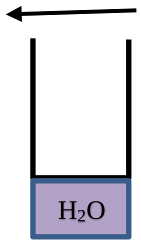
King Saud University
Department of Chemical Engineering
Mass Transfer Operations (CHE 318)
Final Examination

Part 1: Closed Book Jan 02, 2018 Time Allowed: 30 Min.

Name:	Roll No:



(1) Liquid water slowly evaporates into surrounding air from a cylindrical container maintained at constant temperature and pressure. If the mole fraction of water vapor in the surrounding air is deceased, it will

(a) increase driving force for water evaporation	(b) decrease driving force for water evaporation
(c) not affect driving force for water evaporation	(d) no relationship with driving force

(2) Liquid water slowly evaporates into surrounding air from a cylindrical container maintained at constant temperature and pressure. If the mole fraction of water vapor in the surrounding air is deceased, it will

(a) increase the water evaporation rate	(b) decrease the water evaporation rate
(c) not change the water evaporation rate	(d) no relationship with water evaporation rate

(3) It is desired to absorb ammonia from a mixture of feed gases using water as the solvent in an absorber. In order to increase the absorption, one should

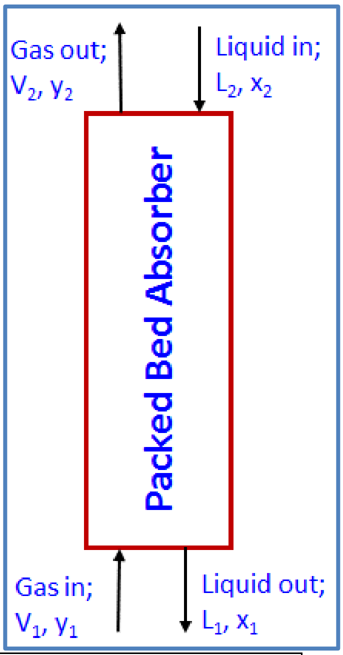
(a) increase temperature and decrease pressure	(b) increase temperature and increase pressure
(c) decrease temperature and increase pressure	(d) decrease temperature and decrease pressure

(4) A good packing provides

(a) high interfacial area and high pressure drop	(b) low interfacial area and low pressure drop
(c) high interfacial area and low pressure drop	(d) low interfacial area and high pressure drop

(5) The gas velocity in the packed bed absorber should be

(a) more than the flooding velocity	(b) equal to the flooding velocity
(c) more than the velocity at the loading point	(d) almost half of the flooding velocity



(6) To calculate the diameter of the absorber, you need to

(a) choose the packing type	(b) compute pressure drop at flooding
(c) specify liquid to gas mass flow rate	(d) all of these are correct

(7) Using structure packing will usually give

(a) larger diameter and higher pressure drop in the absorber	(b) smaller diameter and higher pressure drop in the absorber
(c) larger diameter and lower pressure drop in the absorber	(d) smaller diameter and lower pressure drop in the absorber

(8) For a given separation in a counter-current packed bed absorber, if x_1, y_1 are in equilibrium, this means that

(a) liquid flow is very high	(b) liquid flow is very low
(c) liquid flow is zero	(d) liquid flow is minimum required

(9) If the flowrate of carbon dioxide is increased in your experiments of carbon dioxide absorption in the lab

(a) CO2 concentration in outlet liquid will decrease	(b) CO2 concentration in outlet liquid will increase
(c) No effect on the CO2 concentration	(d) decrease the pressure drop in the column

(10) In the design of the packed bed absorber, if the gas velocity is increased keeping solvent flow constant, it will affect (change) the slope of

(a) both operating and equilibrium lines	(b) the equilibrium line only
(c) the operating line only	(d) none of the two lines

(11) For equi-molar counter-diffusion, the flux of solute A, N_A , is given by

(a) $N_A = K'_x\ (y_{AG} - y_A^*) = K'_y\ (x_A^* - x_{AL})$	(b) $N_A = \frac{K'_y}{(1-y_A)_{*M}}(y_{AG} - y_A^*) = \frac{K'_x}{(1-x_A)_{*M}}(x_A^* - x_{AL})$
(c) both (a) and (b) are correct	(d) both (a) and (b) are incorrect

