ChE 333

Problem 1: A wetted-wall column is sometimes used to strip volatile organic solutes such as TCE from an aqueous solution. To estimate the gas film coefficient (k_G) for a wetted-wall column, a mass-transfer correlation for a gas flow through a pipe can be used but for the liquid film coefficient (k_L) a mass-transfer correlation for a gaseous solute to a falling liquid film is used. Following the steps below, determine the overall mass-transfer coefficient, K_L, for TCE stripping from water into an airstream at 293K. Assume that water evaporation is negligible.

A schematic of the wetted wall column is shown below. The column is 2.0 m high and has an inner diameter of 4.0 cm. The column is run in counter current direction, the air bulk velocity is v_∞=0.40 m/s and mass flow rate of the water is 0.05 kg/s. Correlations for Sh number for flow through a pipe for different Re numbers are listed in section 30.2 WRF 6th and 7th ed and *on the second page of this worksheet.*

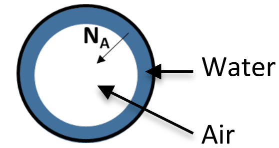
A. Determine the overall K_L

B. Evaluate the concentration of TCE vapor in the air stream exciting the wetted-wall column. (here you need to do a mass balance and integrate, amount coming in/out is (c_A v πr^2) at x and x+Δx plus the flux from the liquid $N_A \pi 2r$).

Hint (suggested steps) to find the overall K_L is to first determine k_G and k_L,

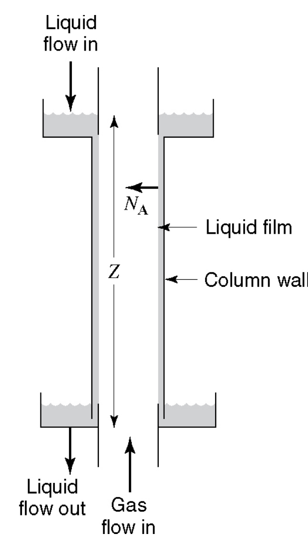
a. Calculate the gas film mass transfer coefficient (k_G) [kgmole/m^2 s atm]?

i. Write a flux equation for flux from the bulk gas to the gas-liquid interface.
ii. To calculated k_G, should you use the properties of the gas or the liquid?
iii. Calculate Re. Is the flow laminar or turbulent?
iv. Determine k_G



Top and cross-sectional view of wetted wall column

To determine k_L for the liquid, we need to use a Sh number correlation for convective mass transfer of gaseous solute into a falling liquid film wetting the inner surface of a tube shown below. The Re number for liquid flowing down the inner surface of the wetted tube.



b. Suggested steps to calculate the liquid film mass transfer coefficient (k_L) [m/s]?

i. Write a flux equation for flux from the bulk liquid to the gas-liquid interface.
ii. To calculated k_L, should you use the properties of the gas or the liquid?
iii. Determine k_L using the appropriated correlation for Sh number.

c. Calculate the overall liquid-phase mass-transfer coefficient, K_L

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Useful data:

The equilibrium solubility of TCE in water follows Henry's law:
$p_{A,i} = H\, c_{A,i}$ were H=9.92 m^3 atm/kgmole

	Air (293 K)	Water (293 K)
Density (ρ)	1.19 kg/m^3	998.2 kg/m^3
Viscosity (μ)	1.84 x 10^{-5} kg/m s	9.93 x 10^{-4} kg/m s
Diff. coef. TCE- air/water	8.0 x 10^{-6} m^2/s	8.9 x 10^{-10} m^2/s

Sherwood number for falling liquid film:

$$Sh = 0.433 Sc^{1/2}\left(\frac{\rho_L^2 \cdot g \cdot z^3}{\mu_L^2}\right)^{1/6} Re_L^{0.4} \qquad Re_L = \frac{4w}{\pi D \mu_L}$$

w is mass velocity.

Convective Mass transfer correlations for <u>flow through pipe</u> (30.2 WRF 6th ed.)

Sieder-Tate eqn	$Sh = 1.86\left(\frac{D}{L} Re \cdot Sc\right)^{1/3}$	Laminar flow Re < 2000 Re Sc (D/L) > 10
Linton and Sherwood	$Sh = 0.023 Re^{0.83} Sc^{1/3}$	Turbulent liquid flow 2000 < Re < 35,000 1000 < Sc < 2260
Gilliland and Sherwood	$Sh = \frac{P}{p_{B,lm}} 0.023 Re^{0.83} Sc^{0.44}$	Turbulent gas flow 2000 < Re < 35,000 0.6 < Sc < 2.5

Solution to part B.

