

CONTROL OF CARBON DIOXIDE REMOVAL RATE BY HOLLOW FIBER MEMBRANE CONTACTOR

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ABSTRACT

To investigate numerically the removal behavior of carbon dioxide in a hollow fiber membrane contactor, the system controlling equations were developed including the non-linear reversible reaction terms. The reversible chemical reactions were incorporated in the system controlling equations, resulting in the coupled nonlinear partial differential equations which could describe either the absorption or the desorption of carbon dioxide. The computer program was coded using the Fortran language and run with a personal computer to find out the effects of the system variables: the pressures of absorbed and desorbed gases, the absorbent flow rate, the concentration of potassium carbonate, the fiber diameter and the length.

THEORY

Flow Configuration of the Membrane Contactor

The adsorbent of the aqueous potassium carbonate solution[1,2,3] is supposed to flow through the bore of the hollow fiber in the system. The liquid always flows through the tube side and the gas is fed in the shell side. The system was controlled which is referred as a non-wetted mode of operation. The schematic diagram of a membrane contactor is shown in Fig. 1. The coordinates of r and x are assigned for the numerical analysis.

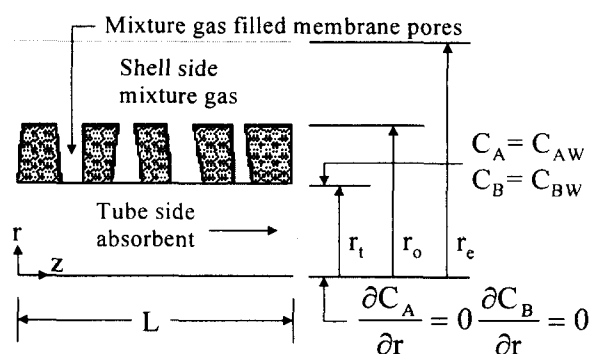


Fig.1. Schematic diagram of a membrane contactor.

System Controlling Equation for Absorption

A theoretical model is developed to be Eq. (1) and Eq. (2) to describe the absorption of carbon dioxide from its mixture into the potassium carbonate aqueous solution[4]. These equations include the non-linear chemical reaction terms[5,6,7]. All concentrations could be expressed in a dimensionless form. The subscript A denotes carbon dioxide and the subscript B denotes bicarbonate ion.

$$2(1-\bar{r}^2) \frac{\partial \bar{C}_A}{\partial z} = \frac{\phi}{Pe_A} \left[\left[\frac{\partial^2 \bar{C}_A}{\partial \bar{r}^2} + \frac{1}{\bar{r}} \frac{\partial \bar{C}_A}{\partial \bar{r}} \right] - D_{KA} \left[1 + A \frac{\tau - \bar{C}_B}{\bar{C}_B} \right] \left[\bar{C}_A - \gamma \frac{\bar{C}_B^2}{\tau - \bar{C}_B} \right] \right] \quad (1)$$

$$2(1-\bar{r}^2) \frac{\partial \bar{C}_B}{\partial z} = \frac{\phi}{Pe_B} \left[\left[\frac{\partial^2 \bar{C}_B}{\partial \bar{r}^2} + \frac{1}{\bar{r}} \frac{\partial \bar{C}_B}{\partial \bar{r}} \right] - D_{KB} \left[1 + A \frac{\tau - \bar{C}_B}{\bar{C}_B} \right] \left[\bar{C}_A - \gamma \frac{\bar{C}_B^2}{\tau - \bar{C}_B} \right] \right] \quad (2)$$

The initial conditions and the boundary conditions for the absorption process are given in Eq. (3), Eq. (4), and Eq. (5).

$$\bar{C}_A = 0.0, \quad \bar{C}_B = \frac{\sqrt{((K_2/K_1)[CO_3^{2-}]) / 2}}{[CO_3^{2-}]}, \quad \text{at all } \bar{r}, \bar{z} = 0 \quad (3)$$

$$\bar{C}_{A,abs} = \bar{C}_{A,des,outlet}, \quad \bar{C}_{B,abs} = \bar{C}_{B,des,outlet}, \quad \text{at all } \bar{r}, \bar{z} = 0 \quad (4)$$

$$\frac{\partial \bar{C}_A}{\partial \bar{r}} = 0, \quad \frac{\partial \bar{C}_B}{\partial \bar{r}} = 0, \quad \text{at } \bar{r} = 0 \quad \bar{C}_A = 1, \quad \bar{C}_B = 1, \quad \text{at } \bar{r} = 1 \quad (5)$$

OPERATION CONDITIONS

The operation conditions were used as follows; gas pressure(10, 20, 30psig); absorbent flow rate (10, 50,100cc/min); concentration of K₂CO₃(0, 5, 10 wt% / 0, 0.3623, 0.7246mole /L); vacuum(1, 5, 10cmHg); fiber I.D.(700, 840, 1000μm); fiber length(10, 20, 30cm). Unless stated in the result, the underlined are used as the typical operating conditions.

RESULTS AND DISCUSSION

The numerical results clearly show that the carbon dioxide concentration increases as the axial distance increases. Also the carbon dioxide concentration and bicarbonate ion concentration near the wall of the fiber are much higher than that of the center of the fiber at the same axial distance. At the outlet, the concentrations in all the radial coordinates become one. This indicates that the solution is fully saturated with carbon dioxide. The bicarbonate

ion concentration increases and is almost saturated as the axial distance increases. The bicarbonate ion concentration at the inlet was not zero, but about 0.7. However, the contribution of bicarbonate ion for absorption is found to be much higher than the pure CO₂ absorption case.