K'_y: overall gas-phase mass-transfer coefficient in $kg\ mol/s \cdot m^2 \cdot mol\ frac$
K'_x: overall liquid-phase mass-transfer coefficient in $kg\ mol/s \cdot m^2 \cdot mol\ frac$
y_A^*: gas-phase value that would be in equilibrium with x_{AL}
x_A^*: gas-phase value that would be in equilibrium with y_{AG}

(12) For diffusion of A through stagnant B, the flux of solute A, N_A , is given by

(a) $N_A = \frac{k'_y}{(1-y_A)_{iM}}(y_{AG} - y_{Ai}) = \frac{k'_x}{(1-x_A)_{iM}}(x_{Ai} - x_{AL})$	(b)$N_A = k'_x(y_{AG} - y_{Ai}) = k'_y(x_{Ai} - x_{AL})$
(c) both (a) and (b) are correct	(d) both (a) and (b) are incorrect

(13) In the design of absorbers for concentrated solution,

(a) the operating line is straight	(b) the operating line is curved
(c) the slope of operating line is small	(d) the slope of the operating line is large

(14) In the design of absorbers, keeping all other parameter unchanged, if the mass transfer coefficient is increased,

(a) its operating line slope will increase	(b) its height will increase
(c) its height will will not change	(d) its height will decrease

(15) In the design of the absorber, if the thermodynamic data is represented as $y = mx$, absorber height (or number of trays) will be least for

(a) m=0.02	(b) m=0.015
(c) m=0.01	(d) m = 0.05

Answers

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15					

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Final Part 2: Open Book	Jan 02, 2018	Time Allowed: 2:30 Min.
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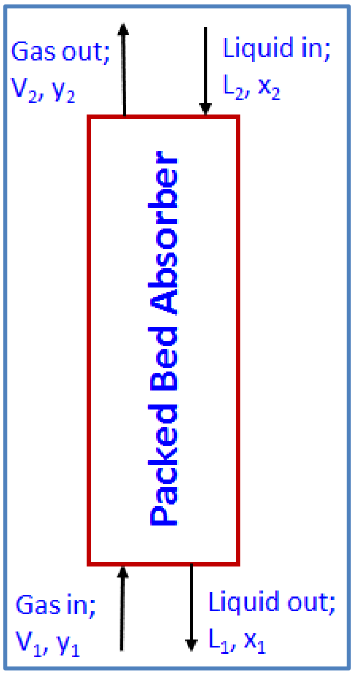
Question 2 (20 Marks): Inlet gas stream to a packed absorption tower (absorber) contains $y_1 = 0.03$ mole fraction ammonia (NH_3). The outlet gas stream contains $y_2 = 0.005$ at 293 K and 101.325 kPa. The inlet pure water flow is $L_2 = 60\ kg\ mol/h$ and the total inlet gas flow is $V_1 = 50\ kg\ mol/h$. The tower cross-sectional area 1 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 given figure and the given data, determine the following.

- Evaluate (**8**)

