Tyler Bradley | ENVE 660 | HW #4 | 2/24/18

1.

(A)	(B)	(C)	(D)
$V_B = 4L$	$V_B = 4L$	$V_B = 3L$	$V_B = 3L$
$V_g = 0.5L$	$V_g = 1L$	$V_g = 1.5L$	$V_g = 2L$
$P_{tot} = 2$ atm	$P_{tot} = 2$ atm	$P_{tot} = 3$ atm	$P_{tot} = 3$ atm
$T = 298$ K	$T = 298$ K	$T = 293$ K	$T = 293$ K
$C_B = 0.05 \frac{mol}{L}$	$C_B = 0.05 \frac{mol}{L}$	$C_B = 0.04 \frac{mol}{L}$	$C_B = 0.04 \frac{mol}{L}$

$H_{pm,B} = 0.556 \frac{atm}{mol/L}$

$MW_B = 252.73$ g/mol

$R = 0.08206 \frac{L \cdot atm}{mol \cdot K}$

a) Assume: Ideal gas

A & B

$C_{B,L_A} = C_{B,L_B}$

$P_{B,A} = P_{B,B} = H_{pm} C_{B,L} = \left(0.556 \frac{atm}{mol/L}\right)\left(0.05 \frac{mol}{L}\right) = 0.0278$ atm

$PV = nRT$

$C_B = \frac{n}{V} = \frac{P}{RT} = \frac{0.0278 \text{ atm}}{\left(0.08206 \frac{L \cdot atm}{mol \cdot K}\right)(298 K)} = 0.001137 \frac{mol}{L}$

$\boxed{C_{B,A} = C_{B,B} = 0.001137 \frac{mol}{L}}$

C & D

$C_{B,L_C} = C_{B,L_D}$

$P_{B,C} = P_{B,D} = H_{pm} C_{B,L} = \left(0.556 \frac{atm}{mol/L}\right)\left(0.04 \frac{mol}{L}\right)$

$= 0.02224$ atm

$C_B = \frac{n}{V} = \frac{P}{RT} = \frac{0.02224 \text{ atm}}{\left(0.08206 \frac{L \cdot atm}{mol \cdot K}\right)(293 K)}$

$\boxed{C_{B,C} = C_{B,D} = 9.25 \times 10^{-4} \frac{mol}{L}}$

b) \$/gram B = \$5.25

\$400 total

which systems [A & B or C & D] could you afford

cost A & B = ~~2(0.001137 mol/L)(252.73 g/1 mol)(\$5.25/g)~~ $= [C_A V_A + C_B V_B] \frac{\$}{gram}$

$\text{Mass}_B\ A = [V_{B,L} C_{B,L} + V_{B,g} C_{B,g}] MW_B = \left[(4L)\left(0.05 \frac{mol}{L}\right) + (0.5L)\left(0.001137 \frac{mol}{L}\right)\right]\left(\frac{252.73 g}{mol}\right)$
$= 50.68$ g

Mass B $= \left[(4L)\left(0.05 \frac{mol}{L}\right) + (1L)\left(0.001137 \frac{mol}{L}\right)\right]\left(\frac{252.73 g}{mol}\right) = 50.83$ g

cost A & B $= (50.68 g + 50.83 g)\left(\frac{\$5.25}{g}\right) = \$532.928$

Mass C $= \left[(3L)\left(0.04 \frac{mol}{L}\right) + (1.5L)\left(9.25 \times 10^{-4} \frac{mol}{L}\right)\right]\left(\frac{252.73 g}{1 mol}\right) = 30.68$ g

Mass D $= \left[(3L)\left(0.04 \frac{mol}{L}\right) + (2L)\left(9.25 \times 10^{-4} \frac{mol}{L}\right)\right]\left(\frac{252.73 g}{1 mol}\right) = 30.78$ g

cost C & D $= (30.68 g + 30.78 g)\left(\frac{\$5.25}{g}\right) = \$322.67$

→ Buy systems C & D b/c cost C & D < \$400

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(2) $d = 0.0021\ m$

$T = 308\ K$

$C_{L,b,0} = 2.33 \times 10^{-3}\ \frac{mol\ CO_2}{L}$

$H_{CA} = 29.4\ \frac{atm\cdot L}{mol}$

$k_{AW} = 8.36 \times 10^{-6}\ \frac{m}{s}$

$X_{CO_2} = 0.000350$

a) what is initial flux direction?

