EXPERIMENTAL STUDY OF ABSORPTION OF CARBON DIOXIDE FROM CARBON DIOXIDE-AIR GAS MIXTURE BY WATER SPRAY

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Introduction

The removal of carbon dioxide from flue gas emitted by the combustion of fossil fuels is an important social and environmental problem. Although many studies have been made of absorption of carbon dioxide by packed columns, little is known about its absorption by spray towers despite their advantage of low pressure drop.

The purpose of the present work is to make an experimental approach to absorption of CO₂ from CO₂-air gas mixture by water spray.

1. Experimental Apparatus and Procedures

1.1 Experimental apparatus

Figure 1 shows a schematic diagram of an experimental apparatus. The spray tower is a 180 mm-inner diameter, 500 mm-long acrylic resin column with a 0.78 mm orifice diameter of its unjet nozzle (Spray Systems Co. Type 1/4TDD1-35). The nozzle is connected to copper tubing by a tube fitting. Ion-exchanged pure water was supplied by a magnetic gear pump to the unjet nozzle. Carbon dioxide from a cylinder and air from a blower was supplied to the top of the column through flow meters and a silica gel-packed column.

1.2 Measurements

1) Local mass flow rate of liquid: Local mass flow rates of liquid, \( L_r \), were determined by sampling and measuring the weight of the liquid at given time intervals at the positions of \( r = 0 \) mm, 15 mm, 30 mm, 45 mm, 60 mm and 75 mm at distances \( z = 0.167 \) m, 0.267 m and 0.367 m. The integrated mass flow rates of the liquid, \( L \), calculated from observed local mass flow rates, \( L_r \), showed good agreement (within less than 5%) with those observed with a precision rotameter.

2) Local amount of absorption: Liquid samples for chemical analysis were taken at the same positions as the local mass flow rate of liquid. The local amount of absorbed gas was determined from the liquid concentration by material balance.

3) Diameter of drop: Absorption runs were made at the same flow rates and with the same nozzle as used in our previous work\(^3\). For this reason the Sauter mean diameter of the drops, \( D_{23} \), which was necessary in the later studies, were taken equal to that observed in the previous work. The Sauter mean drop diameters at \( L = 4 \times 10^{-3}, 6 \times 10^{-3} \) and \( 8 \times 10^{-3} \) kg/s were 0.185, 0.148 and 0.137 mm, respectively.

1.3 Ranges of variables and physical properties

Measurements were made of mass flow rates of liquid \( L = 4 \times 10^{-3} - 8 \times 10^{-3} \) kg/s and inlet mole fraction of CO₂ in gas phase \( y_0 = 0.6 - 1.0 \) at liquid temperature \( T_L = 284 \) K, gas temperature \( T_g = 284 \) K and mass flow rate of gas \( G = 5.0 \times 10^{-4} \) kg/s.

Diffusion coefficients of CO₂ in water were calculated by Wilke-Chang’s equation.\(^4\)

Fig. 1. Schematic diagram of an experimental apparatus

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2. Results and Discussion

Figure 2 shows the radial distribution of local mass flow rates of liquid at $L = 6.0 \times 10^{-3}$ kg/s. The local mass flow rates of liquid considerably decrease with increasing radial distance from the center axis of the column and with increasing distance from the nozzle.

Figure 3 shows changes in amount of absorbed gas with distance from the nozzle at various inlet gas concentrations. The ordinate in the figure is the total amount of absorbed gas, which is calculated by the following equation:

$$W = \int_{0}^{\frac{D r}{2}} 2\pi r \cdot \omega \cdot L \cdot dr$$

(1)

The amount of absorbed gas decreases with decreasing mole fraction of CO$_2$, $y_0$.

Figure 4 shows a comparison of the observed CO$_2$ concentration in the drop with that by the penetration model. $\theta$ in the ordinate is the dimensionless liquid concentration in the drop, given by:

$$\theta = \frac{\omega - \omega_0}{\omega_0}$$

(2)

$\omega$ is the average concentration of absorbed CO$_2$ in the drop and calculated by the following equation:

$$\tilde{\omega} = \frac{24W}{\pi^2 D_1 D_2 p_p}$$

(3)

The abscissa is the Fourier number, $Fo$, defined by:

$$Fo = \frac{D t}{D_2}$$

(4)

where contact time, $t$, is calculated by assuming the motion of a sprayed drop to be the same as that of a single solid sphere with initial velocity at the nozzle exit. The solid line in the figure represents the penetration model$^{1,2)}$:

$$\theta = 1 - \frac{6}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{n^2} \exp(-4n^2Fo)$$

(5)

The observed data showed good agreement with the prediction by the penetration model.

Conclusion

Measurements were made of absorption of CO$_2$ from CO$_2$-air gas mixture by water spray for inlet mole fraction of CO$_2$ $y_0 = 0.6$–1.0, mass flow rate of liquid $L = 4.0 \times 10^{-3} - 8.0 \times 10^{-3}$ kg/s and mass flow rate of gas $G = 5.0 \times 10^{-4}$ kg/s, to give the following conclusion.

The observed data of concentration of CO$_2$ in a water drop showed good agreement with those calculated by the penetration model.

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**Nomenclature**

- \( D_{23} \) = Sauter mean diameter of drop [m]
- \( D_L \) = diameter of column [m]
- \( \varepsilon_d \) = diffusion coefficients of CO\(_2\) in water [m\(^2\)/s]
- \( G \) = mass flow rate of CO\(_2\)-air gas mixtures [kg/s]
- \( L \) = mass flow rate of liquid [kg/s]
- \( L_s \) = local mass flux of spray [kg/(m\(^2\)·s)]
- \( N \) = number flux of drop [1/(m\(^2\)·s)]
- \( r \) = distance from center axis of column [m]
- \( W \) = amount of absorbed gas [kg/s]
- \( y \) = mole fraction of CO\(_2\) in CO\(_2\)-air gas mixture [-]
- \( z \) = distance from tip of nozzle [m]
- \( \rho_r \) = density of drop [kg/m\(^3\)]

\( \omega \) = mass fraction

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**Subscripts**

- \( r \) = radial direction
- \( s \) = interface of drop
- \( 0 \) = initial value
- \( _- \) = average value

**Literature Cited**