FLUCTUATIONS IN HEIGHT OF BUBBLING LAYER IN A BUBBLE COLUMN

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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[1-6]. Gas holdup has been often measured from the difference in height of the bubbling and clear liquid layers[1-6]. The height of the bubbling layers in bubble columns always fluctuates and greatly influences the gas holdup. So it is important to know about the fluctuations in the height of the bubbling layer. But there have been no reports about the fluctuations in the height of the bubbling layers in bubble columns.

In this work, such fluctuations were experimentally observed and measured, and the results were analysed and correlated.

1. Experimental

The bubble columns used were made of transparent acrylic resin. The two-dimensional column was 120 cm high and the cross-section was a rectangle of 30 cm × 3 cm. The three-dimensional column was 16 cm I.D. and 240 cm high. Gas spargers used were perforated plates made of vinyl chloride resin. The thickness of the perforated plates was 5 mm. Details of the gas spargers used are listed in **Table 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 is listed in Table 1.

The fluctuations in height of the bubbling layer were recorded at a frequency of 30 Hz by a video camera. The maximum height h_u and the minimum height h_d of the bubbling layer at each frame were measured on a TV monitor for 96 frames of record for each run (see **Fig. 1**).

The two-dimensional column was used only to observe the mechanism of the fluctuations in height of the bubbling layer by using a video camera.

2. Results and Discussion

Fig. 2 shows the mechanism of the fluctuations of the height of the bubbling layer in the two-dimensional bubble column. Fig. 2 (a) shows that the surface of the bubbling layer becomes higher gradually as a bubble approaches the surface. Fig. 2 (b) shows that the surface becomes highest when the bubble reaches the surface of the bubbling layer. Fig. 2 (c) shows that the surface falls after the bubble breaks away. It is clear from Fig. 2 that the fluctuations in the height of the bubbling layer are caused by the bubbles.

Fig. 3 shows a sketch of one cycle of the fluctuations of the bubbling layer for every 1/30sec at $V_g = 15.4$ cm/s and $H_L = 25.6$ cm in the three-dimensional bubble column. In Fig. 3, the fluctuation starts at $t = 0$s and the surface rises at $t = 1/30$s. The surface becomes highest at $t = 2/30$s and falls a little at $t = 3/30$s. At $t = 6/30$s, the surface becomes highest again and falls at $t = 7/30$s. The fluctuations ends at $t = 8/30$s.

After bubbles approach the surface, they stay there for a short time. During their stay, they coalesce into large bubbles. So the surface rises remarkably, as shown at $t = 2/30$s and $t = 6/30$s in Fig. 3. Then the large bubbles break away and the surface falls as shown at $t = 8/30$s in Fig. 3. This may be the main reason for the fluctuations of the bubbling layers.

Fig. 4 shows an example of the fluctuations of the bubbling layer in the three-dimensional bubble column. It is clear from this figure that the surface always fluctuates.

Fig. 5 shows the effects of the superficial gas velocity V_g and the clear liquid height H_L on the standard deviation σ_u. It is clear from this figure that σ_u increases with V_g, and that σ_u doesn't depend on H_L. At large V_g values, large bubbles are generated from the gas distributor. Also, the number of bubbles approaching the surface increases and the bubbles coalesce near the surface. The fluctuations of the height of the bubbling layer thus become larger. This may be the reason why σ_u increases with V_g. The fluctuations of the bubbling layer are caused by the bubbles. So σ_u does not depend on H_L. σ_u was correlated by the following equation:

$$\sigma_u = 0.62\ V_g^{0.412} \qquad (1)$$

where the range of the parameters are $V_g = 1.7\text{-}18.0$ cm/s, $H_L = 25.6\text{-}107.1$ cm and $D_T = 16$ cm.

Fig. 6 shows the effects of Vg and H_L on $h_{max}/\bar{h}$ and

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Table 1. Details of gas spargers used and H_L

No.	Bubble column	d [mm]	n [-]	p [mm]	H_L [cm]
1	three-dimensional	1	193	2.5	25.6-107.1
2	two-dimensional	2	6	10	45

