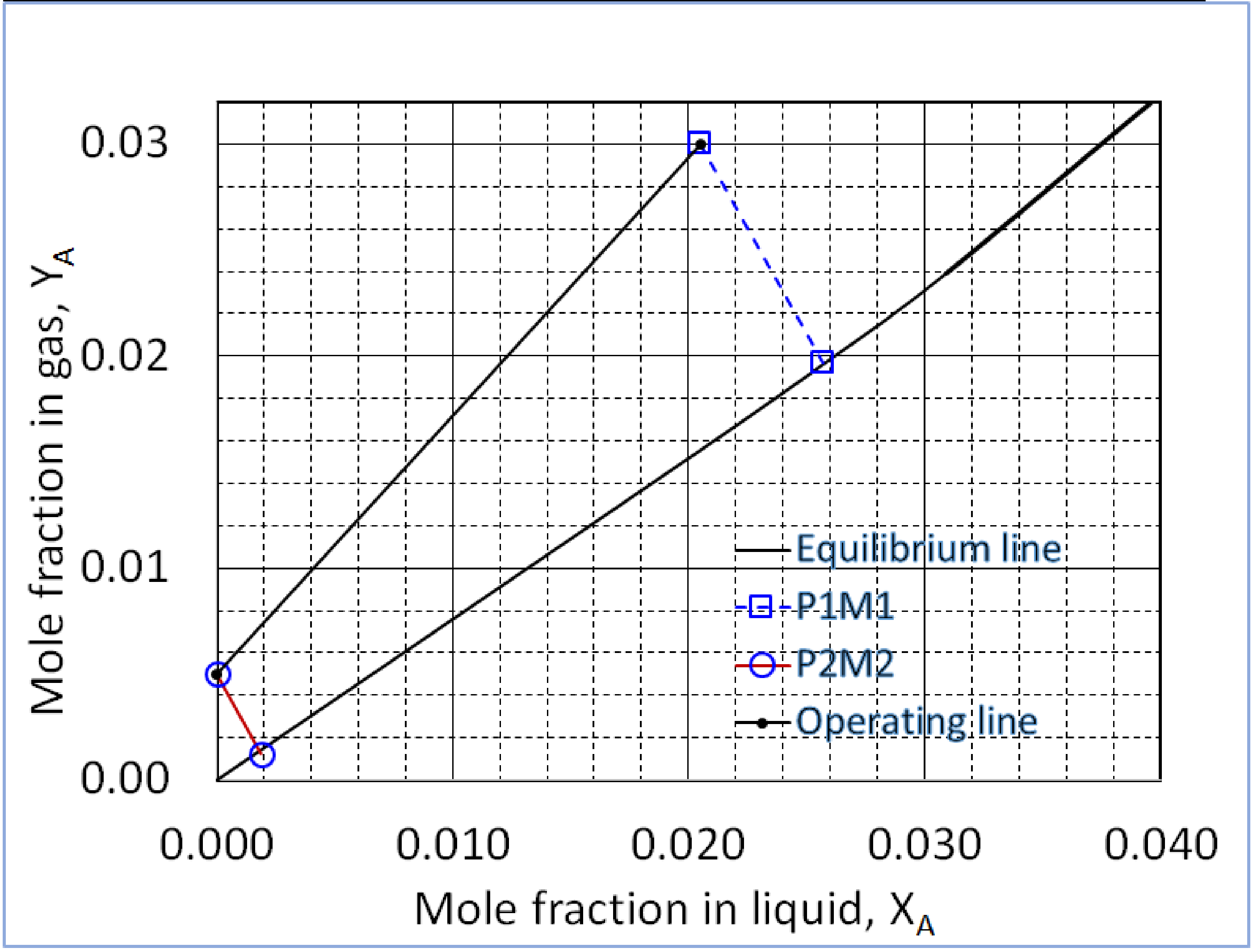
King Saud University
Department of Chemical Engineering
Mass Transfer Operations (CHE 318)

Final Part 2: Open Book	April 18, 2019	Time Allowed: 2:30 Min.
Name:		Roll No:

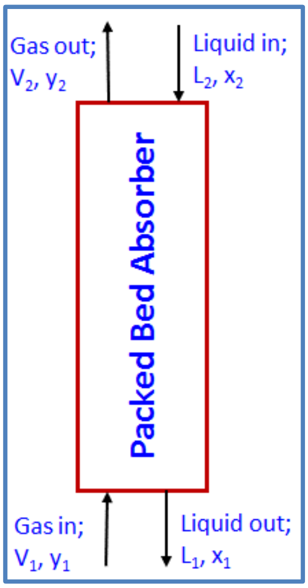


Question 2: (Marks: 20)

Inlet gas stream to a packed absorption tower (absorber) contains $y_1 = 0.03$ mole fraction ammonia (NH_3). The outlet gas stream contains $y_2 = 0.005$ at 293 K and 101.325 kPa. The inlet pure water flow is $L_2 = 60\ kg\ mol/h$ and the total inlet gas flow is $V_1 = 50\ kg\ mol/h$. The tower cross-sectional area 0.5 m^2. The film mass-transfer coefficients are

$$k'_x a = 20 \times 10^{-2}\ \text{kg mol/s} \cdot \text{m}^3 \cdot \text{mol frac}$$
$$k'_y a = 10 \times 10^{-2} \text{kg mol/s} \cdot \text{m}^3 \cdot \text{mol frac}$$

The figure below shows the equilibrium and operating lines. Using the above figure and the given data, determine the following (Show clear calculations on Answer Sheet).



- Evaluate

$V_2 (kg\ mol/h)$	$L_1 (kg\ mol/h)$	$(x_i - x)_M$	$(y - y^*)_M$
48.74	**61.26**	**0.00325**	**0.0089**

-

HTU (H_L)	NTU (N_L)	*Height (m)*	*Min. Solvent,* L'_{min}
0.168	**6.312**	**1.06**	**33**

- For the height calculation using analytical approach , determine

A	N_{OG}	H_{OG}	*Height (m)*
1.54	**2.9**	**0.38**	**1.1**

Given:	$V_1 = 50\ kg\ mol/h;\ L_2 = 60\ kg\ mol/h$
From figure:	$x_2 = 0.00; y_2 = 0.005;\ x_1 = 0.0205; y_1 = 0.030;$

$V' = V_1 \times (1 - y_1) = 50 \times (1 - 0.03) = 48.5$	$L' = L_2 \times (1 - x_2) = 60 \times (1 - 0.00) = 60$
$V_2 = V'/(1 - y_2) = 48.74$	$L_1 = L'/(1 - x_1) = 48.74$

From figure:

$x_{1i} = 0.0257; \quad y_{1i} = 0.0019$	$x_{2i} = 0.0018; \quad y_{2i} = 0.002$

$(x_i - x)_M = \dfrac{(x_{1i} - x_1) - (x_{2i} - x_2)}{\ln[(x_{1i} - x_1)/(x_{2i} - x_2)]}$	$= \dfrac{(0.0257 - 0.0205) - (0.0019 - 0.00)}{\ln[(0.0257 - 0.0205)/(0.0019 - 0.00)]} = 0.00325$
$(y - y^*)_M = \dfrac{(y_1 - y_1^*) - (y_2 - y_2^*)}{\ln[(y_1 - y_1^*)/(y_2 - y_2^*)]}$	$= \dfrac{(0.030 - 0.0156) - (0.005 - 0.00)}{\ln[(0.030 - 0.0156)/(0.005 - 0.00)]} = 0.0089$

$H_L = \dfrac{L_{avg}}{k'_x a S}$	$= \left[\dfrac{(60 + 61.26)/2}{3600}\right]/[20 \times 10^{-2} \times 0.50] = 0.168\ m$
$N_L = \left[\dfrac{(1 - x)_{iM}}{(1 - x)}\right]_{av} \dfrac{(x_1 - x_2)}{(x_i - x)_M}$	$= [1]\dfrac{0.0205 - 0.00}{0.00325} = 6.31$
$z = H_L \times N_L$	$= 0.168 \times 6.31 = 1.06\ m$

