

외부순환형 AIRLIFT반응기에서의 비정상상태의 산소전달에 관한 수학적 모델

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A MATHEMATICAL MODEL FOR UNSTEADY-STATE OXYGEN TRANSFER IN AN EXTERNAL-LOOP AIRLIFT REACTOR

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Introduction

Oxygen transfer coefficients for particular absorption unit are usually determined by dynamic method because the method simplifies comparing oxygen transfer efficiencies with other type of equipment. The dynamic method is based on the comparison of a measured value of dissolved oxygen concentration with the calculated value by a mathematical model. The choice of the model is very important because a poor assumption of hydrodynamic characteristics of the equipment may lead to deviations from the true values. In this paper, considering both the effect of recirculation gas rates and the reactor configuration, a mathematical model for simulation of unsteady-state oxygen transfer in an external-loop airlift reactor was developed.

Theory

In the present study, a tanks-in-series model is used for both liquid and gas phases in the riser and the circulation loop which includes two connection sections and the downcomer. A schematic diagram of the unsteady-state mass transfer model for an external-loop airlift reactor is presented in Fig. 1. It is assumed that the complete mixing prevails for each phase in each tank of interconnected tanks. Under unsteady-state conditions, the oxygen balance on the each stage for the gas phase or liquid phase can be expressed as follows.

1st gas stage in the riser:

$$\frac{dC_{G,1}}{dt} = \frac{\gamma_r(Q_{Gin}C_{Gin} + Q_{Gd}C_{G,M_G+N_G} - Q_{Gr}C_{G,1})}{\epsilon_r V_{ri}} - K_L a_L \frac{(1-\epsilon_r)}{\epsilon_r} (C_{L,1}^* - C_{L,1}) \quad (1)$$

where

$$C_G = \frac{P \cdot Y_{O_2}}{RT}, \gamma_r = \frac{M_L}{M_G}, V_{ri} = \frac{V_r}{M_L}, Q_{Gr} = Q_{Gin} + Q_{Gdb}, C^*_{L,i} = \frac{P_{O_2}}{H} = \frac{C_G RT}{H}$$

1st liquid stage in the riser:

$$\frac{dC_{L,1}}{dt} = \frac{Q_L(C_{L,M_L+N_L} - C_{L,1})}{V_{ri}(1-\varepsilon_r)} + K_L a_L (\bar{C}^*_{L,1} - C_{L,1}) \quad (2)$$

where $\bar{C}^*_{L,i} = \frac{\gamma_r RT}{H} \sum_{j=(i-1)\gamma_r}^{i\gamma_r} C_{G,j}$

*i*th gas stage in the riser below the top connection:

$$\frac{dC_{G,i}}{dt} = \frac{\gamma_r Q_{Gr}(C_{G,i-1} - C_{G,i})}{\varepsilon_r V_{ri}} - K_L a_L \frac{(1-\varepsilon_r)}{\varepsilon_r} (C^*_{L,i} - C_{L,i}) \quad (3)$$

*i*th liquid stage in the riser below the top connection:

$$\frac{dC_{L,i}}{dt} = \frac{Q_L(C_{L,i-1} - C_{L,i})}{V_{ri}(1-\varepsilon_r)} + K_L a_L (\bar{C}^*_{L,i} - C_{L,i}) \quad (4)$$

*i*th gas stage in the riser above the top connection:

$$\frac{dC_{G,i}}{dt} = \frac{\gamma_r (Q_{Gr} - Q_{Gtc})(C_{G,i-1} - C_{G,i})}{\varepsilon_r V_{ri}} - K_L a_L \frac{(1-\varepsilon_{tr})}{\varepsilon_{tr}} (C^*_{L,i} - C_{L,i}) \quad (5)$$

*i*th liquid stage in the riser above the top connection:

$$\frac{dC_{L,i}}{dt} = K_L a_L (\bar{C}^*_{L,i} - C_{L,i}) \quad (6)$$

*i*th gas stage in the top connection:

$$\frac{dC_{G,i}}{dt} = \frac{\gamma_c Q_{Gc}(C_{G,i-1} - C_{G,i})}{\varepsilon_{tc} V_{ci}} - K_L a_L \frac{(1-\varepsilon_{tc})}{\varepsilon_{tc}} (C^*_{L,i} - C_{L,i}) \quad (7)$$

*i*th liquid stage in the top connection:

$$\frac{dC_{L,i}}{dt} = \frac{Q_L(C_{L,i-1} - C_{L,i})}{V_{ci}(1-\varepsilon_{tc})} + K_L a_L (\bar{C}^*_{L,i} - C_{L,i}) \quad (8)$$

where $\gamma_c = \frac{N_L}{N_G}, V_{ci} = \frac{V_c}{N_L}$

*i*th gas stages in the downcomer and the bottom connection:

$$\frac{dC_{G,i}}{dt} = \frac{\gamma_c Q_{Gd}(C_{G,i-1} - C_{G,i})}{\varepsilon_d V_{ci}} - K_L a_L \frac{(1-\varepsilon_d)}{\varepsilon_d} (C^*_{L,i} - C_{L,i}) \quad (9)$$