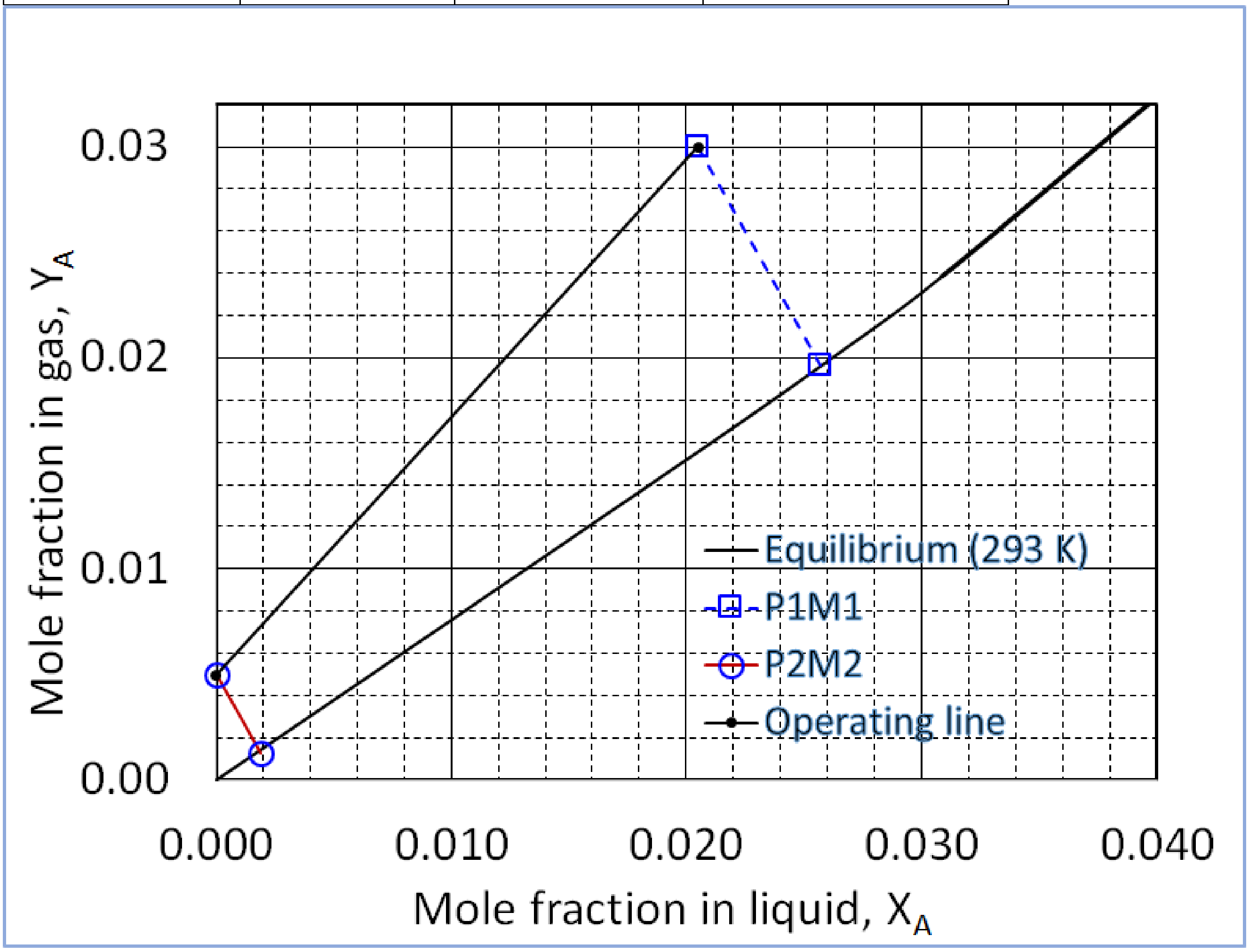
$V_2 (kg\ mol/h)$	$L_1 (kg\ mol/h)$	$x_1 (\ mol\ frac)$	*Henry's law constant (approx.) (mol frac/mol frac))*
48.74	61.26	0.0205	0.77

- Interface concentrations at the bottom and top of the tower (**7**)

