EXAMPLE 13

14 April 2021 CM3120 MOD 4 LECTURE VI (part 2)

# CM3120: Module 4

## Diffusion and Mass Transfer II

Lecture VI continues (part b) →

I. Classic diffusion and mass transfer: d) EMCD
II. Classic diffusion and mass transfer: e) Penetration model
III. Unsteady macroscopic species A mass balances (Intro)
IV. Interphase species $A$ mass transfers—To an interface—$k_x, k_c, k_p$
V. Unsteady macroscopic species A mass balances (Redux)
VI. Interphase species $A$ mass transfers—Across multiple resistances—$K_L, K_G$
VII. Dimensional analysis
VIII. Data correlations

LEC VI b



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# Overall Mass Transfer Coefficients

**Example 13:**

A liquid stripping process ($20^oC$, $1.5\ atm$) is used to transfer hydrogen sulfide ($H_2S$ = species $A$) dissolved in water into an air stream. At a particular elevation in the column, the mole fraction of $H_2S$ in the gas phase is 0.010 and the mole fraction of $H_2S$ in the liquid phase is $6.0 \times 10^{-5}$. Calculate the flux, the overall mass transfer coefficients, and the interface composition.

1. Film coefficients: $k_x = 0.30 \frac{kmol}{m^2} s$, $k_y = 4.5 \times 10^{-3} \frac{kmol}{m^2\ s}$ (obtained from data correlations).
2. Equilibrium relationship: $p_A^*(atm) = \overline{H}\ c_A^* \left(\frac{mol\ H_2S}{m^3}\right)$, where $\overline{H} = 8.8 \times 10^{-3}\ m^3 atm/mol$.

WRF, Ch29, Ex 1



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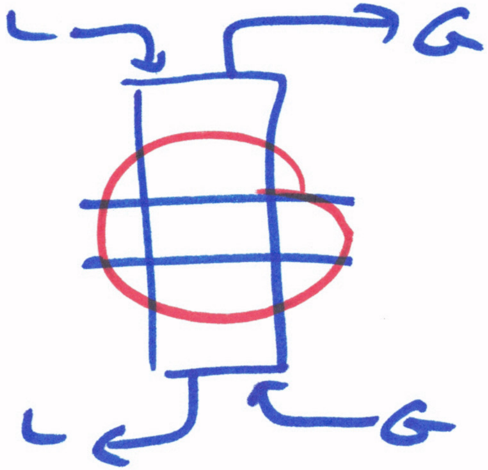
# EXAMPLE 13




c

$H_2S$ = species A

| GAS | LIQUID |
|---|---|
| $y_A = 0.010$ | $x_A = 6.0 \times 10^{-5}$ |
| $P_A = y_A P$ | $\Rightarrow C_A = 3.30485 \frac{\text{mol A}}{\text{m}^3 \text{ mix}}$ |
| $= 0.015$ atm | ($\rho$ 4) |

Calc: $N_A$, $K_L$, $K_G$, $x_{A_i}$; $y_{A_i}$

→

① deal w/units

LIQUID

A $H_2S$

W $H_2O = 1 - 6\times10^{-5}$

$= .999\ldots$

~ basically all water (B)

$$x_A C = C_A$$

$C$: $\frac{\text{mols mix}}{\text{volume mix}}$

$$\rho_B \cdot \frac{1}{\bar{M}_B}$$

$\frac{\text{mass } H_2O}{\text{vol } H_2O}$ $\frac{\text{mols } H_2O}{\text{mass } H_2O}$