$$F_A = k_{AW}\left(C_{A,b0} - C^*_{A,w}\right)$$

$$C^*_{Aw} = \frac{RT}{H_{CA}} C_{Aa,b} = \frac{\cancel{RT}}{H_{CA}}\left(\frac{P}{\cancel{RT}} X_{CO_2}\right)$$

$$= \frac{P}{H_{CA}} X_{CO_2} = \frac{1\ atm}{29.4\ \frac{atm\cdot L}{mol}}(0.000350)$$

$$C^*_{Aw} = 1.19 \times 10^{-5}\ \frac{mol}{L}$$

$$F_A = \left(8.36\times10^{-6}\ \frac{m}{s}\right)\left(2.33\times10^{-3}\ \frac{mol}{L} - 1.19\times10^{-5}\ \frac{mol}{L}\right)\left(\frac{1000\ L}{1\ m^3}\right)$$

$$F_A = 1.938 \times 10^{-5}\ \frac{mol}{m^2\cdot s}$$

↳ since flux is positive with the bulk liquid as its reference point, the flux is going from liquid to air

b) MB:

$$V_d \frac{dC_{CO_2 w,b}}{dt} = -F_{CO_2} A_d \qquad F_{CO_2} = F_A$$

$$= -k_{CO_2,w}\left(C_{CO_2,b} - C^*_{CO_2,A}\right) A_d$$

$$\int_{C_{CO_2,b}(0)}^{C_{CO_2,b}(t)} \frac{dC_{CO_2 b}}{\left(C_{CO_2,b} - C^*_{CO_2,A}\right)} = -\frac{k_{CO_2,w} A_d}{V_d}\int_0^t dt$$

$$A_d = 4\pi\left(\frac{d}{2}\right)^2$$

$$V_d = \frac{4}{3}\pi\left(\frac{d}{2}\right)^3$$

$$\frac{A_d}{V_d} = \frac{4\pi\left(\frac{d}{2}\right)^2}{\frac{4}{3}\pi\left(\frac{d}{2}\right)^3} = \frac{6}{d}$$

$$\ln\left[\frac{C_{CO_2,b}(t) - C^*_{CO_2,A}}{C_{CO_2,b}(0) - C^*_{CO_2,A}}\right] = -\frac{k_{CO_2,w} A_d}{V_d} t$$

$$C_{CO_2,b}(t) - C^*_{CO_2,A} = \left(C_{CO_2,b}(0) - C^*_{CO_2,A}\right)\exp\left(-\frac{k_{CO_2,w} A_d}{V_d} t\right)$$

$$\boxed{C_{CO_2,b}(t) = C^*_{CO_2,A} + \left(C_{CO_2,b}(0) - C^*_{CO_2,A}\right)\exp\left(-\frac{6k_{CO_2,w}}{d} t\right)}$$

c) $C_{CO_2,b}(t = 27\ s) = ?$

$$C_{CO_2,b}(t=27s) = 1.19\times10^{-5}\ \frac{mol}{L} + \left(0.002318\ \frac{mol}{L}\right)\exp\left[-\frac{6\left(8.36\times10^{-6}\ \frac{m}{s}\right)}{0.0021\ m}(27\ s)\right]$$

$$\boxed{C_{CO_2,b}(t=27s) = 0.00123\ \frac{mol}{L}}$$

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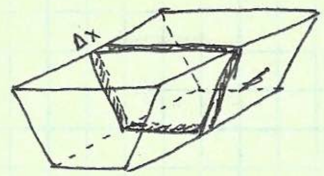
(3) $Q = 0.04\ m^3/s$

$H = 0.5\ m$

$L = 150\ m$

$w_1 = 2\ m$ (top)

$w_2 = 1\ m$ (bottom)



$C_{Aw,b} < C_{Aw}^*$ → Flux is positive from air to water

Lagragian View:

$$V \frac{dC_{Aw,b}}{dt} = -F_A A \qquad F_A = k_{Aw}(C_{Aw,b} - C_{Aw}^*)$$

$A = \Delta x\,(w_1)$ → area exposed to air

$V = \Delta x\left(\frac{w_1+w_2}{2}\right) H$

$$\cancel{\Delta x}\left(\frac{w_1+w_2}{2}\right) H \frac{dC_{Aw,b}}{dt} = k_{Aw}(C_{Aw,b} - C_{Aw}^*)\cancel{\Delta x}(w_1)$$

$$\int_{C_{Aw,b}(0)}^{C_{Aw,b}(t)} \frac{dC_{Aw,b}}{(C_{Aw,b} - C_{Aw}^*)} = \frac{-2 k_{Aw} w_1}{(w_1+w_2) H}\int_0^t dt$$

$$\ln\left[\frac{C_{Aw,b}(t) - C_{Aw}^*}{C_{Aw,b}(0) - C_{Aw}^*}\right] = \frac{-2 k_{Aw} w_1 t}{(w_1+w_2) H}$$

$$\boxed{C_{Aw,b}(t) = C_{Aw}^* + (C_{Aw,b}(0) - C_{Aw}^*)\exp\left(\frac{-2 k_{Aw} w_1 t}{(w_1+w_2) H}\right)}$$

b) what is $C_{Aw,b}(t)$?

