Membrane processes

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Lecture 12

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Reference book: Membrane Technology and Applications, R. W. Baker, Wiley 2012 (3rd ed.)

Question 1

https://forms.gle/wuA56tTr8HgGRZkJ6

The flux through the membrane in a gas separation process is driven by the gradient in:

a. Chemical potential
b. Total pressure
c. Partial pressure
d. Concentration

More than one can be correct!

Question 2

Cross-current flow arrangement is characterized by the fact that:

a. Driving force is very high
b. There is no mixing in the permeate channel
c. Pressure drops are negligible
d. Process is isothermal

Question 3

The configuration that reduces the membrane area for a given separation is:

a. Cross-current flow
b. Co-current flow
c. Counter-current flow
d. They have the same area

Question 4

A recycle loop in the double-stage process is used to:

a. Increase feed pressure
b. Increase feed concentration in the first stage
c. Increase feed concentration in the second stage
d. Increase product purity

Question 5

The parameters used to model the behavior of a membrane material are:

a. Membrane thickness
b. Membrane permeance
c. Membrane selectivity
d. Membrane density

More than one can be correct!

Question 6

The CO_2 recovery of the membrane process is:

a. The ratio between CO_2 flow in the permeate and CO_2 flow in the feed
b. The ratio between CO_2 flow in the retentate and CO_2 flow in the feed
c. The ratio between CO_2 flow in the permeate and CO_2 flow in the retentate
d. The fraction of CO_2 in the permeate

Question 7

If a membrane has CO_2/N_2 selectivity of 30, we should expect:

a. A CO_2 concentration in the retentate higher than in the feed
b. A CO_2 concentration in the permeate higher than in the feed
c. Same CO_2 concentration in the feed and in the permeate
d. CO_2 concentration in the permeate cannot be higher than in the feed

In-class exercise

CO2/N2 separation with membrane discretization

- A gas permeation module with cross-current flow arrangement is separating CO2 from N2 using a membrane with a CO2/N2 selectivity of 16.9 and CO2 permeability of 3.3×10^{-14} mole m^{-1} s^{-1} Pa^{-1}. Feed to the membrane contains 20 mol% CO2. Feed and retentate pressure are 5.5 bar and permeate pressure is 1 bar. Membrane thickness is 1.0 μm.
- Membrane area is 60 m^2 and Q_{feed} is 1 mol/s. Calculate the outlet purity and recovery.

➢ Area of the discretization element: 1 m^2

dA	Area	Xf	Qf	Xperm	J CO2	J N2	J tot	Qr	Xr
1	1	0.2	1	calc	calc	calc	calc	calc	calc
1	2	Xr	Qr	calc	calc	calc	calc	calc	calc
…	…								
1	60	Xr	Qr	calc	calc	calc	calc	calc	calc

First element:

$$X_{CO2,perm} = \frac{1 + (16.9 - 1)\left(\frac{1}{5.5} + 0.2\right) - \sqrt{\left[1 + (16.9 - 1)\left(\frac{1}{5.5} + 0.2\right)\right]^2 - 4 \times 16.9 \times \frac{1}{5.5}(16.9 - 1)0.2}}{2\,\frac{1}{5.5}(16.9 - 1)} = 0.65$$

$$J_{CO2} = 3.3 \times 10^{-8}(5.5 \times 0.2 - 1 \times 0.65) \times 10^5 = 1.48 \times 10^{-3}\ {}^{mol}/_{m^2 s}$$

$$J_{N2} = \frac{3.3 \times 10^{-8}}{16.9}\big(5.5 \times (1-0.2) - 1 \times (1-0.65)\big) \times 10^5$$
$$= 7.9 \times 10^{-4}\ {}^{mol}/_{m^2 s}$$

$$J_{tot} = J_{CO2} + J_{N2} = 2.27 \times 10^{-3}\ {}^{mol}/_{m^2 s}$$

$$Q_r = 1 - 2.27 \times 10^{-3} \times 1 = 0.99\ mol/s$$

$$X_{CO2,r} = \frac{0.2 \times 1 - 1.48 \times 10^{-3} \times 1}{0.99} = 0.199$$

Next element:

$$Q_f[1] = Q_r[0] = 0.99\ mol/s$$

$$X_{CO2,f}[1] = X_{CO2.r}[0] = 0.199\ mol/s$$

→ same calculations as in the first element

- Equations applied for each element until the end of the area (60 elements)

$$Q_{p,out} = 1 - 0.88 = 0.12\ mol/s$$

$$X_{CO2,p,out} = \frac{0.2 \times 1 - 0.15 \times 0.88}{0.12} = 0.59$$

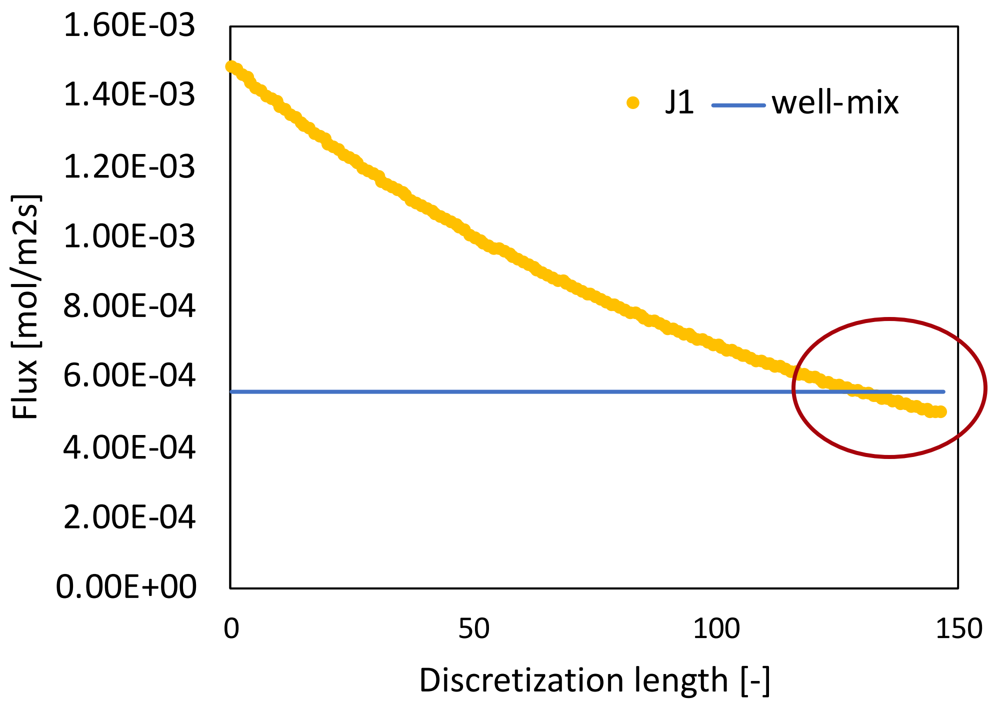
$$Recovery = \frac{0.12 \times 0.59}{1 \times 0.2} = 0.35$$

- Which is the area needed to produce 65% recovery?

$$Area = 147\ m^2$$

Comparison with the well-mixed case

- Target: 65% recovery



$X_{CO2,r}$ ~0.1