Model Analysis for the Commercial Membrane Contactor Module

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Introduction

- **Membrane Contactor Process**
  - **A new way to accomplish separation process**
    - **Liquid/liquid extraction**
    - **Gas absorption/stripping**
  - **Advantages**
    - **High specific area of mass transfer**
    - **No flooding**
    - **The possibility of realization of extreme phase ratios**
    - **Nondispersive phase contact avoiding entrainment**
  - **Disadvantages**
    - **Slower mass transfer**
    - **Expensive and limited applications**

Membrane Contactor

Analysis of Membrane Contator

Key information : Mass Transfer, Equilibrium,
Breakthrough pressure

- **Correlation for Mass transfer coefficients**
  - **Shell side**
    - **Parallel flow : Yang et al.(1986), Prasad et al.(1988)**
    - **Cross flow : Ahmed et al.(1992), Costello et al.(1993)**
  - **Tube side**
    - **Parallel flow : Wickramasinghe et al.(1992)**
- **Equilibrium**
  - **Henry's law**
    - **from vapor-liquid equilibrium data**

Membrane Contactor

- **Sengupta et al.(1998)**
  - **Empirical correlation of mass transfer for transverse flow**
  - **Removal of dissolved oxygen from water with excess sweep gas**
- **Schöner et al.(1998)**
  - **Correlation for calculation the shell side mass transfer coefficient in cross flow**
  - **Application to extraction**

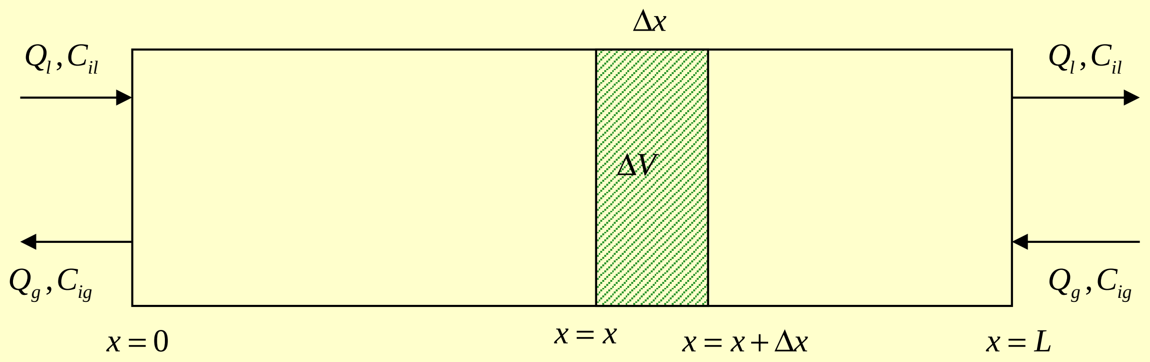
In present work

- **Analysis of mass transfer in shell side according to the flow pattern**
- **Application to ammonia stripping**