$C_{Aw,b}(0) = 5\ g/L$

$P_B = 0.9\ atm$

$H_B = 0.18\ \frac{mol}{L\text{-}atm}$

$k_w = 7 \times 10^{-6}\ \frac{m}{s}$

$MW_B = 78.11\ g/mol$

$C_{Aw}^* = P_B H_B = 0.162\ \frac{mol}{L}$

$C_{Aw,b}(0) = \left(5\ \frac{g}{L}\right)\left(\frac{1\ mol}{78.11\ g}\right) = 0.064\ \frac{mol}{L}$

$t = V/Q = \frac{H\left(\frac{w_1+w_2}{2}\right) L}{Q} = \frac{(0.5\ m)\left(\frac{3\ m}{2}\right)(150\ m)}{0.04\ \frac{m^3}{s}} = 28125\ s$

$$C_{Aw,b}(t = 28125\ s) = 0.162\ \frac{mol}{L} + \left|\left(0.064\ \frac{mol}{L} - 0.162\ \frac{mol}{L}\right)\right| \exp\left(\frac{-2(7\times10^{-6}\ \frac{m}{s})(2\ m)(28125\ s)}{(3\ m)(0.5\ m)}\right)$$

$$\boxed{C_{Aw,b}(t = 2812.5\ s) = 0.069\ \frac{mol}{L}}$$

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(4) $X_B = 0.32$

$X_T = 0.27$

$X_X = 0.21$

$T = 298\ K$

$P_B^\circ = 0.126\ atm$

$P_T^\circ = 0.038\ atm$

$P_X^\circ = 0.012\ atm$

$H_{cB} = 0.55\ \frac{kPa-m^3}{mol}\left(\frac{0.00986\ atm}{1\ kPa}\right) = 0.005423\ \frac{atm-m^3}{mol}$

$H_{cT} = 0.67\ \frac{kPa-m^3}{mol}\left(\frac{0.00986\ atm}{1\ kPa}\right) = 0.006606\ \frac{atm-m^3}{mol}$

$H_{cX} = 0.5\ \frac{kPa-m^3}{mol}\left(\frac{0.00986\ atm}{1\ kPa}\right) = 0.00493\ \frac{atm-m^3}{mol}$

a) estimate the partial pressure of each constituents if they are ideal and follow Raults law

$P_B = X_B P_B^\circ = (0.32)(0.126\ atm)$

$\boxed{P_B = 0.0403\ atm}$

$P_T = (0.27)(0.038\ atm)$

$\boxed{P_T = 0.0103\ atm}$

$P_X = (0.21)(0.012\ atm)$

$\boxed{P_X = 0.0025\ atm}$

b) find mol fraction of each in liquid

$C_{Bw} = \frac{P_B}{H_{cB}} = \frac{0.0403\ atm}{0.005423\ \frac{atm \cdot m^3}{mol}} = 7.43\ \frac{mol}{m^3}$

$X_{Bw} = \frac{C_{Bw}}{55.56\times10^3\ \frac{mol}{m^3}} = \frac{7.43\ \frac{mol}{m^3}}{55.56\times10^3\ \frac{mol}{m^3}}$

$\boxed{X_{Bw} = 0.000134}$

$C_{Tw} = \frac{P_T}{H_{cT}} = \frac{0.0103\ atm}{0.006606\ \frac{atm-m^3}{mol}} = 1.559\ \frac{mol}{m^3}$

$X_{Tw} = \frac{C_{Bw}}{55.56\times10^3\ \frac{mol}{m^3}} = \frac{1.559\ \frac{mol}{m^3}}{55.56\times10^3\ \frac{mol}{m^3}}$

$\boxed{X_{Tw} = 2.806\times10^{-5}}$

$C_{Xw} = \frac{P_X}{H_{cX}} = \frac{0.0025\ atm}{0.00493\ \frac{atm-m^3}{mol}} = 0.507\ \frac{mol}{m^3}$

$X_{Xw} = \frac{C_{Xw}}{55.56\times10^3\ \frac{mol}{m^3}} = \frac{0.507\ \frac{mol}{m^3}}{55.56\times10^3\ \frac{mol}{m^3}}$

