SUPERFICIAL RATE OF BUBBLE BREAKUP IN A BUBBLE COLUMN

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Introduction

Recently, bubble columns have attracted much attention as gas-liquid reactors and bio-reactors because of their simplicity and advantages. The coalescence and breakup of bubbles play an important role in determining bubble size, interfacial area and rise velocity of bubbles in the column. So there have been many studies concerning the coalescence, breakup, size and size distributions of bubbles in columns¹⁻⁹⁾.

Otake *et al.*⁷⁾ and Miyahara *et al.*⁶⁾ have reported that bubbles coalesce into large bubbles just after formation at the gas sparger, that the average diameter of bubbles reaches a maximum at approximately a few centimeter above the gas sparger, that the average diameter decreases with increasing height h above the gas sparger because of breakup of bubbles and that the average diameter becomes nearly constant at $h > 0.4$ m. But their results seem to be contrary to the observations made in present study.

In this paper, the frequencies of bubble passages were experimentally measured in a bubble column and the results were analysed and correlated.

1. Experimental

Figure 1 shows a schematic diagram of the experimental apparatus. The bubble column used was made of transparent acrylic resin. The cross section was a rectangle measuring $0.05 \text{ m} \times 0.1 \text{ m}$ and the height H was 1.1 m . Gas spargers were perforated plates made of polyvinyl chloride resin. The thickness of the perforated plates was 0.005 m . Details of the gas spargers used are listed in **Table 1**. Two plane mirrors were set on both sides of the bubble column to discern overlapping of bubbles (see D in Fig.1).

The liquid used was tap water at room temperature. During each run, liquid was neither fed nor discharged. Air was used as a gas. The height of clear liquid and experimental conditions were listed in **Table 1**.

Three images of the bubbles, one from the front and the others from both sides of the bubble column, were recorded on individual frames of video tape with a frequency of 30 Hz using a video camera and the passage frequency of bubbles at a given height h was measured on a TV monitor for 30 sec at low gas superficial velocity V_g

and for 10 sec at high V_g . The number of bubbles counted amounted to $60\text{--}2000$ for each run. The volume mean diameter d_b of bubbles was calculated from the gas flow rate and passage frequency. The minimum diameter of bubbles counted was $1 \times 10^{-3} \text{ m}$.

2. Results and Discussion

Figure 2 shows the effects of the height h above the gas distributor on the passage frequency N of bubbles. It is clear from this figure that N increases with increasing h and V_g and that bubble breakup is dominant in the bubble column. The following relation was thus obtained.

$$N = \alpha h + N_0 \quad (1)$$

where N_0 is N at $h = 0 \text{ m}$ and α is the rate of change of frequency of bubble passage.

Figure 3 shows the effect of V_g on α . From Fig. 3, it is clear that α increases very much with V_g and that α does not depend upon the conditions of the gas spargers. α was correlated by the following equation as shown in Fig.3.

$$\alpha = 79.2 V_g^{1.6} \quad (2)$$

which is applicable in $V_g = 6.7 \times 10^{-4} \text{--} 1.05 \times 10^{-2} \text{ m/s}$ (see **Table 1**).

The superficial rate of bubble breakup r_b was defined by the following equation.

$$r_b = \frac{1}{N} \frac{dN}{dh} \quad (3)$$

where r_b means the rate of bubble breakup minus the rate of bubble coalescence.

Figure 4 shows the axial distribution of r_b at $d = 2 \times 10^{-3} \text{ m}$ and $n=1$. It is clear from this figure that r_b decreases with increasing h and increases with increasing V_g . The reason why r_b decreases with increasing h may be because the bubbles produced by the breakup of larger bubbles are small and do not break up again. The reason why r_b increases with V_g may be because the intensity of the turbulence increases with V_g in the bubble column. r_b was expressed by the following equations.

$$r_b = r_{b0} \times 10^{-\beta h} \quad (4)$$

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Fig. 1 Schematic diagram of experimental apparatus
A = gas chamber, B = gas sparger, C = bubble column,
D = plane mirror

Table 1. Details of gas spargers used and experimental conditions

No.	d [m]	n [-]	p [m]	H [m]	N_c [-]	$V_g \times 100$ [m/s]
1	0.001	9	0.0025	0.45	6.3	0.067-0.24
2	0.001	9	0.01	0.90	6.3	0.102-0.36
3	0.002	1	-	0.90	14.4	0.069-0.41
4	0.002	9	0.01	0.90	1.6	0.330-1.05
5	0.004	1	-	0.90	3.7	0.067-0.92
6	0.008	1	-	0.45	0.9	0.067-0.33

$$r_{b0} = 1000V_g \quad (5)$$

$$\beta = 37.7V_g^{0.7} \quad (6)$$

where r_{b0} is r_b at $h = 0$ m and β is a function of V_g . Equations (4)-(6) are applicable in the range $V_g = 6.7 \times 10^{-4}$ - 1.05×10^{-2} m/s (see Table 1). Solid lines in Fig. 4 show r_b values calculated by Eqs. (4)-(6). It is clear from this figure that Eqs. (4)-(6) are a rough correlation of data for r_b .