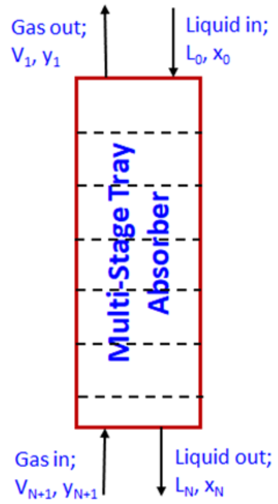
L'_{min} using overall material balance after obtaining $(x_1)_{max}$ from the figure	$y_1 = 0.030;\ (x_1)_{max} = 0.0367\ (From\ Equil.\ curve)$ $V' = V_1(1 - y_1) = 50 \times (1 - 0.030) = 48.5\ kg\ mol/h$ $L'\dfrac{x_2}{(1 - x_2)} + V'\dfrac{y_1}{(1 - y_1)} = L'\dfrac{x_1}{(1 - x_1)} + V'\dfrac{y_2}{(1 - y_2)}$ $\boldsymbol{L'_{min}}\dfrac{x_2}{(1 - x_2)} + V'\dfrac{y_1}{(1 - y_1)} = \boldsymbol{L'_{min}}\dfrac{x_{1max}}{(1 - x_{1max})} + V'\dfrac{y_2}{(1 - y_2)}$ $\boldsymbol{L'_{min}} = 33\ kg\ mol/h$

$A_1 = \dfrac{L_1}{m_1 V_1};\ A_2 = \dfrac{L_2}{m_2 V_2};$	$A_1 = \dfrac{61.26}{(6/8) \times 50} = 1.634; A_2 = \dfrac{60.0}{(3.4/4) \times 48.74} = 1.45$
$A = \sqrt{A_1 \times A_2}$	$A = \sqrt{1.634 \times 1.45} = 1.54$

$N_{OG} = \dfrac{1}{(1 - 1/A)} ln\left[(1 - 1/A)\dfrac{y_1 - mx_2}{y_2 - mx_2} + \dfrac{1}{A}\right]$	$= \dfrac{1}{(1 - 1/1.54)} ln\left[(1 - 1/1.54)\dfrac{0.03 - 0}{0.005 - 0} + \dfrac{1}{1.54}\right] = 2.9$

$H_G = \dfrac{V_{av}}{k'_y a S}$	$= \left[\dfrac{(50+48.74)/2}{3600}\right] / [10 \times 10^{-2} \times 0.50] = 0.274\ m$
$H_{OG} = H_G + (mV/L)H_L = H_G + H_L/A$	$= 0.274 + 0.168/1.54 = 0.383\ m$
$z = H_{OG} \times N_{OG}$	$= 0.383\ \times 2.9 = 1.1\ m$

Question 3: (marks: 20)



A tray tower is to be designed to absorb SO_2 from an air stream by using water at 293 K and 101.3 kPa. The entering gas contains 20 mol % while the leaving air contains 2 mol% SO_2. The inert air flow rate is 4 kg mol air/h.m^2, and the entering recycled water contains 0.02 mol% SO_2. Assume that the tower operates at 293 K. The equilibrium data is given in the following figure.