Mass Transfer

- **Steady state mass balance for shell side flow**

  1. Counter-current flow

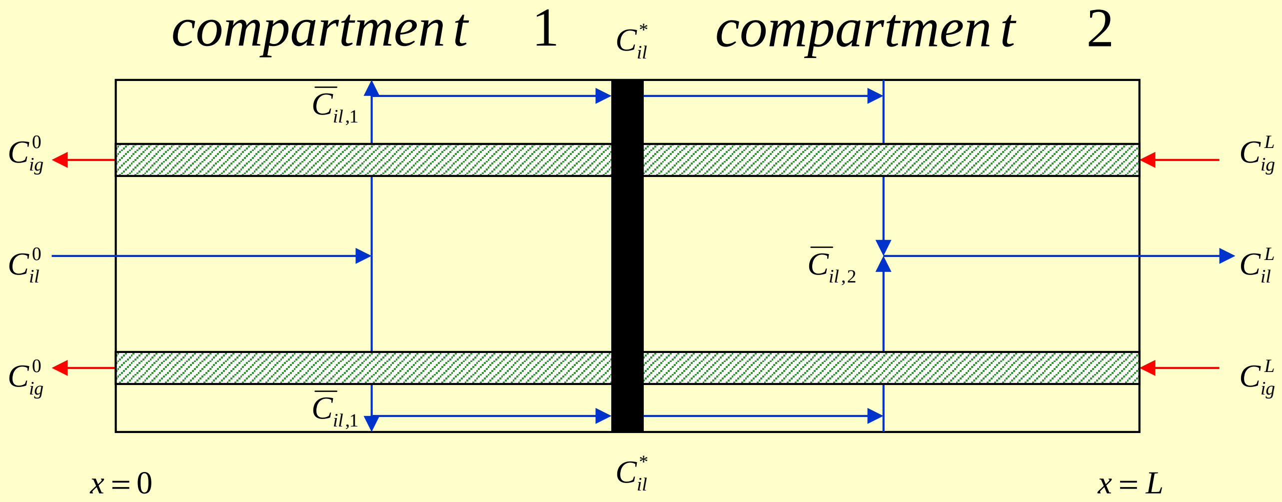


$$\frac{dC_{il}}{dx} + K_Q(1-R)C_{il} = -K_Q\left(RC_{il}^L - C_{ig}^L / H_i\right) \qquad K_Q = K_{il}A/Q_l \qquad R = Q_l / Q_g H_i$$

$$\frac{C_{il}^L}{C_{il}^0} = \frac{1-R}{\exp\left[K_Q(1-R)L\right] - R}$$

Mass Transfer

2. Cross flow



- Compartment 1

$$Q_l\left(C_{il}^0 - C_{il}^*\right) = Q_g\left(C_{ig}^0 - C_{ig}^*\right) \qquad Q_g \frac{dC_{ig}}{dx} = -k_{il}a\left(\overline{C}_{il,1} - \frac{C_{ig}}{H_i}\right)$$

$$\ln \frac{\overline{C}_{il,1} - C_{ig}^*/H_i}{\overline{C}_{il,1} - C_{ig}^0/H_i} = \frac{K_Q}{2H_i} \qquad \overline{C}_{il,1} = \frac{C_{il}^0 - C_{il}^*}{\ln\left(C_{il}^0/C_{il}^*\right)}$$

Mass Transfer

- Compartment 2

$$Q_l\left(C_{il}^{*}-C_{il}^{L}\right)=Q_g\left(C_{ig}^{*}-C_{ig}^{L}\right)$$

$$Q_g\frac{dC_{ig}}{dx}=-k_{il}a\left(\overline{C}_{il,2}-\frac{C_{ig}}{H_i}\right)$$

$$\ln\frac{\overline{C}_{il,2}-C_{ig}^{L}/H_i}{\overline{C}_{il,2}-C_{ig}^{*}/H_i}=\frac{K_Q}{2H_i}$$

$$\overline{C}_{il,2}=\frac{C_{il}^{*}-C_{il}^{L}}{\ln\left(C_{il}^{*}/C_{il}^{L}\right)}$$

- Mass transfer coefficient

$$K_Q=2H_i\ln\frac{1-\dfrac{C_{ig}^{0}}{H_i}\dfrac{\ln\left(C_{il}^{0}/C_{il}^{*}\right)}{C_{il}^{0}-C_{il}^{*}}}{1-R\ln\left(C_{il}^{0}/C_{il}^{*}\right)-\dfrac{C_{ig}^{0}}{H_i}\dfrac{\ln\left(C_{il}^{0}/C_{il}^{*}\right)}{C_{il}^{0}-C_{il}^{*}}}$$

C_{il}^{*} **: Interfacial liquid conc. between compartment 1 & 2**

Henry's Law

- **Henry's Constant**

$$H_i = \lim_{C_{il}\to 0}\frac{C_{ig}}{C_{il}} = \frac{V_l}{RT}\lim_{x_i\to 0}\frac{p_i}{x_i}$$