$$ln\left(\frac{c_A^* - c_{Ao}}{c_A^* - c_{AL}}\right) = \frac{4k_c L}{Dv}$$

Part A. find K_L $\left[\frac{1}{K_L} = \frac{1}{k_L} + \frac{1}{H k_G} \right]$

a) determine k_G

i. Write a flux equation for flux from the bulk gas to the gas-liquid interface.

$$N_A = k_G \left(p_{Ai} - p_{AG} \right)$$

ii. To calculated k_G, should you use the properties of the gas or the liquid?

for k_G we are in gas phase so all gas phase properties

iii. Calculate Re. Is the flow laminar or turbulent?

gas flow through a pipe

$$Re = \frac{v_\infty D}{\nu_{air}} = \frac{(0.40)(0.04)}{1.55 \times 10^{-5}} = 1035 \text{ laminar}$$

iv. Determine k_G

Sh for laminar flow through a pipe

Sieder-Tate eqn , $$Sh = 1.86 \left(\frac{D}{L} Re \cdot Sc \right)^{1/3}$$

$$Sc = \frac{\nu_{air}}{D_{TCE\text{-}air}} = \frac{1.55 \times 10^{-5} \, m^2/s}{8.0 \times 10^{-6} \, m^2/s} = 1.93$$

$$k_c = \frac{D_{AB}}{D} 1.86 \left(\frac{D}{L} Re \cdot Sc \right)^{1/3} = 1.27 \times 10^{-3} \, m/s$$

$$N_A = k_c \left(C_{AG,i} - C_{AG} \right) = \underbrace{\frac{k_c}{RT}}_{=} \left(p_{AG,i} - p_{AG} \right)$$

$$\boxed{k_G = 5.29 \times 10^{-5} \, \text{kgmole}/m^2 \cdot s \cdot atm}$$

b) determine k_L

i. Write a flux equation for flux from the bulk liquid to the gas-liquid interface.

$$N_A = k_L (C_{AL} - C_{Ai})$$

ii. To calculated k_L, should you use the properties of the gas or the liquid?

k_L is for liquid so use properties of bulk liquid

iii. Determine k_L using the appropriated correlation for Sh number.

flow on the walls of a pipe

$$Sh = 0.433 Sc^{1/2} \left(\frac{\rho_L^2 \cdot g \cdot z^3}{\mu_L^2} \right)^{1/6} Re_L^{0.4}$$

$$Re_L = \frac{4w}{\pi D \mu_L} = \frac{(4)(0.05)}{\pi (0.04)(9.95 \cdot 10^{-7})} = 1603$$

$$Sc = \frac{\nu_{water}}{D_{TCE-water}} = \frac{(9.93 \times 10^{-4})}{(998.2)(8.9 \times 10^{-10})} = 1118$$

$$Sh_L = 5.74 \times 10^4$$

$$\boxed{k_L = 2.56 \times 10^{-5}\ m/s}$$

Determine K_L:

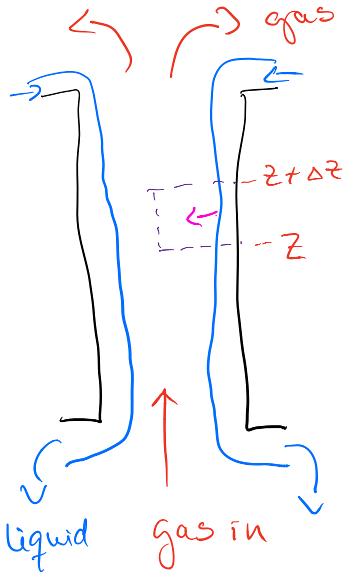
$$\frac{1}{K_L} = \frac{1}{k_L} + \frac{1}{H k_G} \rightarrow \boxed{K_L = 2.44 \times 10^{-5}\ m/s}$$

$\underline{\underline{K_L \simeq k_L}}$ liquid resistant

Part B.

find concentration of TCE in outlet vapor

Material balance



looking for gas phase concentration so do material balance for gas phas

$$\underbrace{\frac{\pi D^2}{4} v_\infty C_A \Big|_z + N_A \pi D \Delta z}_{\text{IN}} - \underbrace{\frac{\pi D^2}{4} v_\infty C_A \Big|_{z+\Delta z}}_{\text{out}} = 0$$

as $\Delta z \to 0$

$$\frac{dC_A}{dz} + N_A \frac{4}{v_\infty D} = 0$$

$\hookrightarrow K_G (C_A^* - C_A)$

could also use $K_L (C_{AL} - C_A^*)$

$$\int_{C_{A,in}}^{C_{A,out}} \frac{dC_A}{C_A^* - C_A} = -\frac{4 K_G}{v_\infty D} \int_0^L dz$$

assumed to be constant.

$$\ln\left(\frac{C_A^* - C_{AL,in}}{C_A^* - C_{AL,out}}\right) = \frac{4 K_G L}{v_\infty D}$$