x_{1i}	y_{1i}	x_{2i}	y_{2i}
0.02567	0.0197	0.0019	0.0013

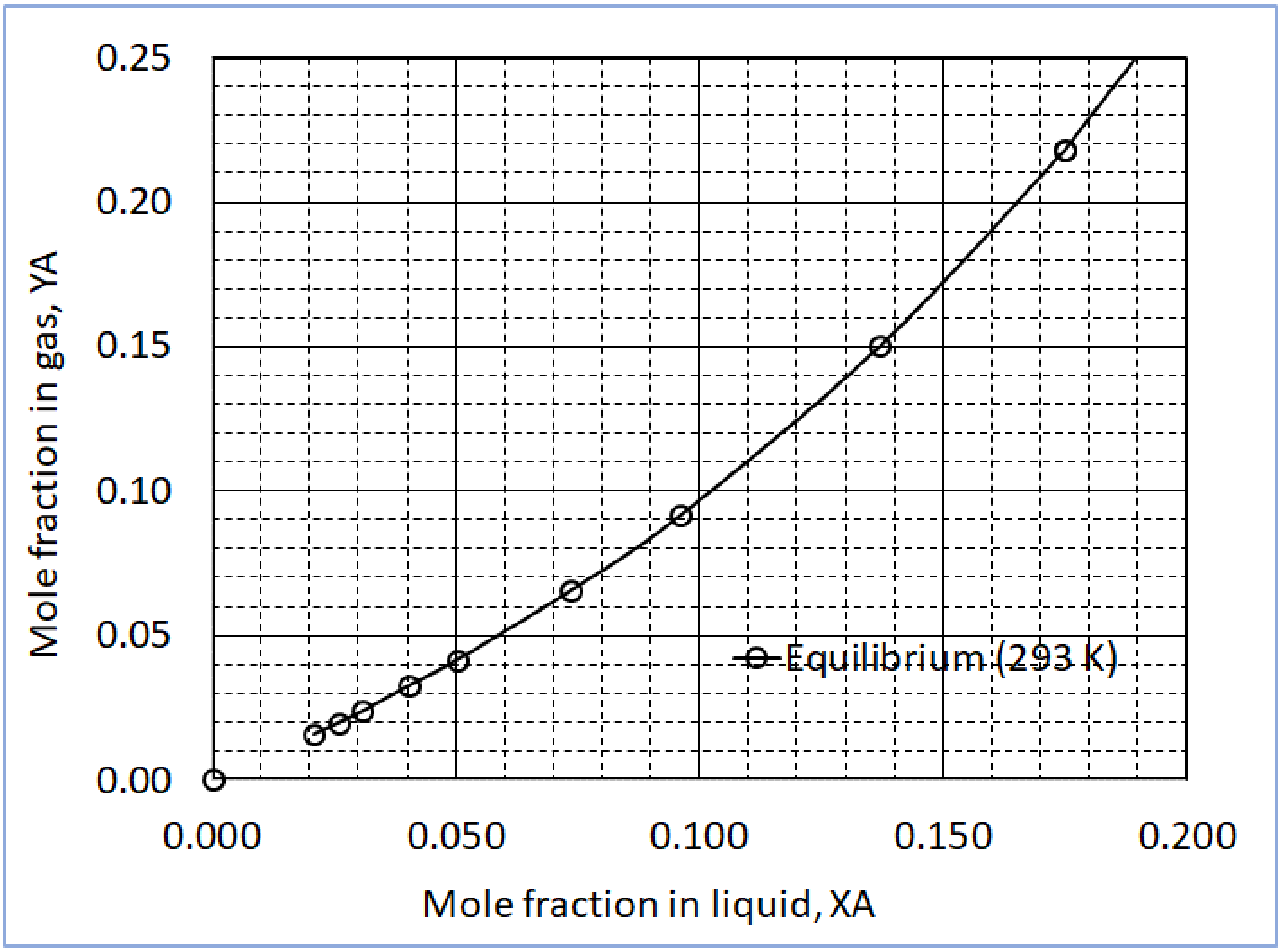
- Evaluate (**5**)

$(x_i - x)_M$	N_L	H_L	*Height (m)*
0.0032	6.312	0.0833 (m)	0.526



Question 3 (20 Marks): The gas stream from a chemical reactor contains 25 mol % ammonia and the rest inert gases. The total gas flow is 160 kg mol/h to a packed bed absorber at 293 K and 1 atm. Pressure. Water containing 0.5 mol % ammonia is used as the solvent. The outlet gas concentration is to be 2.0 mol % ammonia. The figure is given here with the equilibrium line in the following.

