In-class exercise problem 1

You are responsible for the fabrication of a sensor involving patterning Si wafer with the aid of a 540 nm thick polymer film (photoresist). In the last step, the photoresist needs to be removed. The process involves soaking the photoresist in a large reservoir of organic solvent. You noticed that the photoresist dissolves in 10 minutes. Calculate the mass transfer coefficient.

The solubility of photoresist in the solvent is 2.23×10^{-3} g/cm³.
The density of photoresist is 0.96 g/cm³.

$$N = \frac{dm}{dt} \; = \; kA(c_{1i} - c_1) = kAc_{1i} \; = \; \text{constant}$$

$c_1 = 0$ **Large reservoir**

$$\Rightarrow N = \frac{dm}{dt} \; = \; kAc_{1i} \; = \; \text{constant}$$

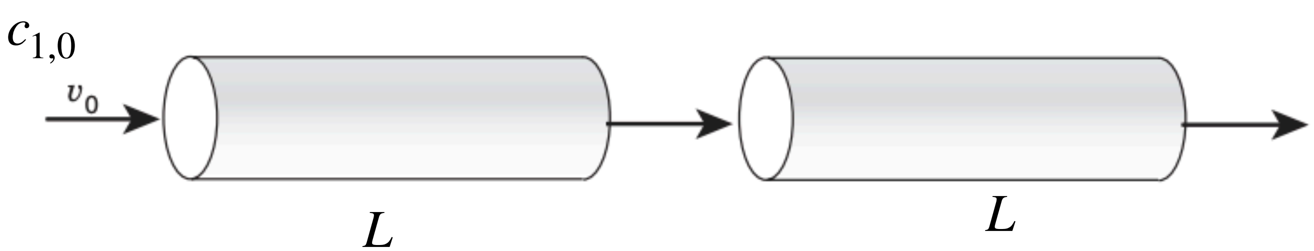
$$\Rightarrow m = kAc_{1i}t \qquad \Rightarrow k = \frac{m}{Ac_{1i}t} = \frac{540 * 10^{-9} * A * 960}{A * 2.23 * 10 * 60}$$

$$k = 3.87 * 10^{-7} \text{ m/s}$$

In-class exercise problem 2

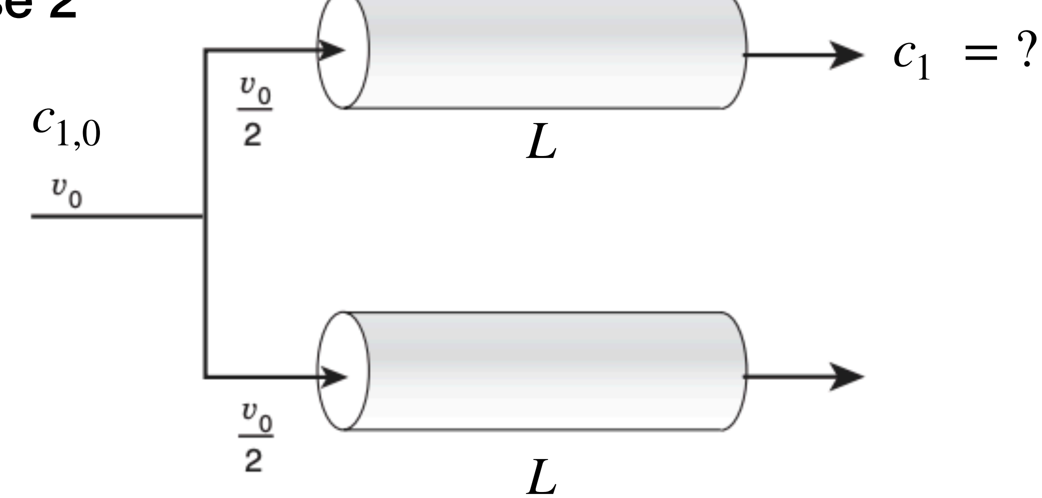
Compare the two cases with irreversible reaction in packed bed and calculate c_1 in case 2.

Case 1



$$c_1 = 0.9\, c_{1,0}$$

Case 2



$$\frac{k}{v^0} = 1.17 \left(\frac{dv^0}{\nu}\right)^{-0.42} \left(\frac{D}{\nu}\right)^{2/3}$$

