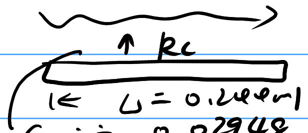
CHE 318 L20

Case 2 parallel to plate



$\mu = 8.71\times10^{-4}$ Pa·s

$\rho = 996$ kg/m^3

$C_{Ai} = 0.02948$ kgmol/m^3

$$N_{Re} = \frac{996 \cdot 0.244 \cdot 0.0610}{8.71\times10^{-4}} = 1.700\times10^{4}$$

Liquid ! Turbulent flow

$$N_{Sc} = \frac{8.71\times10^{-4}}{996 \times 1.245\times10^{-9}} = 702$$

$$j_D = 0.99 \cdot N_{Re,L}^{-0.5} = 0.99\times(1.700\times10^{4})^{-0.5} = 0.00758$$

Use either $j_D \to k_c'$ or $j_D \to N_{Sh} \to k_c'$

$$k_c' = j_D \cdot v \cdot N_{Sc}^{-\frac{2}{3}} = 0.00758 \times 0.0610 \times 702^{-\frac{2}{3}}$$

$$= 5.85\times10^{-6} \text{ m/s} \quad (\text{slow coefficient})$$

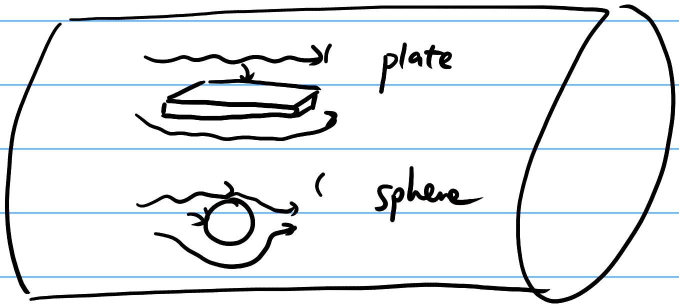
$x_{Bm} \simeq 1 \Rightarrow k_c \simeq k_c'$ ($C_{water} \doteq 55$ kgmol/m^3)

$$N_A \doteq k_c'(C_{Ai} - 0) = 5.85\times10^{-6} \times 0.02948 = 1.726\times10^{-7} \text{ kg mol/m}^2\text{/s}$$

How does geometry affect the conclusion?

Consider case 3. Estimate k_G kg mol/(m^2·s·Pa)

water vapour $T = 338.6\,K$ $p = 101.32\,kPa$



Large duct

$\rightarrow v_m = 3.66\,m/s$

physical property of air

$\mu = 2.03\times10^{-5}\,Pa\cdot s$

$\rho = 1.043\,kg/m^3$

$D_{AB} = 2.88\times10^{-5}\,m^2/s$

$T = 315\,K$

Mass transfer from water vapour to solid

a) If it's sphere $D = 25.4\,mm$

b) Flat surface $L = 25.4\,mm$

c) Packed bed $D = 25.4\,mm$ $\varepsilon = 0.35$

Step 1: Get physical quantities

μ ✓ ρ ✓ D_{AB} ? Use Fuller method

✓ $D_{AB}(338.6\,K) = 2.88\times10^{-5} \times \left(\frac{338.6}{315}\right)^{1.75} = 3.268\times10^{-5}\,m^2/s$

Which dimensionless number constant?

$$N_{Sc} = \frac{\mu}{\rho D_{AB}} = \frac{2.03\times10^{-5}}{1.043\times3.268\times10^{-5}} = 0.596$$

For all geometries, we have $L_D = 25.4\,mm$

$$N_{Re} = \frac{L_D\cdot v\cdot\rho}{\mu} = \frac{0.0254\times3.66\times1.043}{2.03\times10^{-5}} = 4776$$

Case a) Sphere. Which regime?

Gas + High Reynolds

$$N_{Sh} = 2 + 0.552 \cdot N_{Re}^{0.53} \cdot N_{Sc}^{1/3} = 43.40$$

(convection >> diff)

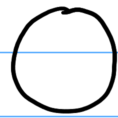
$$k_c' = \frac{N_{Sh} \cdot D_{AB}}{L} = \frac{N_{Sh} \cdot D_{AB}}{D} = \frac{43.40 \times 3.268 \times 10^{-5}}{0.0254}$$

$$= 0.056 \ \text{m/s}$$

$pV = nRT \leftrightarrow p = CRT$

$$k_G' = k_c' / RT = 0.0492 / (8314 \times 338.6$$

$$= 1.984 \times 10^{-8} \ \frac{\text{kg mol}}{\text{m}^2 \cdot \text{s} \cdot \text{Pa}}$$



Case b) Flat surface which regime?