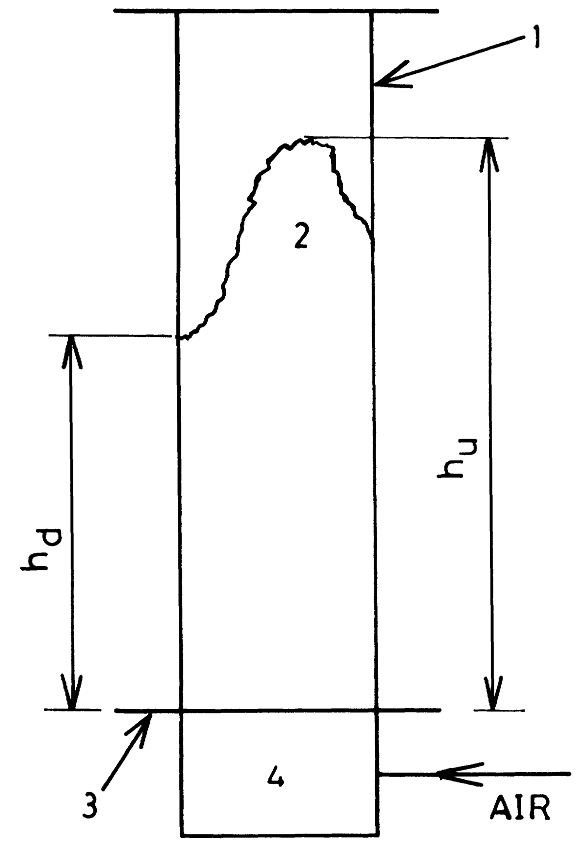

Fig. 1 Definition of h_u and h_d of bubbling layer
1. bubble column 2. bubbling layer 3. gas distributor 4. gas chamber

$h_{min}/\bar{h}$. It is clear that the relative fluctuations ($h_{max}/\bar{h}$ and $h_{min}/\bar{h}$) inceases with V_g and decreasing H_L.

Fig. 7 shows the effects of V_g and H_L on the frequency f of the fluctuations. It is clear from this figure that f does not depend on V_g or H_L. The reason why f does not depend on V_g may be that only the fluctuations of h_u and h_d were considered in this work, and that one cycle of the fluctuations takes a certain short time necessary for bubble growth and breakage near the surface as shown in Fig. 3. From Fig. 7 the following correlation was obtained:

$$\bar{f} = 3.5 \tag{2}$$

where the experimental conditions are the same as those in Eq. (1). Eq. (2) shows that the average time of one cycle of the fluctuations is about 0.3 sec.

It is concluded from the above experimental results that the effects of the fluctuations of the bubbling layer on gas holdup are large at small H_L and large V_g, but that the effects become smaller with increasing H_L and decreasing V_g.

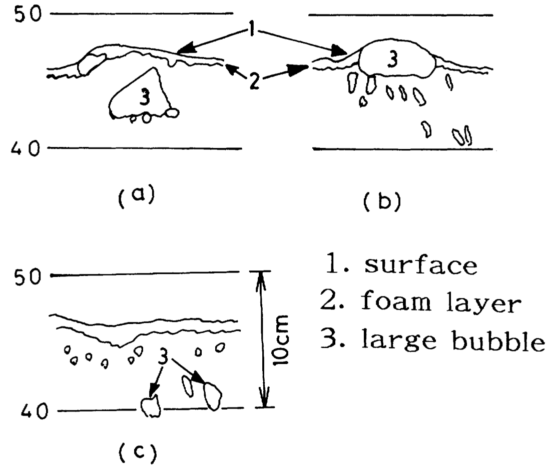

Fig. 2 Mechanism of fluctuations of bubbling layer in two-dimensional bubble column at $V_g = 0.93$ cm/s and $H_L = 45$ cm
(a) $t = 0$ sec. The bubbling layer became higher as a large bubble approached the surface of the layer.
(b) $t = 2/30$ sec. The bubbling layer became highest when the bubble reached the top of the layer.
(c) $t = 6/30$ sec. The bubbling layer fell after the bubble broke away.

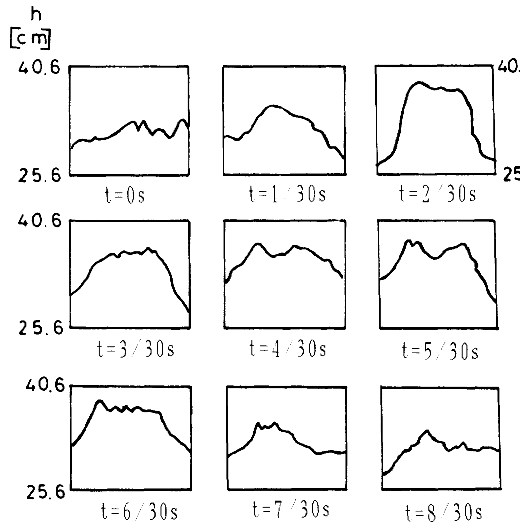

Fig. 3 A sketch of one cycle of fluctuations of bubbling layer for every 1/30 sec at $V_g = 15.4$ cm/s and $H_L = 25.6$ cm in three-dimensional bubble column