  - **From ammonia-water vapor-liquid equilibrium data at several temperatures, (x>0.05)**

Mass Transfer Coefficients

- **Mass Transfer**
  - **mass tranfer of liquid in shell side**
  - **mass transfer of vapor in membrane pore**
  - **mass transfer of vapor in tube side**
- **Overall Mass transfer coefficient**

$$\frac{1}{K_{il}} = \frac{1}{k_{il}^{l}} + \frac{1}{k_{ig}^{p} H_i} + \frac{1}{k_{ig}^{g} H_i}$$

  - **Sengupta et al.(1998)** $K_{il} \approx k_{il}^{l} \quad \left(\because\ k_{il}^{l} \le k_{ig}^{p}, k_{ig}^{g}\right)$
- **Correlation of individual mass transfer coefficient in liquid phase**

$$\left(\frac{k_{il}^{l} d_e}{D_{il}}\right) = a\left(\frac{d_e v_l}{\nu_l}\right)^{b}\left(\frac{\nu_l}{D_{il}}\right)^{c}$$

Experiment

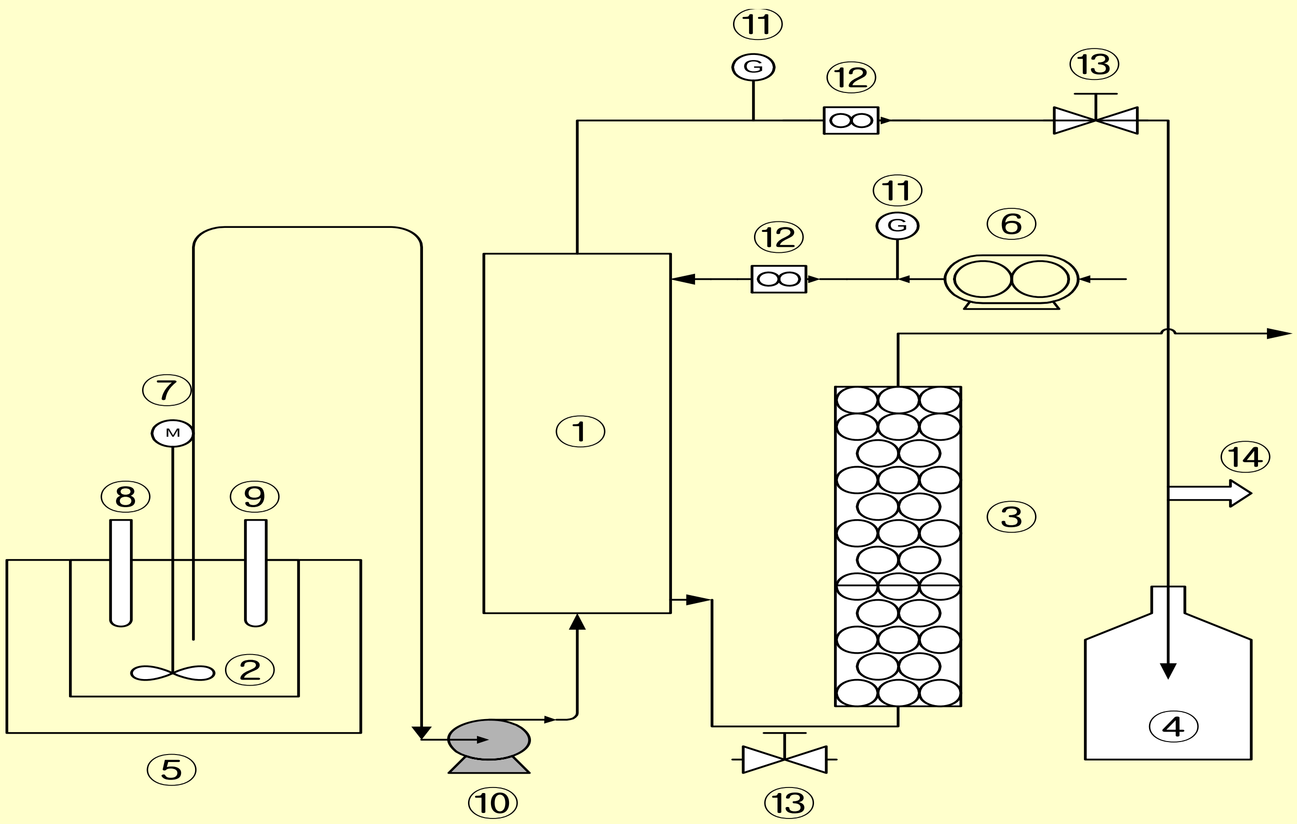


Fig. 1 Schematic diagram of experimental apparatus

① Hollow fiber membrane contactor ② Ammonia solution reservoir ③ Packed column
④ Storage tank ⑤ Water bath ⑥ Air blower ⑦ Stirrer ⑧ pH electrode ⑨ ATC probe
⑩ water pump ⑪ Pressure gauge ⑫ Flow meter ⑬ Needle valve ⑭ Sampling valve

Results

Table 1. Comparison of mass transfer coefficients in liquid phase

Q_l (ml/min)	k_{il} for 2.5"x8" (cm/s)		Q_l (ml/min)	k_{il} for 4"x28" (cm/s)	
	Axial flow	Cross flow		Axial flow	Cross flow
10	8.747×10^{-6}	9.088×10^{-6}	100	9.650x10-6	1.004x10-5
20	1.039×10^{-5}	1.082×10^{-5}	150	1.232x10-5	1.273x10-5
30	1.503×10^{-5}	1.750×10^{-5}	200	1.477x10-5	1.528x10-5
			250	1.596x10-5	1.640x10-5