$\boxed{X_{Xw} = 9.125\times10^{-6}}$

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(5) $v = 0.1 \frac{m}{s}$

$h = 0.1 \, m$

$w = 2.0 \, m$

$k_w = ?$

$d = 500 \, m \rightarrow O_2 \text{ sat} = 75\%$

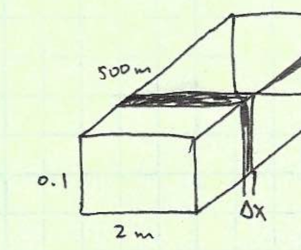
$C_{O_2,w}(0) = 0$

$P_{O_2} = 0.2 \text{ atm}$

$H_{c O_2} = 769 \frac{atm}{mol/L}$

Assumptions

• cross-sectional area of stream is rectangular



$t = \frac{d}{v} = \frac{500 \, m}{0.1 \frac{m}{s}} = 5000 \, s$

$C_{O_2,sat} = \frac{P_{O_2}}{H_{c,O_2}} = 0.00026 \frac{mol}{L} = 2.601 \times 10^{-4} \frac{mol}{L}$

$C_{O_2,w}(t = 5000 \, s) = (0.75)(2.601 \times 10^{-4} \frac{mol}{L}) = 1.951 \times 10^{-4} \frac{mol}{L}$

a) MB: Lagragian View

$$V \frac{dC_{O_2,w}}{dt} = -FA$$

$V = \Delta X \, h \, w$

$A = \Delta X \, w \rightarrow$ area exposed to air

$F = k_{O_2 w} (C_{O_2} - C_{O_2}^*)$

$C_{O_2}^* = C_{O_2,sat}$

$$V \frac{dC_{O_2,w}}{dt} = -k_{O_2 w} (C_{O_2,w} - C_{O_2,w}^*) A$$

$$\int_{C_{O_2 w}(0)}^{C_{O_2 w}(t)} \frac{dC_{O_2 w}}{(C_{O_2,w} - C_{O_2,w}^*)} = -\frac{k_{O_2 w} A}{V} \int_0^t dt$$

$$\frac{A}{V} = \frac{\cancel{\Delta X} \cancel{w}}{\cancel{\Delta X} h \cancel{w}} = \frac{1}{h}$$

$$\ln \left[\frac{C_{O_2 w}(t) - C_{O_2,w}^*}{C_{O_2 w}(0) - C_{O_2,w}^*} \right] = -\frac{k_{O_2,w} A}{V} t$$

$$\boxed{C_{O_2 w}(t) = C_{O_2,w}^* + \left| (C_{O_2,w}(0) - C_{O_2}^*) \right| \exp\left(-\frac{k_{O_2 w} t}{h}\right)}$$

b) what is $k_{O_2 w}$?

$C_{O_2,w}(t) = C_{O_2 w}(t = 5000 \, s) = 1.951 \times 10^{-4} \frac{mol}{L}$

$C_{O_2,w}^* = 2.601 \times 10^{-4} \frac{mol}{L}$

$C_{O_2,w}(0) = 0$

$t = 5000 \, s$

$h = 0.1 \, m$

$$\left(1.951 \times 10^{-4} \frac{mol}{L}\right) = 2.601 \times 10^{-4} \frac{mol}{L} + 2.601 \times 10^{-4} \frac{mol}{L} \exp\left(\frac{-k_{O_2 w} (5000 s)}{0.1 \, m}\right)$$

$$\ln(+0.2499) = -50{,}000 \frac{s}{m} k_{O_2 w}$$

$$\boxed{k_{O_2 w} = 2.773 \times 10^{-5} \frac{m}{s}}$$

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(6) $T = 298\ K$

$k_G / k_L = 150$

a) find fraction of total resistance associated w/ liquid phase for chloroform, bromoform, oxygen

$$\frac{R_L}{R_{tot}} = \frac{1}{\left[\left(\frac{k_L}{k_G}\right)\left(\frac{1}{H}\right) + 1\right]}$$

chloroform: $H = 0.163$

$$\frac{R_L}{R_{tot}} = \frac{1}{\left[\left(\frac{1}{150}\right)\left(\frac{1}{0.163}\right) + 1\right]}$$

$$\boxed{\frac{R_L}{R_{tot}} = 0.961}$$

bromoform: $H = 0.0227$

$$\frac{R_L}{R_{tot}} = \frac{1}{\left[\left(\frac{1}{150}\right)\left(\frac{1}{0.0227}\right) + 1\right]}$$