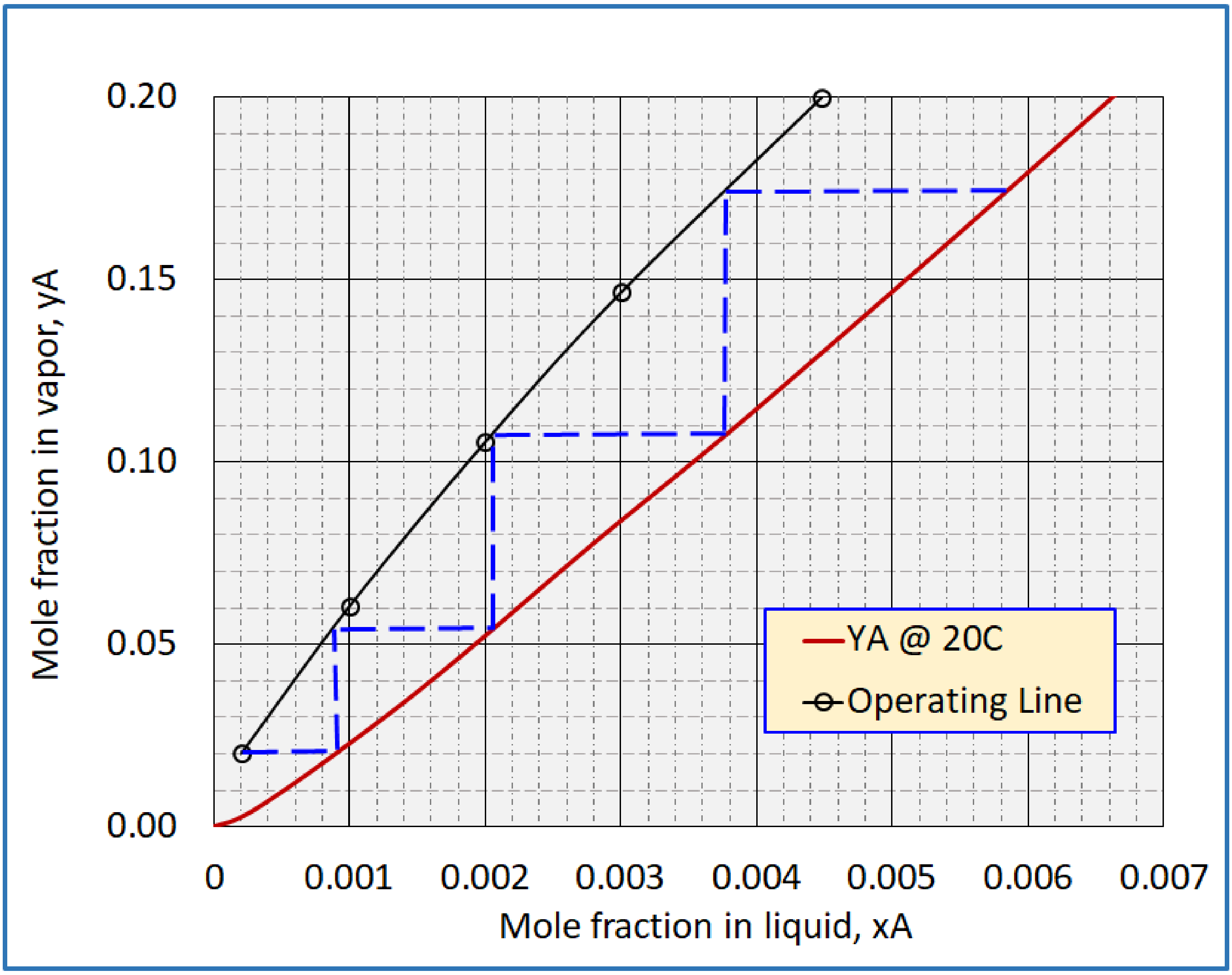
1. Determine the minimum solvent required (L_{min})
2. Using 1.5 times the minimum liquid flow rate, determine the number of trays needed using graphical method in the figure below.
3. What is the composition of liquid and gas streams entering Stage 2?
4. How much SO_2 is removed in Stage 2?

Question 3 Solution:

Overall M.B.	$L'\dfrac{x_0}{(1-x_0)} + V'\dfrac{y_{N+1}}{(1-y_{N+1})} = L'\dfrac{x_N}{(1-x_N)} + V'\dfrac{y_1}{(1-y_1)}$
Overall M.B. for L'_{min}	$L'_{min}\dfrac{x_0}{(1-x_0)} + V'\dfrac{y_{N+1}}{(1-y_{N+1})} = L'_{min}\dfrac{(x_N)_{max}}{(1-(x_N)_{max})} + V'\dfrac{y_1}{(1-y_1)}$
	$L'_{min}\dfrac{0.0002}{(1-0.0002)} + 4\dfrac{0.2}{(1-0.2)} = L'_{min}\dfrac{0.0066}{(1-0.0066)} + 4\dfrac{0.02}{(1-0.02)}$
$L'_{min} = 142.55$	$L_{min} = 1.5 \times L'_{min} = 213.78$
Overall M.B.	$L'\dfrac{x_0}{(1-x_0)} + V'\dfrac{y_{N+1}}{(1-y_{N+1})} = L'\dfrac{x_N}{(1-x_N)} + V'\dfrac{y_1}{(1-y_1)}$
	$213.78\dfrac{0.0002}{(1-0.0002)} + 4\dfrac{0.2}{(1-0.2)} = 213.78\dfrac{\boldsymbol{x_N}}{(\boldsymbol{1-x_N})} + 4\dfrac{0.02}{(1-0.02)}$
$x_N = 0.00448; y_1 = 0.200$	$x_n = 0.001; y_{n+1} = 0.061$ $x_n = 0.002; y_{n+1} = 0.106$ $x_n = 0.003; y_{n+1} = 0.147$ Note: operating line is curved

From figure streams entering stage 3 are: $x_1 = 0.00084; y_1 = 0.108$	$x_1 = 0.00084; y_1 = 0.020$ $x_2 = 0.00208; y_2 = 0.055$ $x_3 = 0.00378; y_3 = 0.108$

SO_2 is removed in Stage 2	$V'\frac{y_3}{(1-y_3)} - V'\frac{y_2}{(1-y_2)} = 4\frac{0.108}{(1-0.108)} - 4\frac{0.055}{(1-0.055)} = 0.2525$



Question 4: (marks: 20)

The solute A is being absorbed from a gas mixture of A and B in a wetted-wall tower with the liquid flowing as a film downward along the wall. At a certain point in the tower the bulk gas concentration $\mathbf{y_{AG} = 0.30}$ mol fraction and the bulk liquid concentration is $\mathbf{x_{AL} = 0.15}$. The tower is operating at 298 K and 101.3 kPa and the equilibrium data given in the figure. The solute A diffuses through stagnant Bin the gas phase and then through a non-diffusing liquid.

The equilibrium data is given in the figure below. Using correlations for dilute solutions in wetted-wall towers, the film mass-transfer coefficient for A in the gas phase is predicted as:

$$k'_y = 3.0 \times 10^{-3} \text{kg mol A/s} \cdot \text{m}^2 \cdot \text{mol frac}$$

$$k'_x = 3.0 \times 10^{-3} \text{kg mol A/s} \cdot \text{m}^2 \cdot \text{mol frac}$$

Determine the interface concentration (x_{Ai}, y_{Ai}) by making only one trial. For the first trial, use $y_{Ai} = 0.20$ and $x_{Ai} = 0.20$ to compute the slope. Then, calculate (show clear calculations on the answer sheet)

- Overall mass transfer coefficient K'_x
- Percent resistance in the gas and the liquid films
- Flux N_A

Assume $(x_{Ai} = 0.2, y_{Ai} = 0.2)$, and compute the slope

$$(1-x_A)_{iM} = \frac{(1-x_{AL})-(1-x_{Ai})}{\ln[(1-x_{AL})/(1-x_{Ai})]} = \frac{(1-0.15)-(1-0.20)}{\ln[(1-0.15)/(1-0.20)]} = 0.825$$

$$(1-y_A)_{iM} = \frac{(1-y_{Ai})-(1-y_{AG})}{\ln[(1-y_{Ai})/(1-y_{AG})]} = \frac{(1-0.20)-(1-0.30)}{\ln[(1-0.20)/(1-0.30)]} = 0.749$$

$$-\frac{k_x}{k_y} = -\frac{\left[\frac{3.0\times10^{-3}}{0.825}\right]}{\left[\frac{3.0\times10^{-3}}{0.749}\right]} = -0.908$$

Using straight line equation,

$$y - y_0 = m(x - x_0)$$

$$y - y_{AG} = -\frac{k_x}{k_y}(x - x_{AL})$$

$$y - 0.30 = -0.908(x - 0.15)$$

Choose any arbitrary value for x to get y. Choosing, $x = 0.25$ gives $y = 0.30 - 0.0908 = 0.209$.

