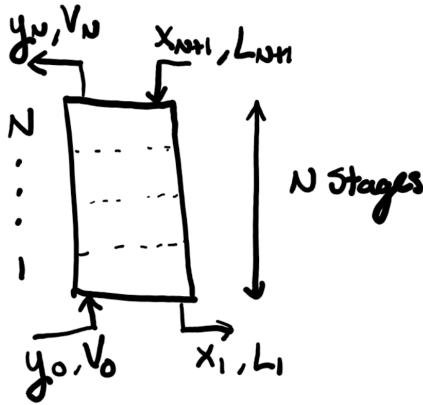


1)

a.



$$y_0 \approx 0$$

$$y_e = 0.85x_e$$

$$V_0/L_{N+1} = V/L = 1.5$$

$$y_N V_N = 0.925 x_{N+1} L_{N+1}$$

$$N_A = 7$$

Assume: Dilute $\Rightarrow L, V$ are approximately constant (CMO).

Solve:

The material balances around the entire column are,

$$y_0 V + x_{N+1} L = y_N V + x_1 L,$$

Using $y_0 \approx 0$,

$$x_{N+1} = \frac{y_N V}{L} + x_1.$$

The removal condition is,

$$\frac{y_N V}{L} = 0.925 x_{N+1},$$

giving,

$$x_{N+1} = 0.925 x_{N+1} + x_1,$$

or,

$$\frac{x_{N+1}}{x_1} = \frac{1}{0.075} = 13.33.$$

The stripping factor is,

$$S = \frac{KV}{L} = (0.85)(1.5) = 1.275.$$

The Kremser equation with $y_0 = 0$ may now be used,

$$\begin{aligned} N &= \frac{\ln \left(\left[\frac{x_{N+1}}{x_1} \right] \left[1 - \frac{1}{S} \right] + \frac{1}{S} \right)}{\ln(S)} \\ &= \frac{\ln \left([13.33] \left[1 - \frac{1}{1.275} \right] + \frac{1}{1.275} \right)}{\ln(1.275)} \\ &= 5.34. \end{aligned}$$

Thus, $\boxed{N_I = 6}$ ideal stages are required. The efficiency, E , is given by,

$$\boxed{E = \frac{N}{N_A} = \frac{5.34}{7} = 0.763}.$$

b.

For there to be equilibrium between the outlets of each stage, they must be operating at a constant temperature and pressure. Furthermore, the phase rule dictates that at each stage, i , we have $P_i = P_i(x_i, y_i)$, and $T_i = T_i(x_i, y_i)$. The x_i and y_i compositions are fixed by the operating and equilibrium lines, however, in this example, we cannot solve for the operating line as one more inlet or outlet concentration needs to be specified. If the x_i and y_i are known, then the pressure and temperature at each stage may be calculated. For example, if Raoult's law applies to a component, j , then,

$$f(T_i) = y_{i,j} - \frac{x_{i,j} P_{i,j}^{sat}(T_i)}{\sum_j x_{i,j} P_{i,j}^{sat}(T_i)} = 0,$$

which can be root-solved for T_i . However, if the changes in x_i and y_i are small, then the changes in T_i and P_i are small between stages, meaning the P and T in the entire column are practically constant. In fact, since we have assumed a constant K , we have implicitly assumed that the temperature and pressure in the entire column are constant.

2)

a.

The given data can be converted to liquid mole fractions by assuming 100 kg of water and calculating the resulting moles of each component. The vapor mole fractions can be calculated by dividing the ammonia (A) partial pressure by the total pressure.

Table 1: $\text{NH}_3 - \text{H}_2\text{O}$ Equilibrium Data

x_A	0.021	0.031	0.041	0.050	0.074	0.096
P_A (kPa)	2.57	3.95	5.35	6.80	10.60	14.67
y_A	0.024	0.038	0.051	0.065	0.101	0.140

This data yields the following figures.

