Characteristics of Gas-liquid Mass Transfer and Interfacial Area in a Bubble Column

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Abstract – Characteristics of gas-liquid mass transfer and interfacial area were investigated in a bubble column of diameter and height of 0.102 m and 2.5 m, respectively. Effects of gas and liquid velocities on the volumetric gas-liquid mass transfer coefficient \(k_{L}a\), interfacial area \(a\) and liquid side true mass transfer coefficient \(k_{L}a\) were examined. The interfacial area and volumetric gas-liquid mass transfer coefficient were determined directly by adopting the simultaneous physical desorption of \(O_2\) and chemical absorption of \(CO_2\) in the column. The values of \(k_{L}a\) and \(a\) increased with increasing gas velocity but decreased with increasing liquid velocity in the bubble column which was operated in the churn turbulent flow regime. The value of \(k_{L}a\) increased with increasing gas velocity but did not change considerably with increasing liquid velocity. The liquid side mass transfer was found to be related closely to the liquid circulation as well as the effective contacting frequency between the bubbles and liquid phases.

Key words: Bubble Column, Volume Mass Transfer Coefficient, Interfacial Area, Liquid Side Mass Transfer Coefficient, Liquid Circulation

1. Introduction

Simplicity, low operating and maintenance costs, and high heat and mass transfer rates in the column have enabled the bubble column to be employed widely in the fields of biochemical, food, energy, environmental and medical engineering processes [1-3]. Numerous investigations, therefore, have been conducted to utilize the unique features of bubble columns, including the phase holdups, mixing, heat and mess transfer, bubble properties etc. [1-3].

To design, scale-up and operate the bubble column reactors or contactors, the information on the mass transfer between the continuous liquid and the discrete bubble phase has been an essential factor, since the information is necessary to analyze and estimate the performance of the reactors or contactors adopting the bubble columns. For the analysis of mass transfer of gas phase such as \(O_2\), \(CO_2\), \(SO_2\) and \(NO_2\) from the flowing bubbles to the liquid phase, the interfacial area between the two phases has to be determined. In addition, the liquid side true mass transfer coefficient should be verified, since the resistance in the gas phase for the mass transfer has been understood to be negligible [1-4]. However, various kinds of investigations have focused on the overall volumetric mass transfer coefficients, and the values of interfacial area between the contacting two phases have been estimated from a knowledge of the bubble size and its holdup indirectly [5-9]. In the present study, the interfacial area and liquid side true mass transfer coefficient in addition to the overall volumetric mass transfer coefficient were determined directly by resorting to the simultaneous physical desorption of \(O_2\) and chemical absorption of \(CO_2\) [10-13]. Characteristics of the gas-liquid interfacial area and the liquid side and volumetric mass transfer coefficients were also discussed.

2. Experiments

The experiments were in a bubble column of diameter and height of 0.102 m and 2.5 m, respectively, as can be seen in Fig. 1. A perforated plate served as a gas and liquid distributor. The plate, which contained 120 evenly spaced holes of \(2.0 \times 10^{-3}\) m in diameter, was installed between the main column section and a 0.2 m high stainless steel distributor box into which the liquid phase was introduced through a 0.025 m pipe from a liquid reservoir. Oil-free compressed gas was fed to the column through a pressure regulator, filter and a calibrated gas flowmeter. The gas was admitted to the column through 3.0 \(\times 10^{-3}\) m ID perforated pipes with 88 holes of \(1.0 \times 10^{-3}\) m ID drilled horizontally in the plate. The details of gas and liquid distributor can be found elsewhere [14-16]. The gas holdup was determined by means of static pressure drop method [2,3], by measuring the pressure drop variations in the column. Five pressure taps were mounted flush with the wall of the column with 0.2 m height intervals, 0.5 m apart from the gas and liquid distributor. The signals of pressure drops were processed to produce the digital data [17,18]. Compressed \(O_2\) and \(CO_2\) were used as the gas phase, and tap water and sodium carbonate/sodium bicarbonate solutions were used as the continuous liquid phase, of which temperature was kept at 20 ± 2 °C. When a steady state was reached at a given operating condition, five liquid samples were obtained simultaneously by means of solenoid valves and sampling ports located axially at the wall of the column at an interval of 0.1 m
and 0.6 m from the distributor. The sampling was conducted at three radial coordinators, \( r/R, 0, 0.5 \) and 1.0 for a given axial position. The sample was passed through a tube containing an oxygen probe (membrane type) to measure the dissolved oxygen concentration in the sample and was then analyzed to measure the carbonate/bicarbonate concentration by a titration method for the determination of \( \text{CO}_2 \) concentration in the sample [12,13].