- Determine the minimum solvent flow L'_{min} and its composition (**8**).
- How much ammonia is removed from the gases in the absorber (**4**).
- Using solvent flow $L' = 1.5L'_{min}$, plot the operating line (**8**).



$$L'_{min}\frac{x_2}{(1-x_2)} + V'\frac{y_1}{(1-y_1)} = L'_{min}\frac{x_{1\,max}}{(1-x_{1\,max})} + V'\frac{y_2}{(1-y_2)}$$

From the given figure, $\boldsymbol{x_{1\,max}} = \mathbf{0.19}$ corresponding to $y_2 = 0.25$

$$V' = V_1(1-y_1) = 160 \times (1-0.25) = 120\ \frac{kg\ mol}{h}$$

$$L'_{min}\frac{0.005}{(1-0.005)} + 120\frac{0.25}{(1-0.25)} = L'_{min}\frac{0.19}{(1-0.19)} + 120\frac{0.02}{(1-0.02)}$$

$$\boldsymbol{L'_{min} = 163.85\ \frac{kg\ mol}{h}}$$

$$V_2 = \frac{V'}{(1-y_1)} = \frac{120}{(1-0.02)} = 122.45\frac{kg\ mol}{h}$$

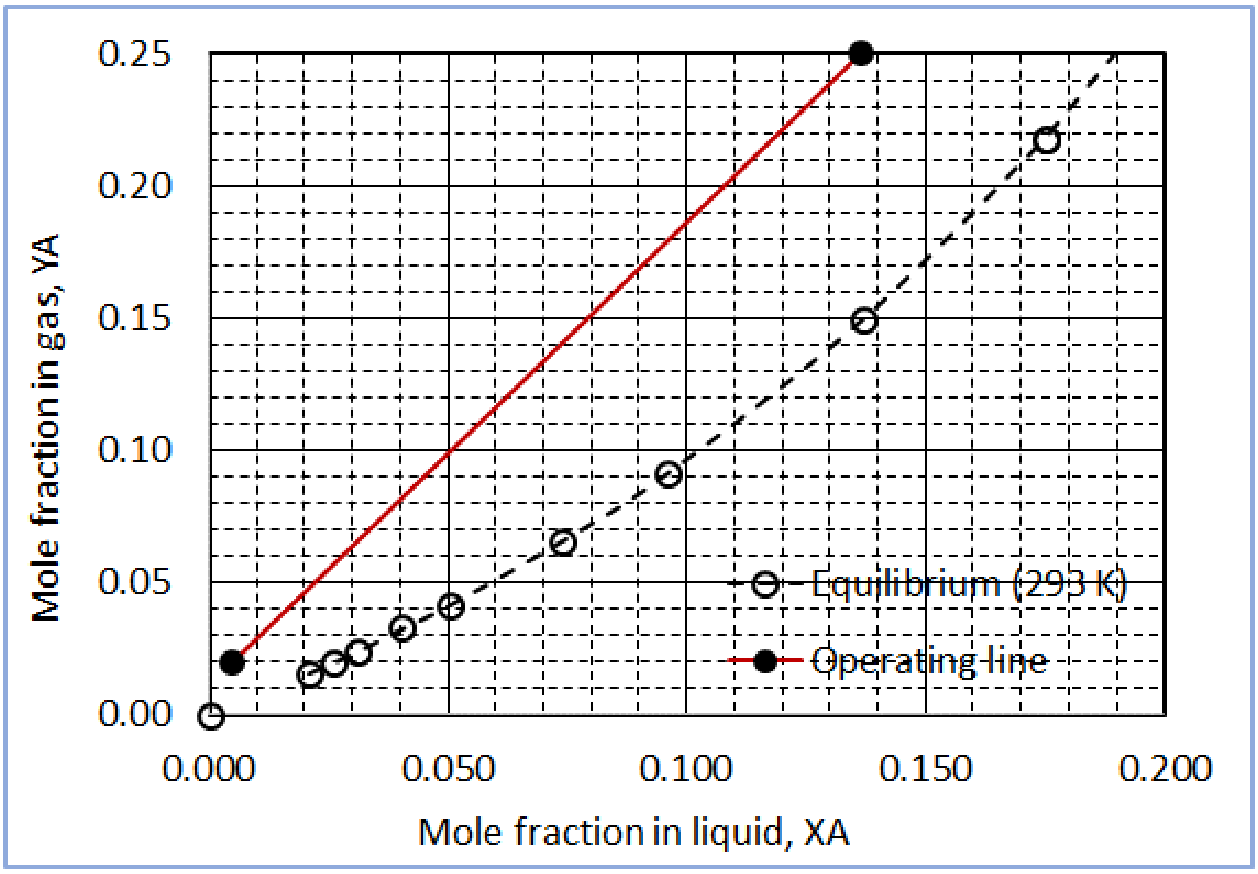
Ammonia removed =

$$V_1 - V_2 = 160 - 122.45 = 37.55\ \frac{kg\ mol}{h}$$

$$L' = 1.5L'_{min} = 1.5 \times 163.59 = 245.8\ \frac{kg\ mol}{h}$$

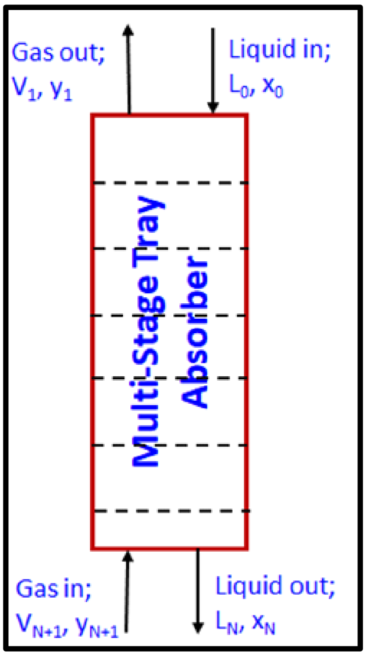