$$c_1 = c_{1,0} \exp\left(-\frac{kaz}{v}\right)$$

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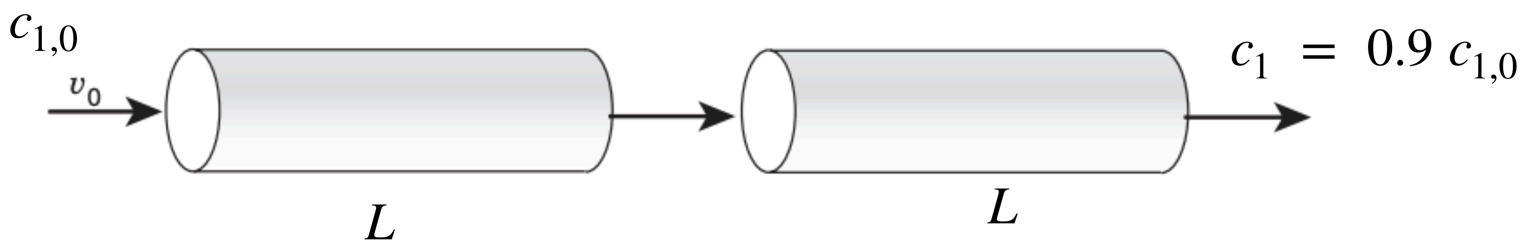
Case 1



$$\frac{k}{v^0} = 1.17 \left(\frac{dv^0}{\nu}\right)^{-0.42} \left(\frac{D}{\nu}\right)^{2/3}$$

$$c_1 = c_{1,0} \exp\left(-\frac{kaz}{v^0}\right)$$

$$z = 2L$$

$$k = constant * (v^0)^{0.58}$$

$$c_1 = c_{1,0} \exp\left(-\frac{constant * (v^0)^{0.58} a(2L)}{v^0}\right)$$

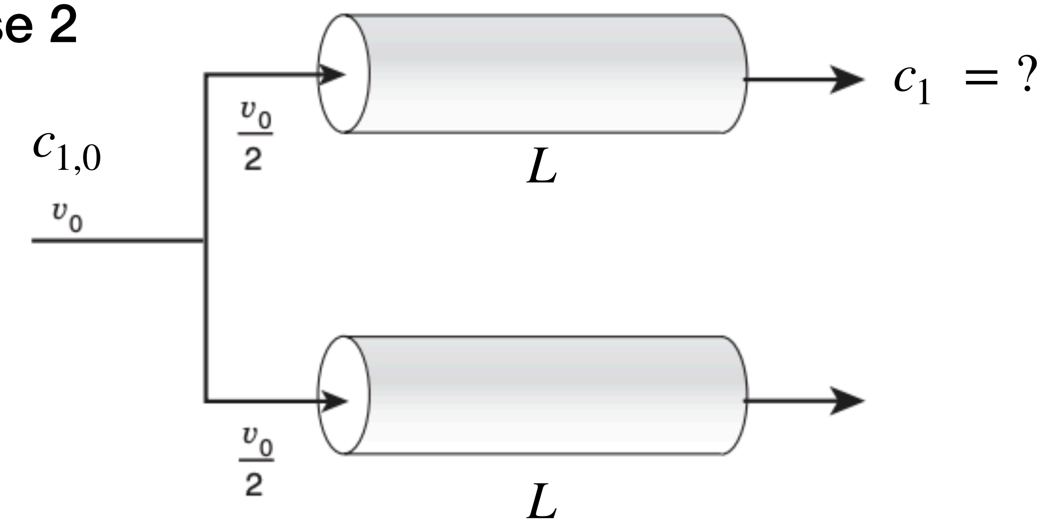
$$c_1 = c_{1,0} \exp\left(-\frac{2 * constant * aL}{(v^0)^{0.42}}\right) = 0.9c_{1,0}$$

$$\Rightarrow \frac{2 * constant * aL}{(v^0)^{0.42}} = -\ln(0.9)$$

In-class exercise problem 2

Compare the two cases with irreversible reaction in packed bed and calculate c_1 in case 2.

Case 2



$z = L$

$$c_1 = c_{1,0} \exp\left(-\frac{kaz}{(v^0/2)}\right)$$

$$\frac{k}{v^0} = 1.17\left(\frac{dv^0}{\nu}\right)^{-0.42}\left(\frac{D}{\nu}\right)^{2/3}$$

$$k = constant * (v^0/2)^{0.58}$$

$$\Rightarrow c_1 = c_{1,0} \exp\left(-\frac{constant * (v^0/2)^{0.58} aL}{v^0/2}\right)$$

$$\Rightarrow c_1 = c_{1,0} \exp\left(-\frac{constant * aL}{(v^0/2)^{0.42}}\right)$$

$$\Rightarrow c_1 = c_{1,0} \exp\left(-\frac{2^{0.42} constant * aL}{(v^0)^{0.42}}\right)$$

$$\frac{2 * constant * aL}{(v^0)^{0.42}} = -\ln(0.9)$$

$$\Rightarrow c_1 = c_{1,0} \exp(2^{0.42} * \ln(0.9)/2) = 0.93 c_{1,0}$$

EPFL

Exercise problem 1:

NH_3 is being irreversibly absorbed in water using a packed bed contactor. The contactor height was designed to reduce NH_3 concentration by 100 fold. However, when experiments were carried out, the concentration only decreased by 10-fold. After some analysis, you found out that this could be because of bypass. Calculate the extent of bypass.