The concentrations of desorbing \( \text{O}_2 \) and chemically absorbing \( \text{CO}_2 \) gas were determined from the mean values of the experimentally measured values at the axial and radial positions of the column. The values of the interfacial area and volumetric mass transfer coefficient were obtained, based on the following equations [10-13], that is, after measuring of oxygen concentration in the liquid sample by using oxygen probe and of \( \text{CO}_2 \) concentration by means of titration method, the values of \( a \) and \( k_L a \) were calculated by using Eqs. (1)-(5).

The absorption can be assumed to be a fast pseudo first-order reaction in the liquid phase as [4].

\[
 R_{CO_2} a = k_{L,CO_2}^* (D_{\text{CO}_2}/D_{\text{CO}_2})^{1/2} (1)
\]

Since the desorption rate coefficient of oxygen can be written as Eq. (2). and the physical desorption rate of \( \text{O}_2 \) can be written as Eq.(3),

\[
 R_{O_2} a = k_{L,O_2} a \Delta C_{O_2} (3)
\]

the desorption rate of oxygen can be expressed as Eq. (4).

\[
 R_{O_2} a = k_{L,CO_2} a (D_{\text{O}_2}/D_{\text{CO}_2})^{1/2} \Delta C_{CO_2} (4)
\]

Therefore, the interfacial area, \( a \), can be determined from Eqs. (1) ~-(4) as Eq. (5).

\[
 a = [(R_{CO_2} a/C_{CO_2}^*)^2 - k_{L,CO_2} a^2]/D_{\text{CO}_2} k_{L} C_{CO_2} (5)
\]

The liquid-side mass transfer coefficient was determined by using Eq. (6) with the assumption that the gas phase resistance can be negligible.

\[
 k_L = k_L = (k_L a)/a (6)
\]

### 3. Results and Discussion

Gas-liquid mass transfer is closely related to the bubble holdup in the column, since the bubbles are flowing as a dispersed phase in the continuous liquid medium. Effects of gas and liquid velocities on the gas holdup can be seen in Fig. 2. The gas holdup increases proportional to the increase in the gas velocity, but it decreases with an increase in the liquid velocity. The increase in the gas velocity leads to the increase in the amount of gas per unit cross sectional area of the column, which consequently results in the increase in the gas holdup. However, the increase in the liquid velocity results in the increase in the liquid holdup, which causes to the decrease in the gas

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**Fig. 1. Experimental apparatus.**

1. Main column
2. Gas/liquid separator
3. Liquid reservoir
4. Control valve
5. Liquid flowmeter
6. Gas flowmeter
7. Sampling tap
8. Pressure tap
9. Pressure sensor
10. Amplifier
11. Low-pass filter
12. Data acquisition system
13. A/D converter
14. Computer
15. G/L distributor
16. \( \text{CO}_2 \) gas bomb
17. \( \text{O}_2 \) gas bomb
18. \( \text{N}_2 \) gas bomb
19. Liquid sample analyzer
20. Liquid pump
21. Gas filter & regulator
22. Calming section
23. Liquid supplying tank
24. \( \text{N}_2 \) sparger
25. Thermocouple
26. Solenoid valve
27. Dissolved gas analyzer

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**Fig. 2. Effects of gas and liquid velocities on the gas holdup in bubble columns.**

\( U_L \times 10^3 \, [\text{m/s}] : \) 2.0 3.0 4.0 6.0 8.0 10.0