$$\boxed{\frac{R_L}{R_{tot}} = 0.773}$$

oxygen: $H = 31.4$

$$\frac{R_L}{R_{tot}} = \frac{1}{\left[\left(\frac{1}{150}\right)\left(\frac{1}{31.4}\right) + 1\right]}$$

$$\boxed{\frac{R_L}{R_{tot}} = 0.9998}$$

b) repeat w/ $k_G / k_L = 20$

chloroform: $\frac{R_L}{R_{tot}} = \frac{1}{\left[\left(\frac{1}{20}\right)\left(\frac{1}{0.163}\right) + 1\right]}$

$$\boxed{\frac{R_L}{R_{tot}} = 0.765}$$

bromoform: $\frac{R_L}{R_{tot}} = \frac{1}{\left[\left(\frac{1}{20}\right)\left(\frac{1}{0.0227}\right) + 1\right]}$

$$\boxed{\frac{R_L}{R_{tot}} = 0.312}$$

oxygen: $\frac{R_L}{R_{tot}} = \frac{1}{\left[\left(\frac{1}{20}\right)\left(\frac{1}{31.4}\right) + 1\right]}$

$$\boxed{\frac{R_L}{R_{tot}} = 0.9984}$$

7. $M_t = 10\ g$

$V_A = 1\ m^3$

$V_w = 0.1\ m^3$

$V_o = 0.01\ m^3$

$T = 293\ K$

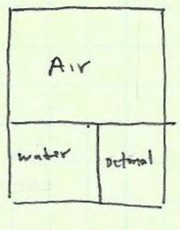
$K_{ow,B} = 130$

$P_B^o = 12.7\ kPa$

$H_B = 0.55\ \frac{kPa \cdot m^3}{mol}$

$R = 0.0083145\ \frac{kPa \cdot m^3}{mol \cdot K}$

$MW_B = 78.11\ \frac{g}{mol}$



$$n_{total} = C_{B,w} V_w + C_{B,A} V_A + C_{B,o} V_o \qquad n_{total} = 10\,g \left(\frac{1\ mol}{78.11\ g}\right) = 0.128\ mol$$

$$K_{ow,B} = \frac{C_{B,o}}{C_{B,w}} \Rightarrow C_{B,o} = K_{ow,B}\, C_{B,w}$$

$$P_B = H_B C_{B,w} \qquad P_B = \frac{nRT}{V}$$

$$\frac{nRT}{V} = H_B C_{B,w}$$

$$\frac{n}{V} = C_{B,A} = \frac{H_B C_{B,w}}{RT}$$

$$n_{total} = C_{B,w} V_w + \frac{H_B C_{B,w}}{RT} V_A + K_{ow,B}\, C_{B,w} V_o$$

$$= C_{B,w}\left(V_w + \frac{H_B}{RT} V_A + K_{ow,B} V_o\right)$$

$$C_{B,w} = \frac{n_{total}}{V_w + \frac{H_B}{RT} V_a + K_{ow,B} V_o} = \frac{0.128\ mol}{0.1\ m^3 + \left[\frac{0.55\ \frac{kPa \cdot m^3}{mol}}{\left(8.315 \times 10^{-3}\ \frac{kPa \cdot m^3}{mol \cdot K}\right)(293\ K)}\right] 1\ m^3 + (130)(0.01\ m^3)}$$

$$C_{B,w} = 0.0787\ \frac{mol}{m^3}$$

$$M_{B,w} = \left(0.0787\ \frac{mol}{m^3}\right)(0.1\ m^3)\left(78.11\ \frac{g}{mol}\right)$$

$$\boxed{M_{B,w} = 0.615\ g}$$

$$C_{B,o} = K_{ow,B}\, C_{B,w} = (130)\left(0.0787\ \frac{mol}{m^3}\right) = 10.23\ \frac{mol}{m^3}$$

$$M_{B,o} = \left(10.23\ \frac{mol}{m^3}\right)(0.01\ m^3)\left(\frac{78.11\ g}{mol}\right)$$

$$\boxed{M_{B,o} = 7.991\ g}$$

$$C_{B,A} = \frac{H_B C_{B,w}}{RT} = \frac{\left(0.55\ \frac{kPa \cdot m^3}{mol}\right)\left(0.0787\ \frac{mol}{m^3}\right)}{\left(8.3145 \times 10^{-3}\ \frac{kPa \cdot m^3}{mol \cdot K}\right)(293\ K)} = 0.0178\ \frac{mol}{m^3}$$

$$M_{B,A} = \left(0.0178\ \frac{mol}{m^3}\right)(1\ m^3)\left(78.11\ \frac{g}{mol}\right)$$

$$\boxed{M_{B,A} = 1.39\ g}$$