$$C_A = x_A \frac{\rho_B}{M_B}$$

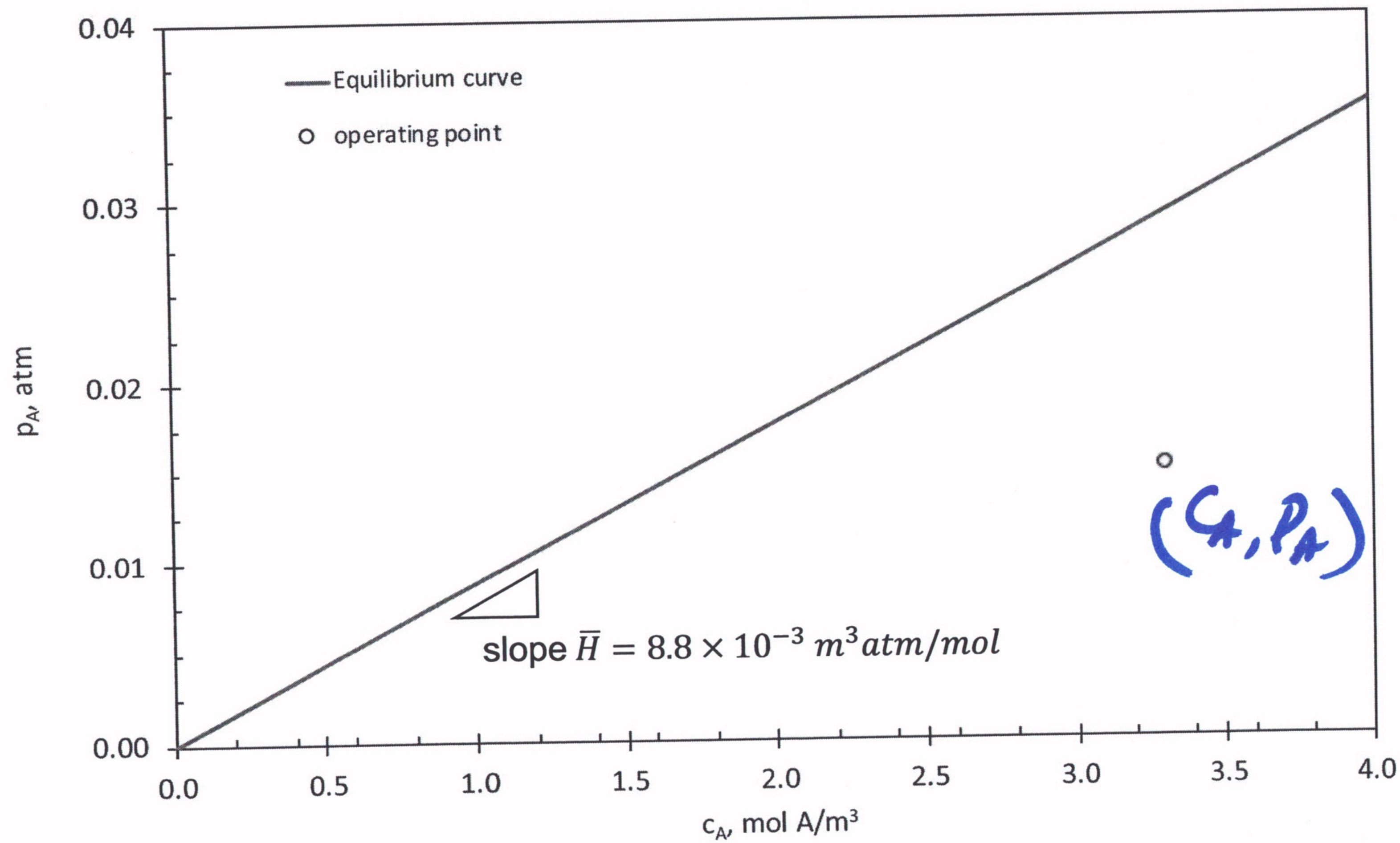
$$C_A = 3.30485 \; \frac{\text{mol A}}{\text{mol mix}}$$

$\Rightarrow$ operating point $(C_A, P_A)$

choose these units. (because equil curve)

**Example 13**: Liquid stripping process (remove $H_2S$ from water)

5



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Looking to calc $N_A$ (from film coef? from $k$? )
(objective (2))

to calc $c_{Ai}$, $p_{Ai}$
to calc $K_L$, $K_G$

$$N_A = k_c (c_{Ai} - c_A) = k_p (p_A - p_{Ai})$$

($k_c \Rightarrow \frac{k_x}{c}$, $k_p \Rightarrow \frac{k_y}{P}$)

$$= k_x (x_{Ai} - x_A) = k_y (y_A - y_{Ai}) \qquad x_A = \frac{c_A}{c}$$

$$= k_x \left( \frac{c_{Ai}}{c} - \frac{c_A}{c} \right) = k_y \left( \frac{p_A}{P} - \frac{p_{Ai}}{P} \right) \qquad \frac{p_A}{P} = y_A$$

$$= \frac{k_x}{c} (c_{Ai} - c_A) = \frac{k_y}{P} (p_A - p_{Ai})$$

Now, to calc $(C_{Ai}, P_{Ai})$:
(interface point)

