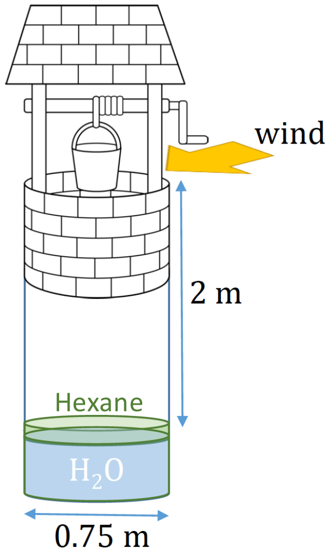
Introduction to Transport Phenomena: Exercises Module 4

Exercise 4.1

(only Fick's Law)

n-hexane in the well: Oops! You accidently spilled 5 liters of hexane down a will with a depth of 2m and a diameter of 0.75m. Since the well is outside (20°C, 1bar), where it is assumed to be windy, it is possible to just let the hexane evaporate. Can you estimate how long it would take for the hexane to completely evaporate considering it is isothermal at 20°C? Consider a linear concentration profile.

Useful data: the vapor pressure of hexane at 20°C is 0.16bar $D_{hex-air} = 7.55 * 10^{-6} \frac{m^2}{s}$. Density of hexane is 660 kg/m^3, molar mass of hexane is 86 g/mol



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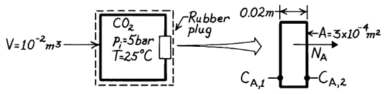
Exercise 4.2

(Fick's Law)

Pressure and temperature of CO_2 in a container of prescribed volume: The pressure and temperature of CO_2 in the container is known. Also the thickness and surface area of the rubber plug is known (see figure). Calculate the mass rate of CO_2 loss from the container. Also find the pressure reduction over a 24h time period.



The following *assumptions* are made:

- Loss of CO_2 is only by diffusion through the rubber plug
- One-dimensional diffusion through a stationary medium
- Diffusion rate is constant over the 24h period
- Perfect gas behavior
- Negligible CO_2 pressure outside the plug

Given values for the CO_2-rubber interaction (@ 298K, 1atm):

$$D_{AB} = 0.11 * 10^{-9} \frac{m^2}{s}$$

$$S = 40.15 * 10^{-3} \frac{kmol}{m^3 bar}$$

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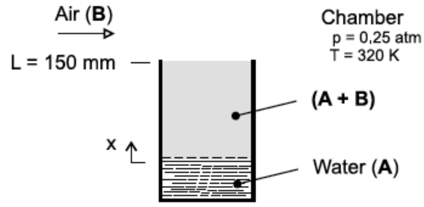
Exercise 4.3

(Evaporation of a liquid through a column of flowing gas)

Water evaporation: A column contains liquid water (phase A) which evaporates into air (phase B). Find the evaporation rate of water $\left(\frac{kg}{hm^2}\right)$ using the value of the binary diffusion coefficient for the water vapor-air mixture (Phase A+B).
The following values are given:



$$D_{AB} = 1.157 * 10^{-4} \frac{m^2}{s}$$

$$P_{sat} = 0.1053\ bar$$

The following *assumptions* are made:

- Steady-state, one-dimensional diffusion in the column
- Constant properties
- Uniform temperature throughout the column
- Water vapor exhibits ideal gas behavior
- Negligible water vapor in the chamber air

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Exercise 4.4

(Application of mass transfer coefficient)

Mass transfer of Formaldehyde: Water containing a small amount of formaldehyde ($c_{A,L,bulk} = 3.3mM$) is produced by a waste stream of a chemical plant. A pool of the waster water is released outside and the overall flux of formaldehyde into the air ($c_{A,G,bulk} = 0mM$)is estimated to be $n_{A,0} = 2.01 * 10^{-7} \frac{mol}{m^2s}$. The equilibrium relation between the concentration of formaldehyde in the liquid and the gas is $H = \frac{c_{A,G}}{c_{A,L}}$ where $H = 2.0 * 10^{-5}$ at 25°C. The local mass transfer coefficient on the gas side is known to be $17.9 \frac{m}{hr}$. Can you estimate the mass transfer coefficient on the liquid side, $k_{A,L}^{app}$ and the overall mass transfer coefficients for both the liquid and gas phases $K_{A,G}^{app}$, $K_{A,L}^{app}$. Is mass transfer on one side limiting?

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Exercise 4.5

(Application of mass transfer coefficient)

The mass transfer coefficient in a blood oxygenator: Blood oxygenators are used to replace the human lungs during open-heart surgery. To improve oxygenator design, you are studying mass transfer of oxygen into water in one specific blood oxygenator. From published correlations of mass transfer coefficients, you expect that the mass transfer coefficient based on the oxygen concentration difference in the water is 3.3 × 10^{-3} centimeters per second ($K_{C,L}$). You want to use this coefficient in an equation given by the oxygenator manufacturer: $n_{O2} = K_{p,G}(p_{O2,bulk} - p_{O2,eq})$ where $p_{O2,bulk}$ is the actual oxygen partial pressure in the gas, and $p_{O2,eq}$ is the hypothetical oxygen partial pressure that would be in equilibrium with water under the experimental conditions. The manufacturer expressed both pressures in millimeters of O_2. You also know the Henry's law (equilibrium) constant of oxygen in water at your experimental conditions:

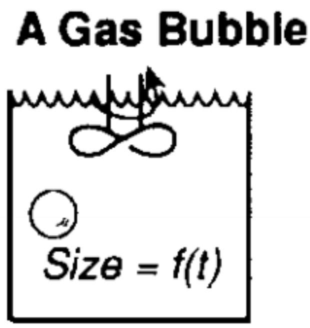
p_{O2}= 44,000 atm x_{O2}, where x_{O2}, is the mole fraction of the total oxygen in the water.

Can you find the mass transfer coefficient $K_{p,G}$?

Exercise 4.6

(Application of mass transfer coefficient)

Mass transfer from an oxygen bubble: A bubble of pure oxygen gas originally 0.1 centimeter in diameter is injected into excess stirred water, as shown schematically in the figure. The water has an initial concentration of O_2 of zero. After 7 minutes, the bubble is 0.054 centimeter in diameter. Estimate the mass transfer coefficient on the liquid side assuming that the mass transfer resistance on the gas side is small, and using the oxygen concentration at saturation in water: about 1.5 x 10^{-3} moles per liter under these conditions. Assume a constant pressure of 1 bar.



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