Results

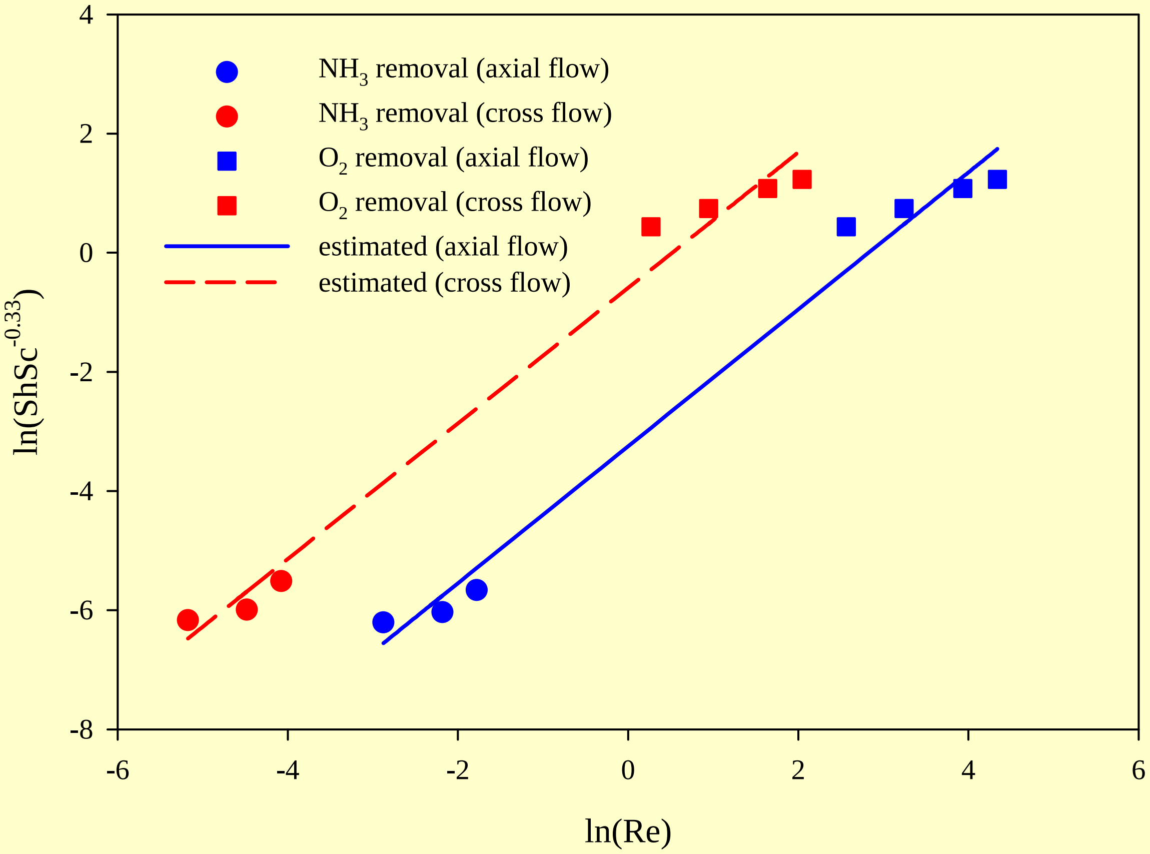


Fig. The correlation of shell side mass transfer of 2.5"x8" membrane contactor module