Exercise problem 1: Solution

NH_3 is being irreversibly absorbed in water using a packed bed contactor. The contactor height was designed to reduce NH_3 concentration by 100 fold. However, when experiments were carried out, the concentration only decreased by 10-fold. After some analysis, you found out that this could be because of bypass. Calculate the extent of bypass.

$$\frac{c_{1L}^{ideal}}{c_{10}} = \frac{1}{100} \qquad \frac{c_{1L}^{real}}{c_{10}} = \frac{1}{10} \qquad c_{1L}^{real} = \theta c_{10} + (1-\theta) c_{1L}^{ideal}$$

$$\Rightarrow \frac{c_{1L}^{real}}{c_{10}} = \theta + (1-\theta)\frac{c_{1L}^{ideal}}{c_{10}}$$

$$\Rightarrow \frac{1}{10} = \theta + (1-\theta)\frac{1}{100}$$

$$\Rightarrow \theta = \frac{1}{11}$$

EPFL

Exercise problem 2

You are doing a mass transfer related experiment for poorly soluble benzoic acid in water to use benzoic acid as a food preservative at 25 ºC. For this, you added benzoic acid pellets at the bottom of the cylindrical water jar at t=0. The jar diameter is 10 cm. Its height is 20 cm and is completely filled with water. You carried two different experiments.

When there is no stirring, it takes 60 minutes to reach benzoic acid concentration 1.5 g/L at a height of 1 mm from the bottom. Concentration at the top of jar at 60 minutes was 0. Note that the concentration reaches 3 g/L everywhere after a very long time.

When there is vigorous stirring, benzoic acid concentration becomes 1.5 g/L in 5 minutes. Assume a uniform bulk concentration with stirring.

Calculate the mass transfer coefficient when stirring is used.

Also estimate
(i) the thickness of the boundary layer for mass transfer assuming the film theory for mass transfer coefficient, and
(ii) surface renewal time assuming the surface renewal theory for mass transfer.

$$\frac{c(z,t) - c_S}{c_\infty - c_S} = erf\,\zeta \;=\; \frac{2}{\sqrt{\pi}}\int_0^{\zeta} \exp(-r^2)dr$$

Solution to Exercise problem

In the absence of stirring

$$\frac{c(z,t) - c_S}{c_\infty - c_S} = erf\ \zeta \ = \ \frac{2}{\sqrt{\pi}} \int_0^\zeta \exp(-r^2) dr$$

$$erf\ \zeta = \frac{1.5 - 3}{0 - 3} = 0.5$$

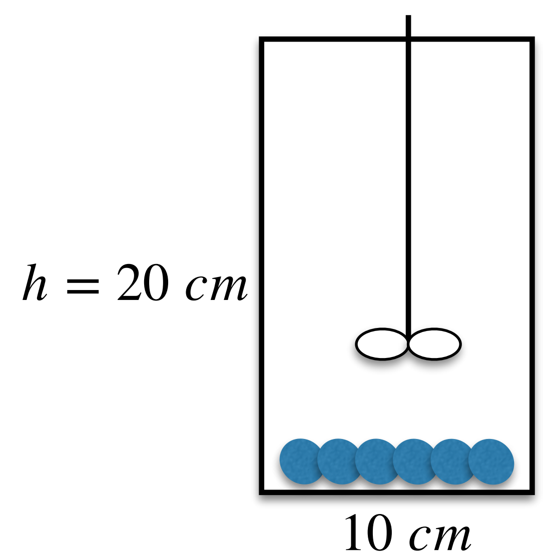
$$\Rightarrow \zeta = 0.48 \qquad \zeta = \frac{z}{\sqrt{4Dt}}$$

$$\Rightarrow \frac{z^2}{4Dt} = 0.48^2 = 0.23 \qquad \Rightarrow D = 3 \times 10^{-10}\ m^2/s$$

Mass balance in the case of stirred reactor

$$\frac{d(cV)}{dt} \ = \ kA(c_s - c)$$

$$\Rightarrow \frac{dc}{dt} \ = \ \frac{k}{h}(c_s - c)$$



$$\Rightarrow \frac{dc}{dt} = \frac{k}{h}(c_s - c)$$

Solving this with boundary condition $t = 0, \;\; c = 0$

$$\ln\left(\frac{c_s - c}{c_s}\right) = -\frac{k}{h}t$$

$$\Rightarrow k = -\frac{h}{t}\ln\left(\frac{c_s - c}{c_s}\right)$$

$$\Rightarrow k = 4.6 \times 10^{-4} \; m/s$$

Film theory: $\delta = D/k = 6.5 \times 10^{-7} \; m$

Surface renewal time : $\tau = D/k^2 = 1.4$ milliseconds

EPFL