Here still $N_{Re} < 15{,}000$ gas Laminar!

$$j_D = 0.664 \cdot N_{Re}^{-0.5} = 0.664 / \sqrt{4776} = 0.0096$$

$$N_{Sh} = j_D \cdot N_{Re} \cdot N_{Sc}^{\frac{1}{3}} = 0.0096 \times 4776 \times 0.569^{\frac{1}{3}}$$

$$= 38.026$$

$$k_c' = \frac{N_{Sh} \cdot D_{AB}}{L} = 0.0489 \ \text{m/s}$$

$$k_G' = 1.738 \times 10^{-8} \ \text{kg mol} / (\text{m}^2 \cdot \text{s} \cdot \text{Pa})$$

c) Packed Bed ? $v \Rightarrow$ superficial velocity w/o packs

Gas use relation 1

$$j_D = \frac{0.4548}{\varepsilon} N_{Re}^{-0.4069}$$

$$= \frac{0.4548}{0.35} (4776)^{-0.4069} = 0.04138$$

$$N_{Sh} = j_D N_{Re} N_{Sc}^{\frac{1}{3}} = 0.04138 \times 4776 \times (0.596)^{\frac{1}{3}}$$

$$= 166.32$$

$$k_c' = \frac{N_{Sh} \cdot D_{AB}}{L} = 0.2140 \text{ m/s}$$

$$k_G' = k_c'/RT = 7.60 \times 10^{-8} \text{ kg mol}/(\text{m}^2 \cdot \text{s} \cdot \text{Pa})$$

k_c, k_G and N_{Sh} ranking

Flat surface < single sphere < packed bed

why ?

Packed bed mass balance

$$\text{In} - \text{Out} + \text{Gen} = \cancel{\text{Acc}}$$

$$Q(C_{A1} - C_{A2}) + N_A \cdot A = 0$$

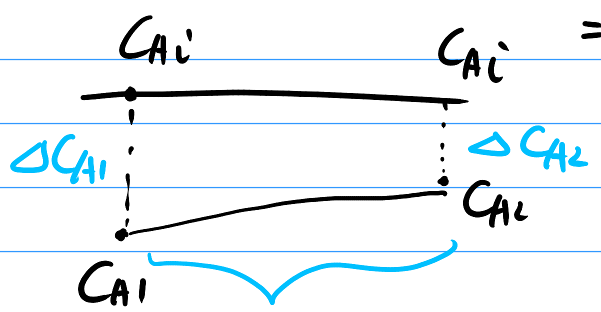
$$A \cdot N_A = Q \cdot (C_{A2} - C_{A1})$$

$$A = \frac{6(1-\varepsilon)}{D_p} \cdot V_b$$

N_A ?

$$N_A = k_c \frac{(C_{Ai} - C_{A1}) - (C_{Ai} - C_{A2})}{\ln\left(\frac{C_{Ai} - C_{A1}}{C_{Ai} - C_{A2}}\right)}$$

$$= k_c \cdot \text{LogMean}[(C_{Ai} - C_{A1}), (C_{Ai} - C_{A2})]$$



Driving force is logmean of ΔC_{A1} & ΔC_{A2}

Alternative form for packed bed

$$A \cdot k_c \frac{(C_{Ai} - C_{A1}) - (C_{Ai} - C_{A2})}{\ln\left(\frac{C_{Ai} - C_{A1}}{C_{Ai} - C_{A2}}\right)}$$

$$= A \cdot k_c \frac{\cancel{C_{A2} - C_{A1}}}{\ln\left(\frac{C_{Ai} - C_{A1}}{C_{Ai} - C_{A2}}\right)}$$

$$= Q \, \cancel{(C_{A2} - C_{A1})}$$

$$\ln\left(\frac{C_{Ai} - C_{A1}}{C_{Ai} - C_{A2}}\right) = \frac{A k_c}{Q}$$

$$\frac{C_{Ai} - C_{A1}}{C_{Ai} - C_{A2}} = \exp\left(\frac{A k_c}{Q}\right)$$

$$C_{A2} = C_{Ai} - (C_{Ai} - C_{A1}) \cdot \exp\left(-\frac{A k_c}{Q}\right)$$

analog: reactive wall

$$C_{A2} = C_{Ai} - (C_{Ai} - C_{A1}) \cdot \exp\left(-\frac{4 k_c}{v_m} \cdot \frac{L}{D}\right)$$

$$Q \doteq v_m \cdot \frac{\pi D^2}{4}$$

$$A = \frac{6(1-\varepsilon)}{D_p} \cdot V_b \qquad \frac{A}{Q} = \frac{4 a \cdot V_b}{\pi v_m D^2} = \frac{4 a \pi D^2 L}{\pi v_m D^2}$$

If a tube $V_b = \pi D^2 L$

so $$\frac{A}{Q} = \frac{4 a \cdot D}{v_m} \cdot \frac{L}{D}$$

only differ by factor $a \cdot D$

How long do we need the packed tower to be?

For saturation, let $\frac{A \cdot k_c}{Q} = 5$ (exp part is $\exp(-5) \approx 0.006$)

Previous example

$k_c = 0.2140 \text{ m/s}$

$$A = \frac{6(1-\varepsilon)}{D_p} \cdot \frac{\pi D^2}{4} \cdot H$$

$$Q = U_m \cdot \frac{\pi D^2}{4}$$

$$\frac{A \cdot k_c}{Q} = \frac{6(1-\varepsilon)}{D_p} \cdot \frac{H \cdot k_c}{U_m} = 5$$

$$H = \frac{5 \cdot \underbrace{U_m}_{\Rightarrow 3.66 \text{ m/s}} \cdot \underbrace{D_p}_{\Rightarrow 0.0254}}{6(1-\underbrace{\varepsilon}_{0.35}) \underbrace{k_c}_{\Rightarrow 0.2140 \text{ m/s}}} =$$