GAS HOLDUP IN BUBBLE COLUMNS

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Introduction

Usually gas holdup in a bubble column increases with gas feed rate, but sometimes it passes through a maximum. Though gas holdup is influenced by many factors, such as superficial gas velocity, physical properties of liquid, and the type of gas distributor[1-5], the condition necessary for the appearance of maximum gas holdup remains obscure. It seems to be defined mainly by the properties of the gas distributor, but their effects on gas holdup have never been discussed in detail except by Freedman *et al.*[2].

Here the authors measured and analyzed gas holdup in three- and two-dimensional bubble columns, and obtained some information about the factors determining the maximum gas holdup.

Experimental

The two-dimensional column was 107 cm high with and without two or four interwalls, and the cross section was a rectangle of 30 cm × 1 cm. The three-dimensional column was an acrylic resin tube of 10.2 cm I.D. and 200 cm length. Gas distributors were perforated plates made of brass (0.7 mm thick). Holes of the perforated plate were arranged at the assigned pitch triangularly in the three-dimensional column and in a line along the longer center line of the plate in the two-dimensional column.

The operational conditions were as follows:

feed gas: air
superficial gas velocity: ~30 cm/sec
liquid: tap water

The average gas holdup in a bubble column was measured by the usual method. The properties of perforated plates used are described in **Table 1**.

Results and Discussion

Figures 1 and **2** show some examples of the observed gas holdup ε_g, in three- and two-dimensional columns. When the hole diameter of the distributor was small, the maximum of gas holdup, $\varepsilon_{g\max}$, was observed, though it was very broad in the three-dimensional column. With increasing hole diameter $\varepsilon_{g\max}$ dissapears gradually and the relation ε_g vs. V_g approached a definite curve, independent of n, d, p and F_A. It was found that the altimate curve of ε_g is dependent only on V_g and D_T and is expressed by the following equations:

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Table 1 The properties of perforated plates

	d [cm]	n [—]	p [cm]	F_A [%]
A	0.02–0.35	1–334	~6.0	0.06–100
B	0.03–0.2	3–113	0.5–1.0	3.33–93.3

Note: A and B refer to the plates of the three-dimensional and two-dimensional columns, respectively.

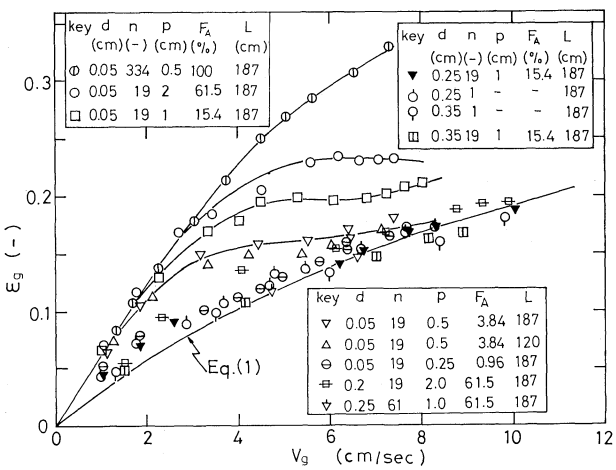


Fig. 1 ε_g vs. V_g in the three-dimensional bubble column of D_T = 10.2 cm

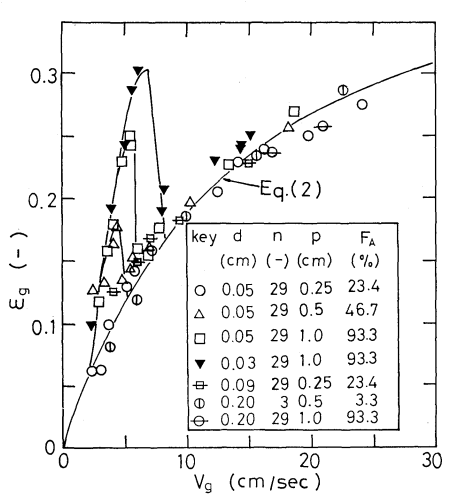


Fig. 2 ε_g vs. V_g in the two-dimensional bubble column

for three-dimensional columns,

$$\varepsilon_g = V_g/(2.2V_g + 0.3\sqrt{gD_T}) \quad (1)$$

and for two-dimensional columns,

$$\varepsilon_g = V_g/(2.2V_g + 0.4\sqrt{gD_e}) \quad (2)$$

Here D_e is the equivalent column diameter, whose cross-sectional area is equivalent to that of the two-dimensional column.

