RELATIONSHIP BETWEEN GAS HOLDUP AND VOLUMETRIC MASS TRANSFER COEFFICIENT IN A BUBBLE COLUMN WITH SINGLE HOLE ORIFICES

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Introduction

Gas holdup ϕ and volumetric mass transfer coefficient $k_L a$ are very important parameters for mass transfer operations in a bubble column. In some investigations^{1,2)}, $k_L a$ has been empirically or semi-theoretically correlated as a function of ϕ .

With increasing u_{G0} , the flow regime in a bubble column usually changes from a uniform bubble flow to a heterogeneous bubble flow via a transition regime⁵⁾. It is a well-known fact that ϕ is a geometric property of a bubble. $k_L a$, however, is the dynamic property for mass transfer through the gas-liquid interface, because k_L is influenced by transformation, coalescence, division and other phenomena associated with bubbles even if ϕ or a are constant. Hence, the relationship between ϕ and $k_L a$ is very useful for analyzing the phenomenon for mass transfer.

In this paper, we related $k_L a$ as a function of ϕ in a bubble column with a single hole orifices and discussed the results obtained. When using this type of distributor, there is always a zone with few bubbles above the column bottom.

1. Experimental

The inner diameter and height of the bubble column used were 0.157 m and 2.03 m, respectively. Three gas distributors were used, all with different single hole orifices ($d = 0.002, 0.003$ and 0.005 m in diameter). In this study, estimates of ϕ and $k_L a$ were carried out using an air-water system. The liquid used was tap water at 303 K. Un-aerated liquid heights Z_0 were 0.51, 1.0 and 1.15 m, respectively.

To measure the static pressure in the bubble column, fifteen pressure taps with hole diameters of 1 mm were inserted into the column and were connected to glass manometer tubes. The aerated liquid height Z was determined by using the method of Yoshitome⁷⁾ because the total volume of bubbles dispersed throughout the liquid was minimal. ϕ was calculated using the following equation.

$$\phi = (Z - Z_0) / Z \quad (1)$$

The dissolved oxygen concentration C was measured

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and monitored with the use of an oxygen probe (YSI model 5739) connected to an oxygen meter (YSI model 54A) and a recorder. The probe was fixed at distances of 0.2, 0.5 and 0.8 m from the bottom of the bubble column for measurement at three Z_0 values. $k_L a$ was determined by the following equation under completely mixed conditions³⁾.

$$k_L a = (1 - \phi) \ln \{ (C^* - C) / (C^* - C_0) \} / t \quad (2)$$

2. Results and Discussion

2.1 Average gas holdup

Figure 1 shows the effects of u_{G0} , d and Z_0 on ϕ . Each ϕ value increases with increasing u_{G0} , though there is little effect of d on ϕ . At the same u_{G0} , ϕ increases with Z_0 . This effect of Z_0 on ϕ is caused by heterogeneity of bubble dispersion due to the unusual zone existing immediately above the column bottom. The results of Akita *et al.*¹⁾ are shown in the same figure for comparison.

Since ϕ for each d is directly proportional to u_{G0} at low u_{G0} , the bubble rising velocities $u_B (= u_{G0} / \phi)$ show constant values slightly increasing with d . Hence, the bubble flow in this region is regarded as a uniform bubble flow regime. The bubble flow in the region at higher u_{G0} in this study is thus considered as the transition regime.

2.2 Average volumetric mass transfer coefficient

Figure 2 shows the effects of u_{G0} , d and Z_0 on $k_L a$ measured under the same ϕ conditions. From this figure, it is found that $k_L a$ increases linearly with increasing u_{G0} , though there is a slight effect of d on $k_L a$. The values of $k_L a$ increase with Z_0 , when compared at the same u_{G0} .

In the uniform bubble flow region, $k_L a$ for each d is directly proportional to u_{G0} . This increase seems to be caused by increasing the number of bubbles dispersed in the aerated liquid when both k_L and d_B are constant. In the transition region, while $k_L a$ linearly increases with increasing u_{G0} , ϕ does not, as mentioned above. This fact suggests that there is a difference in mass transfer and/or bubble characteristics between the two bubble flow regimes.

2.3 Relationship of $k_L a$ by ϕ

Figure 3 shows a plot of $k_L a$ against ϕ for data obtained in the bubble column. From this figure, the rela-

Fig. 1 Effects of u_{G0} , d and Z_0 on ϕ

Fig. 2 Effects of u_{G0} , d and Z_0 on $k_L a$
(Keys as Fig. 1)

relationship for $k_L a$ is seen as two straight lines with slopes of 1.0 and 1.2.

In the uniform bubble flow region, since both $k_L a$ and ϕ were directly proportional to u_{G0} , the relationship for $k_L a$ showed unit slope. Assuming spherical bubbles with d_B , the relationship between $k_L a$ and ϕ is expressed by the following equation^{3) 6)}.

$$k_L a = (6k_L / d_B) \phi \quad (3)$$

As shown in Fig. 3, since the relationship in this flow region can be represented by Eq. (3), k_L / d_B is constant. Furthermore, regarding d_B as a constant value due to constant bubble rising velocity in this region, k_L is constant also.

The relationship in the transition region had a

Fig. 3 Relationship between $k_L a$ and ϕ
(keys as Fig. 1)

slightly larger slope with respect to ϕ than that in the uniform bubble flow region. Here, assuming that $k_L a$ is proportional to ϕ and that d_B is constant due to extreme agitation of the gas-liquid mixed fluid⁴⁾, k_L slightly increases with ϕ and becomes larger than that in the uniform bubble flow region. This fact shows that the effects on k_L of the behavior of the gas-liquid interface in each region are different. From this figure, it is clear that the change from the uniform bubble flow regime to the transition regime increases $k_L a$. The slope in this region agrees with the results of Bello *et al.*²⁾

Nomenclature

a	= gas-liquid interfacial area per unit aerated liquid volume	[1/m]
C	= concentration of oxygen in liquid	[kg/m ³]
C_0	= initial concentration of oxygen in liquid	[kg/m ³]
C^*	= saturation concentration of oxygen in liquid	[kg/m ³]
D	= tube diameter	[m]
d	= hole diameter	[m]
d_B	= mean bubble diameter	[m]
$k_L a$	= volumetric mass transfer coefficient	[1/s]
t	= time	[s]
u_B	= bubble rising velocity	[m/s]
u_{G0}	= superficial gas velocity	[m/s]
Z	= aerated liquid height	[m]
Z_0	= unaerated liquid height	[m]
ϕ	= average gas holdup	[-]

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