*i*th liquid stages in the downcomer and the bottom connection:

$$\frac{dC_{L,i}}{dt} = \frac{Q_L(C_{L,i-1} - C_{L,i})}{V_{ci}(1-\varepsilon_d)} + K_L a_L (\bar{C}^*_{L,i} - C_{L,i}) \quad (10)$$

Liquid stage in the top region:

$$\frac{dC_{G,M_G+N_G+1}}{dt} = \frac{(Q_{Gtc} - Q_{Gd})(C_{G,N_{Gst}} - C_{G,M_G+N_G+1})}{\varepsilon_{tc} V_t} - K_L a_L \frac{(1-\varepsilon_{tc})}{\varepsilon_{tc}} (C^*_{L,M_G+N_G+1} - C_{L,M_L+N_L+1}) \quad (11)$$

Gas stage in the top region:

$$\frac{dC_{L,M_L+N_L+1}}{dt} = K_L \alpha_L (C_{L,M_G+N_G+1}^* - C_{L,M_L+N_L+1}) \quad (12)$$

It is assumed that the oxygen probe system is a first order lag system:

$$\frac{dC_{Lp,i}}{dt} = \frac{(C_{L,i} - C_{Lp,i})}{t_e} \quad \text{for } i=1, \dots, M_L+N_L+1 \quad (13)$$

The initial conditions are: $C_{L,i} = C_{L0}$ for $i=1, \dots, M_L+N_L+1$;

$$C_{G,j} = \frac{C_{L0}RT}{H} \quad \text{for } j=1, \dots, M_G+N_G+1.$$

Equations (1)-(13) form a system of $2M_L+2N_L+M_G+N_G+3$ linear first order differential equations with constant coefficients. The model equations can be solved by a second order Runge-Kutta method (Andre et al., 1983). The overall volumetric mass transfer coefficient is then determined by fitting the C_{Lp} calculated by the model to the experimentally determined transition curve.

Experimental

The external-loop airlift reactor used in this study has previously been described in detail (Choi, 1989). Tap water and air were used as the liquid and gas phases in the experiments. All experiments were carried out at ambient temperature and atmospheric pressure. Overall gas holdup was measured by comparison of aerated and unaerated liquid heights. Water manometers were used to obtain gas holdup data in the riser, the downcomer and the top of the riser. The circulation liquid velocity was determined by a tracer impulse method. The overall volumetric mass transfer coefficient, $K_L \alpha_L$, was determined by a physical dynamic method.

Results and Discussion

Numerical values of several constants had to be adopted in order to perform the calculations. From data reported by Perry (1984), the following relation may be obtained, which links H with t :

$$H = 4.163 \times 10^{-4} T - 0.0997 \quad (14)$$

The circulation gas rates in both the top connection and the downcomer were taken from data obtained by Choi (1989), and can be expressed as a function of the gas holdup as follows:

$$Q_G = 2959.19 \varepsilon - 0.64 \quad (15)$$

Fig. 2 shows the comparison of the calculated C_{Lp} and the experimental value. In Fig. 2, the transition curve of the probe response calculated by the

well-mixed model (Chisti and Moo-Young, 1988) was also presented. Fig. 2 indicates that the present model showed better agreement with experimental results than the well-mixed model.

References

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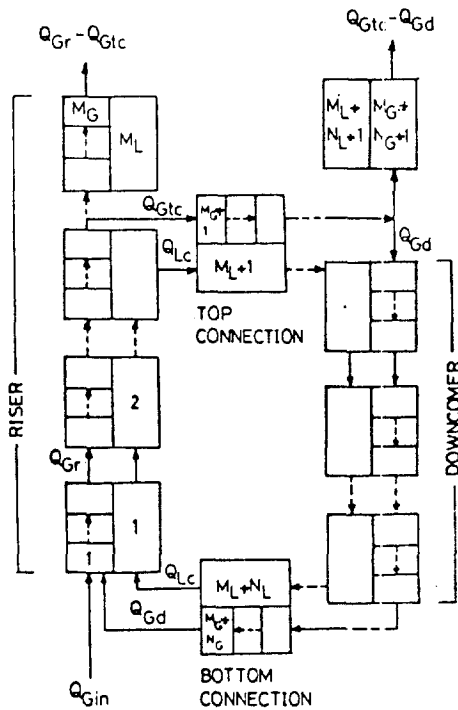


Fig. 1. Block diagram of the unsteady state mixing model for the airlift reactor.

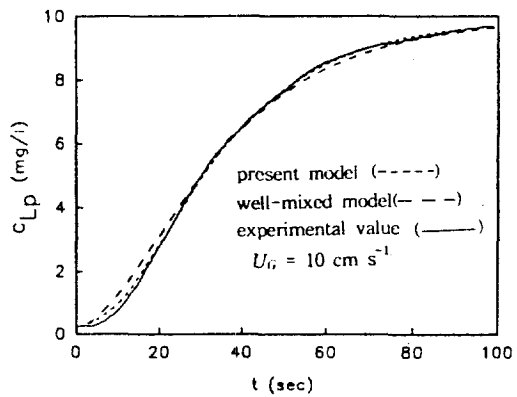


Fig. 2. Comparison of the calculated C_{Lp} and the experimental value.