Results

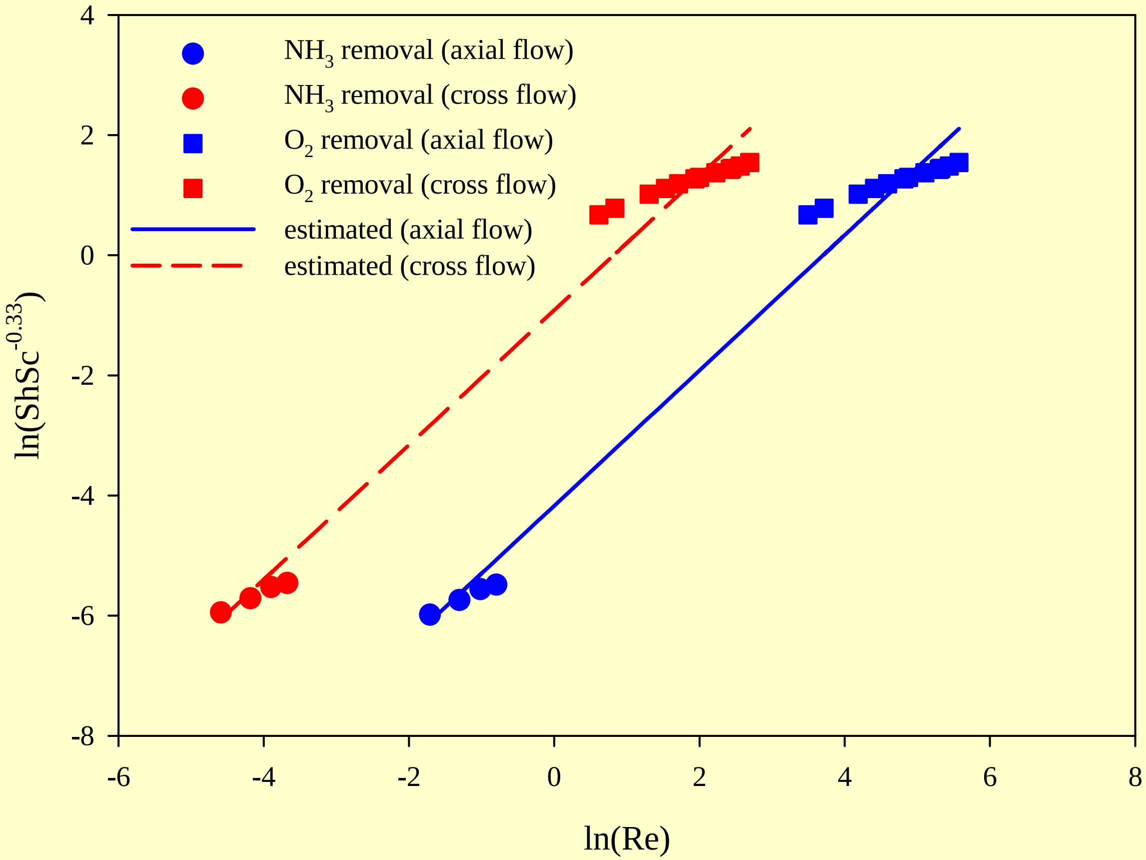


Fig. The correlation of shell side mass transfer of 4"x28" membrane contactor module