Gas holdup in a column with a distributor having a hole diameter larger than 0.2 cm, or having a pitch less than 0.25 cm, is expressed thoroughly by these equations. For smaller hole diameters ε_g's depend on n, p, d and F_A, as shown in Figs. 1 and 2. However, the height, L, has little effect on ε_g (compare the cases of L=187 cm and 120 cm with d=0.05 cm, n=19, p=0.5 cm and F_A=3.84% in Fig. 1). ε_g's in both cases are nearly the same and have a very broad maximum, or a broad horizontal zone, at the same gas-rate condition. These results suggest that the production of $\varepsilon_{g\max}$ is determined mainly by the entrance condition of the column, i.e. the type of distributors.

It was known that if D_e' were used as D_e in Eq. (2), ε_g in the two-dimensional column with two or four interwalls could be expressed well by Eq. (2), too. Here D_e' is the modified equivalent column diameter whose cross-sectional area is equivalent to that divided by interwalls in the two-dimensional column.

$\varepsilon_{g\max}$'s observed here and in the previous study[4] are correlated with the parameters of gas distributors, n, d [cm], p [cm] and D_T [cm], and Eq. (3) was derived for three-dimensional columns, though the right-hand side of the equation is not non-dimensional.

$$\varepsilon_{g\max} = 0.12(np/dD_T^2)^{0.29} \quad (3)$$

For the two-dimensional column a similar relation was obtained, and it is interesting that if the equivalent column diameter D_e is used, $\varepsilon_{g\max}$'s of the column are correlated well by Eq. (3) as is shown in **Fig. 3**.

Figures 4 and **5** are examples of the visual observation of the two-dimensional bubble column. Fig. 4 shows bubble dispersion in the column at the low condition of V_g, and Fig. 5 shows bubble dispersion at the high condition. Such visual observations reveal that bubble dispersion changes appreciably across the state of $\varepsilon_{g\max}$. For lower gas rate, small nearly uniform bubbles were observed in the column, but, for larger gas flow rate, large coalesced bubbles and vigorous mixing by them were observed.

In a two-dimensional column, due to the narrow wall effect coalesced bubbles grow rapidly with increasing gas feed rate, and this may be the reason why the sharp $\varepsilon_{g\max}$ was observed in comparison with the case of the three-dimensional column.

As $\varepsilon_{g\max}$ is determined only by the parameters of a distributor, coalescences of bubbles will happen mainly just above the distributor. The large bubbles formed disturb liquid, and with increasing gas feed rate a broad distribution of bubble size will be established. Such a distribution is independent of the properties of a distributor, and Eqs. (1) and (2) express the gas holdup in such states of bubble columns.

These results are consistent with the analysis of bubble columns in the previous paper[4].