Now draw a straight line with points $(0.15, 0.30)$ and $(0.25, 0.21)$. Its intersection with the equilibrium line from the graph gives

$$(x_{Ai} = 0.26, y_{Ai} = 0.20)$$

$$\frac{1}{K_x} = \frac{1}{K'_x/(1-x_A)_{*M}} = \left(m''\frac{k'_y}{(1-y_A)_{iM}}\right)^{-1} + \left(\frac{k'_x}{(1-x_A)_{iM}}\right)^{-1}$$

$$(1-x_A)_{*M} = \frac{(1-x_{AL})-(1-x_A^*)}{\ln[(1-x_{AL})/(1-x_A^*)]} = 0.765$$

$$(1-x_A)_{iM} = \frac{(1-x_{AL})-(1-x_{Ai})}{\ln[(1-x_{AL})/(1-x_{Ai})]} = \frac{(1-0.15)-(1-0.26)}{\ln[(1-0.15)/(1-0.26)]} = 0.795$$

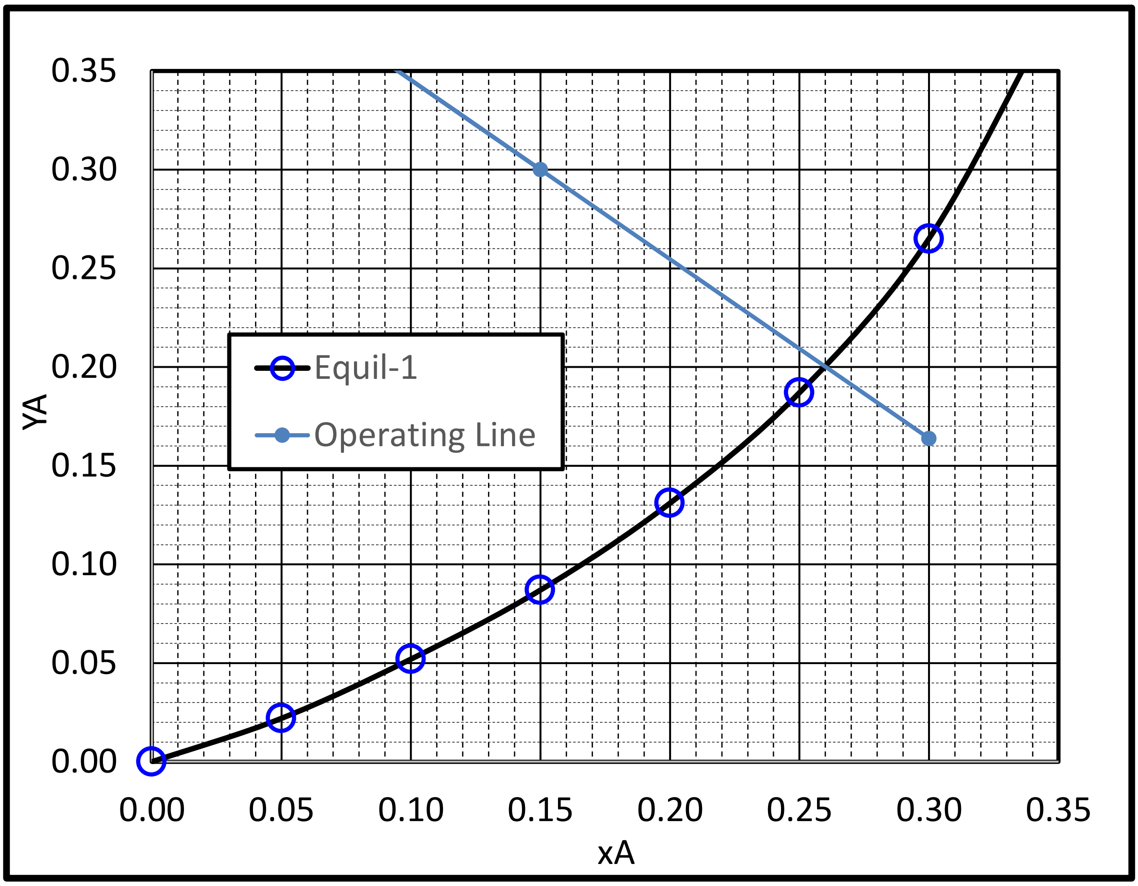
$$m'' = \frac{y_{AG} - y_{Ai}}{x_A^* - x_{Ai}} = \frac{0.30 - 0.20}{0.315 - 0.26} = 1.78$$