$$L'\frac{x_2}{(1-x_2)} + V'\frac{y_1}{(1-y_1)} = L'\frac{x_1}{(1-x_1)} + V'\frac{y_2}{(1-y_2)}$$

$$x_1 = 0.136$$



Question 4 (10 Marks):

Inlet gas stream to a multi-stage tray absorption tower (absorber) contains $y_{N+1} = 0.03$ ammonia (NH_3). The outlet gas stream contains $y_1 = 0.005$ at 293 K and 101.325 kPa. The inlet pure water flow is $L_0 = 60\ kg\ mol/h$ and the total inlet gas flow is $V_{N+1} = 50\ kg\ mol/h$. The equilibrium data is given in **Question 2**. Determine the number of ideal stage required for separation using the analytical Kremser equation.



For **ABSORPTION** (transfer of solute A from V to L)

$$N = \log\left[\frac{y_{N+1} - mx_0}{y_1 - mx_0}\left(1 - \frac{1}{A}\right) + \frac{1}{A}\right] / \log A\,;$$

$$m = 0.8; \frac{L}{V} = 1.2; A \cong 1.5; x_0 = 0.0; \frac{y_{N+1} - mx_0}{y_1 - mx_0} = \frac{0.030 - m \times 0}{0.005 - m \times 0} = 6$$

$$N = \log\left[\frac{y_{N+1} - mx_0}{y_1 - mx_0}\left(1 - \frac{1}{A}\right) + \frac{1}{A}\right] / \log A = \log\left[6\left(1 - \frac{1}{1.5}\right) + \frac{1}{1.5}\right] / \log 1.5 = 2.43$$