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Nomenclature

D_T	=	diameter of bubble column	[cm]
d	=	diameter of hole	[cm]
f	=	frequency of fluctuations in bubbling layer	[1/s]
$\bar{f}$	=	average of f	[1/s]
h	=	average height of bubbling layer (= $(h_u + h_d)/2$)	[cm]
$\bar{h}$	=	average of h	[cm]
h_d	=	minimum height of bubbling layer	[cm]

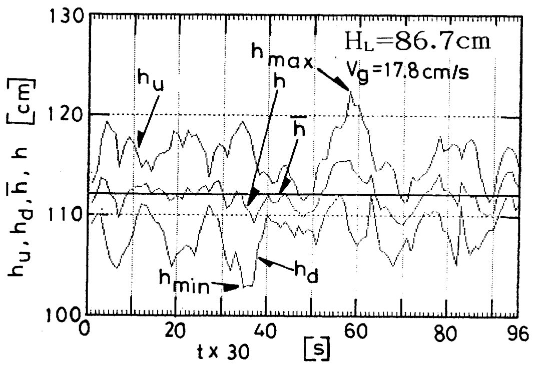

Fig. 4 An example of fluctuations of bubbling layer in three dimensional column at V_g = 17.8 cm/s and H_L = 86.7 cm, $\bar{h}$ = 112.0 cm

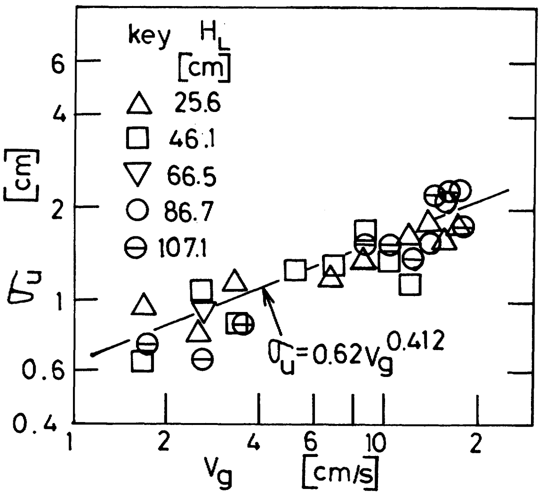

Fig. 5 Effect of V_g and H_L on σ_u

H_L	=	clear liquid height	[cm]
h_{max}	=	maximum of h_u	[cm]
h_{min}	=	minimum of h_d	[cm]
h_u	=	maximum height of bubbling layer	[cm]
$\bar{h}_u$	=	artrage of h_u	[cm]
N	=	number of data	[-]
n	=	number of holes	[-]
p	=	pitch of holes	[cm]
V_g	=	superficial gas velocity	[cm/s]

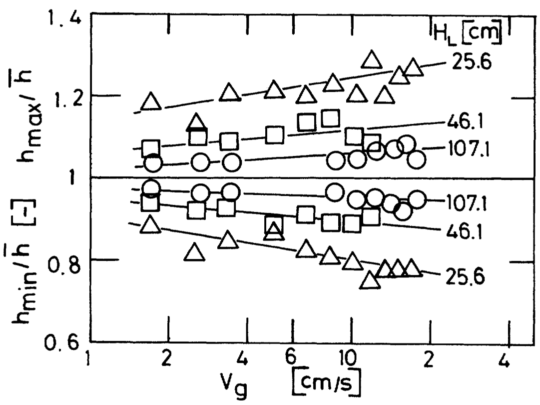

Fig. 6 Effect of V_g and H_L on $h_{max}/\bar{h}$ and $h_{min}/\bar{h}$

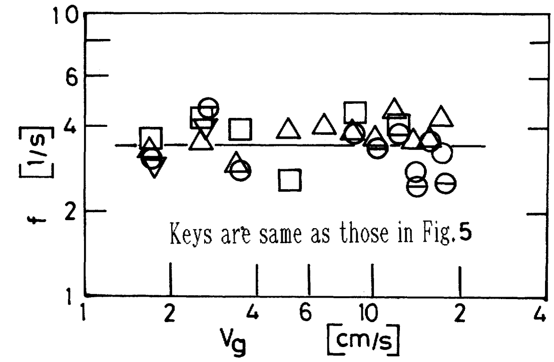

Fig. 7 Effect of V_g and H_L on f

σ_u = standard deviation of h_u $\left(=\left[\sum_{i=1}^{N}(h_{ui}-\bar{h}_u)^2/N\right]^{0.5}\right)$ [cm]

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