(flux = in both phases)

$$N_A = \underbrace{k_c (C_{Ai} - C_A)}_{LIQ} = \underbrace{k_p (P_A - P_{Ai})}_{GAS}$$

$$k_p P_A - k_p P_{Ai} = k_c C_{Ai} - k_c C_A$$

intersect at $C_{Ai}, P_{Ai}$

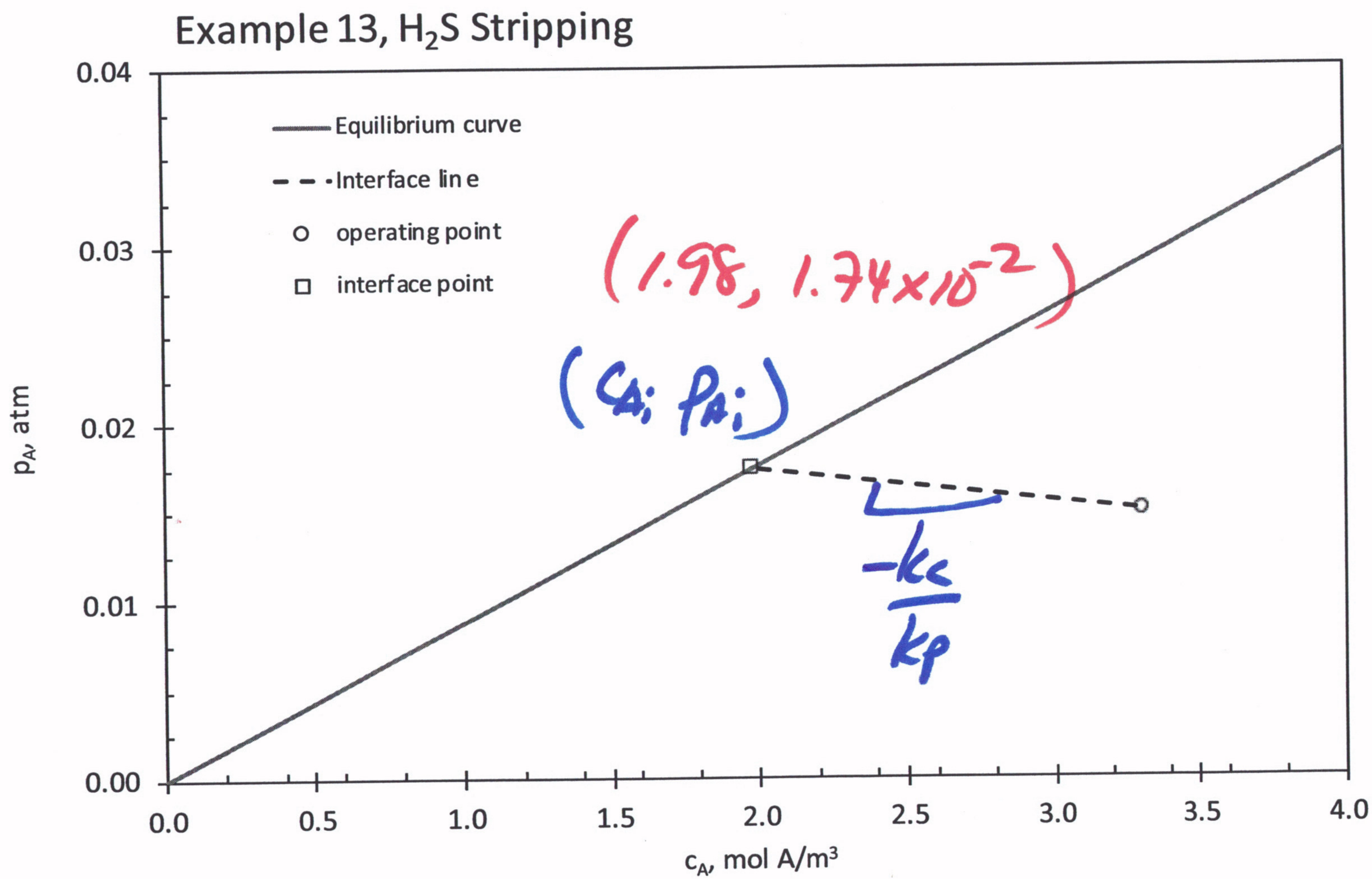
$$(P_A - P_{Ai}) = \underbrace{-\frac{k_c}{k_p}}_{slope} (C_A - C_{Ai})$$