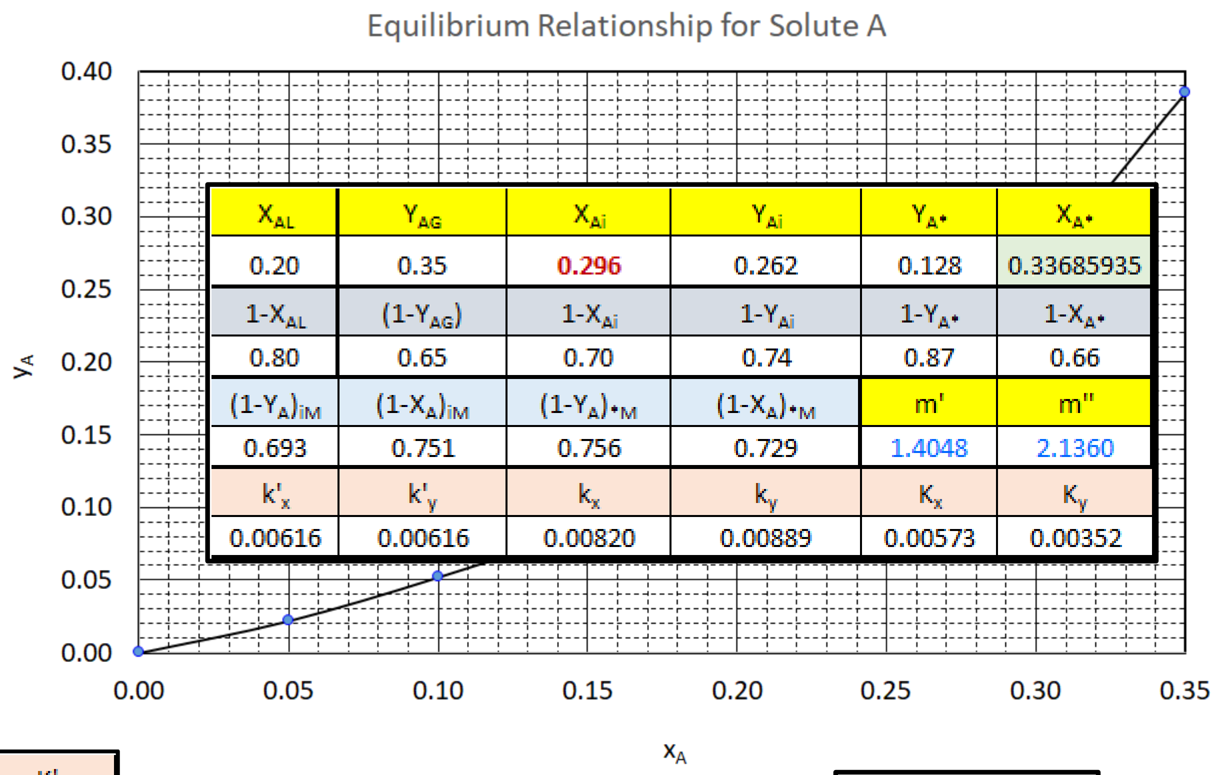
Question 5 (20 Marks):: The solute A is being absorbed from a gas mixture of A and B in a wetted-wall tower with the liquid flowing as a film downward along the wall. At a certain point in the tower the bulk gas concentration $y_{AG} = 0.35$ mol fraction and the bulk liquid concentration is $x_{AL} = 0.20$. The tower is operating at 298 K and 1013 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.

Using correlations for dilute solutions in wetted-wall towers, the film mass-transfer coefficient for A in the gas phase is predicted as:

$$k'_y a = 6.16 \times 10^{-2} \text{kg mol/s} \cdot \text{m}^3 \cdot \text{mol frac}$$

$$k'_x a = 6.16 \times 10^{-2} \text{kg mol/s} \cdot \text{m}^3 \cdot \text{mol frac}$$

Calculate the overall mass transfer coefficient $K'_y a$ and the percent resistance in the gas and the liquid films and the flux N_A. If required, assume $a = 10\ \text{m}^2/\text{m}^3$. Use the given figure showing the equilibrium line and make only one trial to obtain interface concentration assuming $(1 - y_A)_{iM} = (1 - x_A)_{iM} = 1$.



X_{AL}	Y_{AG}	X_{Ai}	Y_{Ai}	Y_{A^*}	X_{A^*}
0.20	0.35	0.296	0.262	0.128	0.33685935
$1-X_{AL}$	$(1-Y_{AG})$	$1-X_{Ai}$	$1-Y_{Ai}$	$1-Y_{A^*}$	$1-X_{A^*}$
0.80	0.65	0.70	0.74	0.87	0.66
$(1-Y_A)_{iM}$	$(1-X_A)_{iM}$	$(1-Y_A)_{*M}$	$(1-X_A)_{*M}$	m'	m''
0.693	0.751	0.756	0.729	1.4048	2.1360
k'_x	k'_y	k_x	k_y	K_x	K_y
0.00616	0.00616	0.00820	0.00889	0.00573	0.00352

K'_y
0.00266

$N_A = K_y(Y_{AG} - Y^*_A)$	$= k_y(Y_{AG} - Y$
0.000784	0.000784

Slope	Slope(Cal.)
-0.923	-0.923

Operating line	
X	Opt Line
0.20	0.35
0.296	0.26