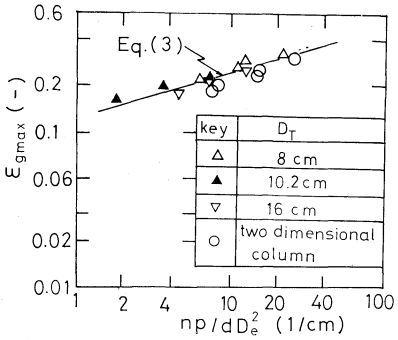


Fig. 3 ε_{gmax} vs. np/dD_e^2 in two- and three-dimensional columns

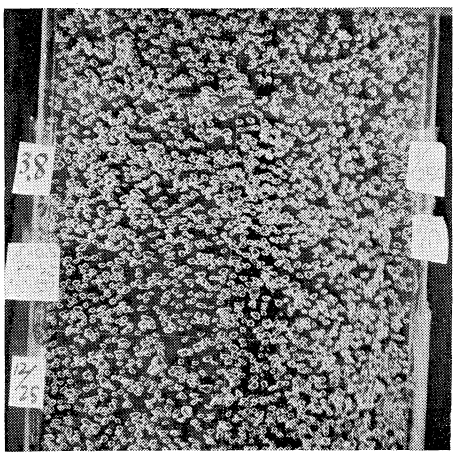
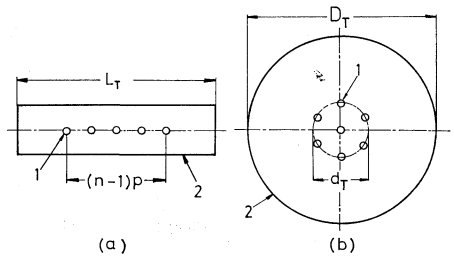


Fig. 4 Bubble dispersion in the two-dimensional column at V_g=3.8 cm/sec, d=0.05 cm, n=57 and p=0.5 cm

Fig. 5 Bubble dispersion in the two-dimensional column at V_g=8.4 cm/sec, d=0.05 cm, n=57 and p=0.5 cm



1: hole 2: gas distributor

Fig. 6 Schematic diagram of gas distributors (a) and (b) refer to the plates of the two- and the three-dimensional columns, respectively

Appendix

F_A[%] was calcultated by the following equations (see Fig. A): for two-dimensional column,

$$F_A=(n-1)p/L_T\times 100 \qquad \text{(A-1)}$$

and for three-dimensional column,

(1) if n was larger than 1,

$$F_A=W_H/W_T\times 100 \qquad \text{(A-2)}$$

(2) if n was equal to 1,

$$F_A=\pi d^2/4W_T\times 100 \qquad \text{(A-3)}$$

Nomenclature

D_e	=	equivalent column diameter whose cross sectional area is equivalent to that of two-dimensional column	[cm]
D'_e	=	modified equivalent column diameter whose cross sectional area is equivalent to that divided by interwalls in the two-dimensional column	[cm]
d	=	diameter of holes	[cm]
d_T	=	diameter of the outermost shell which contains holes on gas distributor (see Fig. A)	[cm]
F_A	=	the fraction of the base which was aerated on bubble column (see Appendix)	[%]
L	=	height of bed	[cm]
L_T	=	length of longer axis of cross-sectional rectangle of two-dimensional column (see Fig. A)	[cm]
n	=	number of holes	[—]
p	=	pitch of holes	[cm]
V_g	=	gas superficial velocity	[cm/sec]
W_H	=	$\pi d_T^2/4$	[cm^2]
W_T	=	$\pi D_T^2/4$	[cm^2]
ε_g	=	average gas holdup	[—]
$\varepsilon_{g\max}$	=	maximum of ε_g	[—]

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SHAPE OF DROPS IN NON-NEWTONIAN FLUID SYSTEMS

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This work is an extension of an experimental study in which motion and mass transfer of fluid spheres in non-Newtonian fluid systems were investigated[2]. Motion of deformed drops in Newtonian fluid systems has been studied extensively. However, references for non-Newtonian fluid systems are few. The shape of drops in non-Newtonian fluid systems is experimentally investigated.

Experimental

The shape of drops is measured from still photographs. The experimentally measured physical properties of the liquid pairs investigated are presented in **Table 1**. Experimental systems are mutually saturated by mixing the phases together prior to the study and measurement of properties.

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Results and Discussion

The shape of non-Newtonian drops moving through Newtonian fluids is presented in **Fig. 1**. We define the eccentricity of the drop as the ratio of vertical diameter to horizontal diameter. Drop shapes observed vary from spherical to oblate spheroidal with increasing drop size. The eccentricity of the oblate spheroidal non-Newtonian drops in Newtonian fluids decreases with increasing Weber number.

For Newtonian fluid systems, Wellek *et al.*[5] obtained the following correlation:

$$\varepsilon=(1.0+0.091We^{0.95})^{-1} \qquad (1)$$

Experimental data do not agree with this correla-