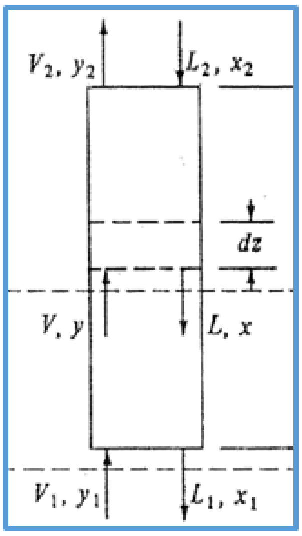
$$\frac{1}{K_x} = \frac{1}{K'_x/0.765} = \left(1.78\frac{0.003}{0.749}\right)^{-1} + \left(\frac{0.003}{0.795}\right)^{-1} = 140.3(35\%) + 265(65\%)$$

$$K_x = 2.41\times10^{-3}\ \text{kg mol A/s}\cdot\text{m}^2\cdot\text{mol frac}$$

$$K'_x = 1.84\times10^{-3}\text{kg mol A/s}\cdot\text{m}^2\cdot\text{mol frac}$$

$$N_A = k_y(y_{AG} - y_{Ai}) = (0.003/0.749)\times(0.30-0.20) = 4\times10^{-4}\ \text{kg mol A/s}\cdot\text{m}^2\cdot$$





Question 5: (marks: 10) The gas stream from a chemical reactor contains 5 mol % acetone and the rest inert gases. The total gas flow is 5.0 kg mol/h to a PACKED BED ABSORBER of area 0.010 m^2 and height 2 m to remove acetone. At 293 K and 1.013×10^5 Pa pressure, recycled water with acetone concentration of 0.1 mol% ($x_2 = 0.001$) and a flowrate of 10 kg mol/h is used as the scrubbing liquid. The outlet gas concentration is to be 0.50 mol % acetone. The solvent (water) from the absorber contain 1.73 mol% acetone. The equilibrium relationship can be assumed to be $y_A = mx_A = 2.0x_A$.

Determine the experimental value of the mass transfer coefficients ($K'_y a$) in $kg\ mol/s \cdot m^3 \cdot mol\ frac$

Solution

$x_1 = 0.0173; x_2 = 0.001; y_1 = 0.050;\ y_2 = 0.005;$

$$(y - y^*)_M = \frac{(y_1 - y_1^*) - (y_2 - y_2^*)}{\ln[(y_1 - y_1^*)/(y_2 - y_2^*)]}$$

$y_1^* = mx_1 = 2 \times 0.0173 = 0.0346;$

$y_2^* = mx_2 = 2 \times 0.001 = 0.0020;$

$$(y - y^*)_M = \frac{(0.05 - 0.0346) - (0.005 - 0.002)}{\ln[(0.05 - 0.0346)/(0.005 - 0.002)]} = 7.6 \times 10^{-3}$$

$S = 0.010\ m^2; z = 2\ m$

$$\frac{V}{S}(y_1 - y_2) = K'_y az(y - y^*)_M$$

$$\frac{0.288}{0.01 \times 3600} = K'_y az(y - y^*)_M = K'_y a \times 2 \times 7.6 \times 10^{-3}$$

$$K'_y a = 52.65 \times 10^{-2} kg\ mol/s \cdot m^3 \cdot mol\ frac$$