equal flux magnitude in both phases

$$P_{Ai} = \bar{H} C_{Ai}$$

equilibrium curve

objective (1)


Example 13, $H_2S$ Stripping
Equilibrium curve
Interface line
operating point
interface point
(1.98, 1.74x10^-2)
(cAi, pAi)
-kc/kp
pA, atm
0.00
0.01
0.02
0.03
0.04
cA, mol A/m3
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

(9)



**Liquid-phase-units**
**Film Linear driving force model:**

$$N_A \equiv k_x(x_{A,i} - x_{A,b})$$
$$N_A \equiv k_{cL}(c_{AL,i} - c_{AL,b})$$

**Gas-phase-units:**
**Film Linear driving force model:**

$$N_A \equiv k_p(p_{A,b} - p_{A,i})$$
$$N_A \equiv k_{cG}(c_{AG,b} - c_{A,i})$$
$$N_A \equiv k_y(y_{A,b} - y_{A,i})$$

***Let's take these tools out for a spin!***

We know enough to calc $N_A$ from these (2) objective

**Liquid-phase-units**
**Overall Linear driving force model:**

$$N_A \equiv K_x(x_A^*(\ \ ) - x_{A,b})$$
$$N_A \equiv K_{cL}(c_{AL}^*(\ \ ) - c_{AL,b})$$

$$(\ \ ) = p_{A,b} \text{ or } c_{A,b} \text{ or } y_{A,b}$$

**Gas-phase-units:**
**Overall Linear driving force model:**

$$N_A \equiv K_p\left(p_{A,b} - p_A^*(\ \ )\right)$$
$$N_A \equiv K_{cG}\left(c_{AG,b} - c_{AG}^*(\ \ )\right)$$
$$N_A \equiv K_y\left(y_{A,b} - y_A^*(\ \ )\right)$$

$$(\ \ ) = x_{A,b} \text{ or } c_{AL,b}$$

$$N_A = -7.22545 \times 10^{-6} \frac{kmol}{m^2 s}$$

$$K_x = \frac{1}{\frac{1}{k_x} + \frac{1}{m'' k_y}},\qquad K_y = \frac{1}{\frac{1}{k_y} + \frac{m'}{k_x}}, \text{ etc.}$$



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Last objective:

calc $K_c, K_p$ (3)

$p_A^* = \bar{H} C_A^*$

$$K_c = \frac{N_A}{C_A^* - C_A} = \frac{N_A}{\frac{p_A}{\bar{H}} - C_A}$$

$$= \frac{\left(-7.22545\times10^{-6}\ \frac{\text{kmol}}{\text{m}^2\text{s}}\right)\left(\frac{10^3\ \text{mol}}{\text{kmol}}\right)}{\left(\frac{0.015\ \text{atm}}{\left(8.8\times10^{-3}\ \frac{\text{m}^3\ \text{atm}}{\text{mol}}\right)}\right) - 3.30485\ \frac{\text{mol}}{\text{m}^3}}$$

$$\boxed{K_c = 4.52\times10^{-3}\ \frac{\text{m}}{\text{s}}}$$

$$N_A = K_p\left(P_A - P_A^*(C_A)\right)$$

$$K_p = \frac{-7.22545 \times 10^{-6} \frac{kmol}{m^2 s}}{\left(0.015\,atm - \left(8.8 \times 10^{-3} \frac{m^3 atm}{mol}\right)\left(3.30485 \frac{mol}{m^3}\right)\right)}$$

$$K_p = 5.13 \times 10^{-4} \frac{kmol}{m^2\,atm\,s}$$