdup in aqueous solutions of electrolytes. In this figure, the values of the gas holdup of air in sodium chloride and calcium chloride solutions are shown as a log-log plot of $\epsilon_g(\sigma/72)^{2/3}(\mu_L/1)^{0.05}$ vs. u_G , and compared with Eq. (5) which was obtained for the gas holdup in non-electrolyte solutions. It can be seen that the electrolyte solutions give the gas holdup considerably larger than that in non-electrolyte solutions probably because of the occurrence of smaller

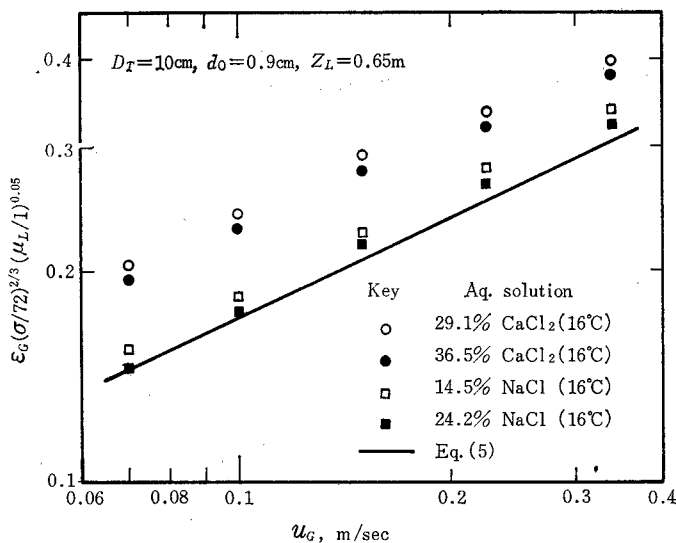


Fig. 13. Gas holdup for aqueous electrolyte solution-air systems

gas bubbles due to the electrostatic potential at the gas-liquid interface. Similar observations have been reported by Yoshida and Akita¹⁾ and other previous investigators. Akita and Yoshida³⁾ have suggested that for the gas holdup in electrolyte solutions the values of ϵ_g predicted from the correlation obtained for the case of non-electrolyte solutions should be increased by 25%. Fig. 13 indicates that the gas holdup in electrolyte solutions depends upon the nature of electrolyte and cannot be correlated by such a simple correlation as proposed by Akita and Yoshida.

Notation

D_T : column diameter, cm or m
 d_o : diameter of gas inlet nozzle, cm
 g : gravitational constant, cm/sec²
 g_e : gravitational conversion factor, g cm/g(force) sec²
 P : static pressure in the column, kg(force)/m²
 u_g : superficial gas velocity, m/sec or cm/sec
 Z : height above the bottom of the column, m
 Z_L : height of clear liquid, m

Greek letters

ϵ_g : fractional gas holdup, —
 ρ_L : density of liquid, g/cm³
 μ_L : viscosity of liquid, c. P. or g/cm sec
 σ : surface tension of liquid, dyne/cm or g/sec²

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