As shown in Fig. 2, the permeation rate of carbon dioxide increases as the pressure of gas mixture increases. This seems to be due to the high carbon dioxide concentration in the liquid interface which is in equilibrium with gas. When 5 wt% potassium carbonate solution is used as an absorbent, there is no big difference in the permeation rate because the potassium carbonate may be completely saturated with the carbon dioxide at the outlet of the fiber.

The Fig. 3 shows the permeation rates of carbon dioxide as a function of absorbent flow rate with several different concentrations of potassium carbonate. As the absorbent flow rate increases, the permeation rate of carbon dioxide increases because the liquid boundary layer resistance decreases with increase of the liquid velocity. Also, the transfer rate of carbon dioxide into the liquid increases as the concentration of potassium carbonate increases since the facilitated absorption ratio also increases.

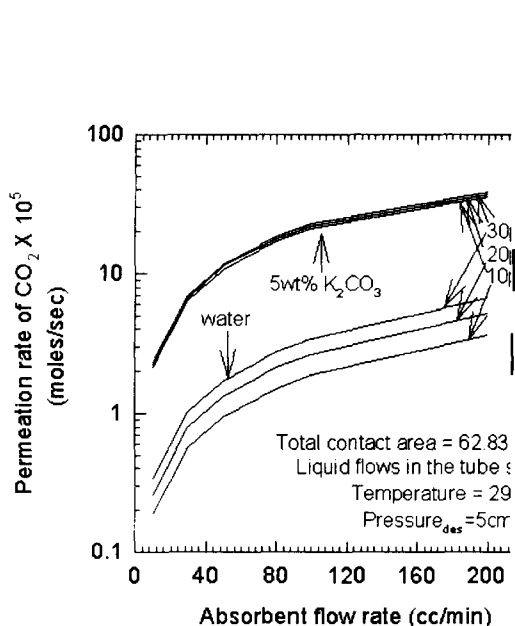


Fig.2. Permeation rate of CO₂ versus absorbent flow rate with various pressures of gas mixture for absorption mode.

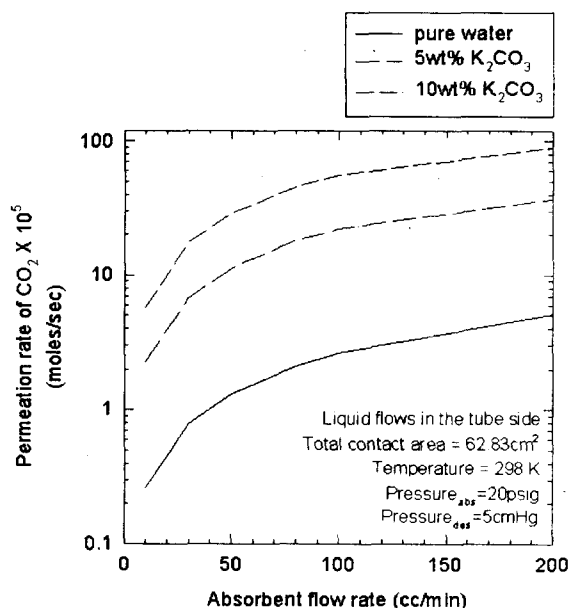


Fig.3. Permeation rate of CO₂ versus absorbent flow rate with various absorbent concentrations.

The absorbent liquid may be easily saturated in between the fiber length, which means that the left big portion of the fiber may not be used for absorption. As shown in Fig. 4, the saturation point moves toward to the direction of the outlet of the fiber as the liquid flow rate increases. It is thought that since it takes same time for the liquid to be saturated whether or

not the flow rate is different, the saturation point will be moved to the outlet if velocity increases. Also the liquid is not saturated at the outlet position for the relatively high flow rate such as 80cc/min if the radius of the fiber is as big as 500 μ m. It means that the capacity of absorption for the given absorbent could not be fully utilized.

CONCLUSIONS

The coupled partial differential equations were developed for both the absorption and the desorption of carbon dioxide using the reversible reaction rates of the potassium carbonate with carbon dioxide in hollow fiber membrane contactors. The equations could be solved numerically. The removal behavior of carbon dioxide could be successfully described.

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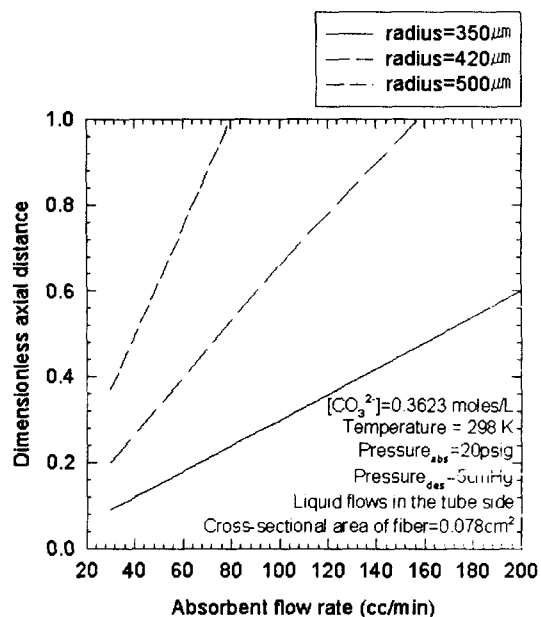


Fig.4. Dimensionless axial distance where saturation is obtained.