Figure. 5 shows the axial distribution of volume mean diameter d_b of bubbles. It is clear from this figure that d_b decreases with h , and that d_b is expressed by the following equation.

$$d_b = d_{b0} \times 10^{-mh} \quad (7)$$

$$d_{b0} = 0.15 d_1^{0.3} V_g^{0.144} \quad (8)$$

$$m = 0.123 d^{-0.245} (100V_g)^\gamma \quad (9)$$

$$\gamma = 0.0142 d^{-0.640} \quad (10)$$

Fig. 2 Axial distribution of passage frequency N of bubbles at $d = 2 \times 10^{-2}$ m, $n = 9$, $p = 1 \times 10^{-3}$ m and $H_L = 0.90$ m

Fig. 3 Effect of V_g on α

Fig. 4 Effect of h on r_b at $d = 2 \times 10^{-3}$ m and $n = 1$
Solid lines mean r_b values calculated by Eqs. (4)-(6)

where d_{b0} is d_b at $h = 0$ m and m is the slope of the straight lines in Fig. 5. The range of parameters is listed in Table 1. d_1 is the diameter of holes in the gas sparger and is defined by the following equations:

$$d_1 = d \quad \text{for } d \leq 4 \times 10^{-3} \text{ m} \quad (11)$$

$$d_1 = 4 \times 10^{-3} \quad \text{for } d > 4 \times 10^{-3} \text{ m} \quad (12)$$

Straight lines in Fig. 5 show $d_{b,cal}$ values calculated by Eqs. (7)-(12). It is clear from Fig. 5 that Eqs. (7)-(12) show a good agreement with the experimental results.

3. Comparison between Results of This Work and The Previous Works

3.1 Volume mean diameter of bubbles

Figure. 6 shows the comparison between the results of this work and the correlations of the previous works for volume mean diameter d_b of bubbles at $h = 0.4$ m. It is clear from this figure that d_b at $d = 1 \times 10^{-3}$ m and $d = 2 \times 10^{-3}$ m is nearly equal to the correlations of Koide *et al.*³⁾, and Miyahara *et al.*⁵⁾ but that d_b at $d = 4 \times 10^{-3}$ m and $d = 8 \times 10^{-3}$ m are less than their correlations and nearly equal to the correlation of Tadaki *et al.*^{8,9)}. In particular, d_b at $N_w > 16$ shows a good agreement with the correlation of Tadaki *et al.*^{8,9)}.

3.2 Axial distribution of bubble diameter

Otake *et al.*⁷⁾ and Miyahara *et al.*⁶⁾ reported that bubbles coalesce with each other, forming large bubbles just after formation at the gas sparger, that d_b becomes maximum at about a few centimeters above the gas sparger because of the increase in rate of breakup of bubbles and the decrease in rate of coalescence of bubbles with increasing h and that d_b becomes nearly constant at

Fig. 5 Axial distribution of bubble diameter d_b at $d = 4 \times 10^{-3}$ m and $n = 1$. $d_{b,cal}$ means values calculated by Eqs. (7)-(12)

Fig. 6 Comparison between d_b of this work and the correlations of previous works at $h = 0.4$ m
---values calculated by the correlations of Tadaki *et al.*^{8,9)}

$h > 0.4$ m. But in this work, d_b was found to decrease with increasing h as shown in Figs. 2 and 5. The reason for this discrepancy might be because small bubbles were not measured accurately at large h in their works.

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Nomenclature

d	= diameter of hole	[m]
d_b	= volume mean bubble diameter $\left[= \left(\frac{6Q}{\pi N} \right)^{1/3} \right]$	[m]
$d_{b,cal}$	= d_b value calculated by Eqs. (7)-(12)	[m]
d_{b0}	= d_b at $h = 0$	[m]
d_1	= diameter of holes defined by Eqs.(11) and (12)	[m]
F_r	= Froude number $(= u^2 / gd)$	[-]
g	= gravitational acceleration	[m/s ²]
h	= height above gas distributor	[m]
H	= height of bubble column	[m]
H_L	= height of clear liquid	[m]
m	= parameter defined by Eq.(9)	[1/s]
n	= number of holes	[-]
N	= frequency of bubble passage	[1/s]
N_0	= N at $h = 0$	[1/s]
N_c	= $V_c g \rho / \left[\frac{\pi}{4} d^2 n (P_O + P_{hs}) \right]$	[-]
N_w	= $W_d F_r^{1/2}$	[-]
p	= pitch of holes	[m]

P_o	=	barometric pressure	[Pa]
P_{hs}	=	hydrostatic pressure at gas sparger	[Pa]
Q	=	gas flow rate	[m ³ /s]
r_b	=	superficial rate of bubble breakup defined by Eq.(3)	[1/m]
r_{b0}	=	r_b at $h = 0$	[1/m]
u	=	gas velocity through holes	[m/s]
V_c	=	volume of gas chamber	[m ³]
V_g	=	superficial gas velocity	[m/s]
W_e	=	Weber number ($= \rho u^2 d / \sigma$)	[-]
α	=	rate of change of passage frequency of bubbles defined by Eq. (1)	[s ⁻¹ .m ⁻¹]
β	=	parameter defined by Eq. (6)	[1/m]
γ	=	parameter defined by Eq. (10)	[-]
ρ	=	density of liquid	[Kg/m ³]
σ	=	surface tension of liquid	[N.m ⁻¹]

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