Results

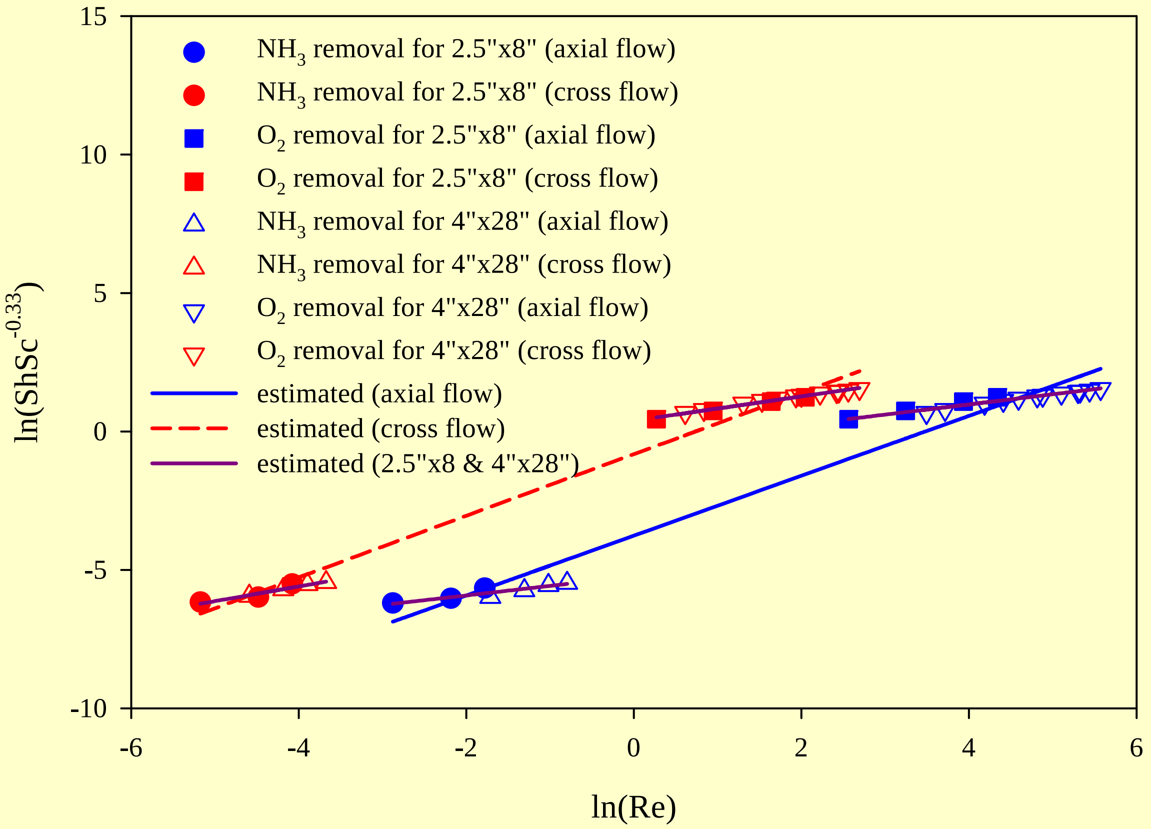


Fig. The correlation of shell side mass transfer for 2.5"x8" and 4"x28" membrane contactor modules

Conclusions

- We obtained the correlations of mass transfer in counter-current flow and cross flow.
- The correlatoins of mass transfer were applicable to the ammonia and oxygen stripping systems in wide range of size.