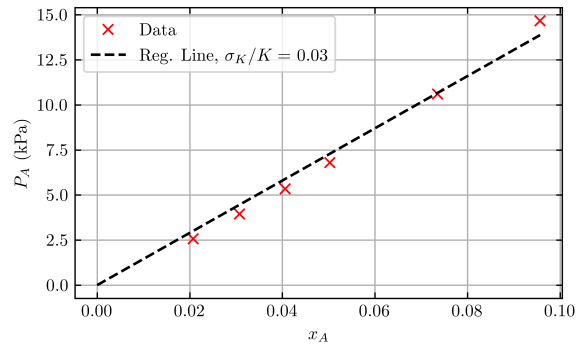
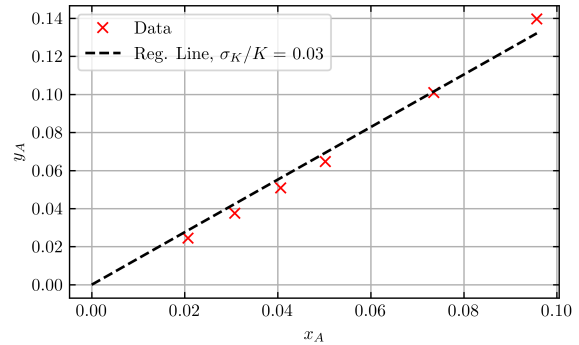
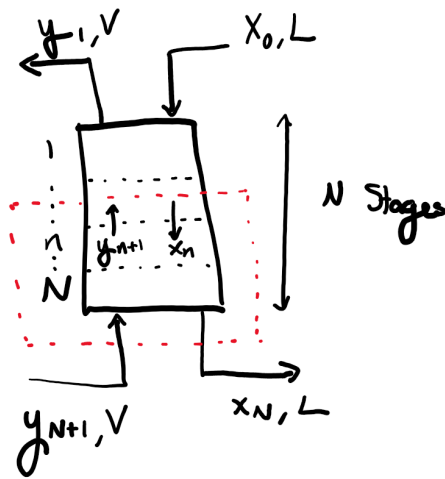
(a) Fit: $P_A = Kx_A$, where $K = 155$ kPa.(b) Fit: $y_A = Kx_A$, where $K = 1.38$.

Figure 1: $\text{NH}_3 - \text{H}_2\text{O}$ equilibrium curves. σ_K denotes the estimated standard deviation of K (Max. Likelihood Est.).

b.



$$P = 105.1 \text{ kPa}$$

$$T = 303 \text{ K}$$

$$\dot{V} = 4200 \text{ m}^3/\text{hr}$$

$$y_{N+1} = 0.04$$

$$y_e = 1.38x_e$$

$$x_N L_N = 0.98 y_{N+1} V_{N+1}$$

Assume: Low pressure \Rightarrow assume ideal gasses. $x_0 \approx 0$.

Solve:

Solve for V_{N+1} ,

$$V_{N+1} = \frac{P\dot{V}}{RT} = \frac{(105100 \text{ Pa})(4200 \text{ m}^3/\text{hr})}{(8.3145 \frac{\text{Pa}\cdot\text{m}^3}{\text{mol}\cdot\text{K}})(303 \text{ K})} = 175216 \text{ mol/hr.}$$

The minimum L_N value is given by using $y_{N+1} = Kx_N$,

$$x_N L_N = 0.98 K x_N V_{N+1},$$

$$\Rightarrow L_{N,\min} = (0.98)(1.38)(175216 \text{ mol/hr}) = 237091 \text{ mol/hr.}$$

Solving for $L_{0,\min}$,

$$L_{0,\min} = (1 - x_N)L_{N,\min} = [237091 - (0.98)(0.04)(175216)] \text{ mol/hr} = 230223 \text{ mol/hr.}$$

Thus,

$$L_{min} = 230000 \text{ mol/hr}.$$

c.

Solve for L_0 ,

$$L_0 = 1.5L_{min} = (1.5)(230223 \text{ mol/hr}) = 345334 \text{ mol/hr}.$$

Solve for L_N ,

$$\begin{aligned} L_N &= L_0 + x_N L_N \\ &= L_0 + 0.98 y_{N+1} V_{N+1} \\ &= [345334 + (0.98)(0.04)(175216)] \text{ mol/hr} \\ &= 352203 \text{ mol/hr}. \end{aligned}$$

x_N may now be solved for,

$$x_N = \frac{0.98 y_{N+1} V_{N+1}}{L_N} = \frac{(0.98)(0.04)(175216)}{352203} = 0.0195.$$

The material balances around the entire column are,

$$L_0 + V_{N+1} = L_N + V_1,$$

$$x_0 L_0 + y_{N+1} V_{N+1} = x_N L_N + y_1 V_1.$$

Rearranging,

$$\begin{aligned} V_1 &= L_0 + V_{N+1} - L_N, \\ y_1 &= \frac{x_0 L_0 + y_{N+1} V_{N+1} - x_N L_N}{V_1}, \\ \Rightarrow y_1 &= \frac{x_0 L_0 + y_{N+1} V_{N+1} - x_N L_N}{L_0 + V_{N+1} - L_N}. \end{aligned}$$

We have the condition that the oil flow rate is constant, i.e.,

$$(1 - x_0)L_0 = (1 - x_N)L_N,$$

or,

$$L_0 = \frac{1 - x_N}{1 - x_0} L_N.$$

Therefore,

$$y_1 = \frac{y_{N+1} V_{N+1} + \left(\frac{1 - x_N}{1 - x_0} x_0 - x_N \right) L_N}{V_{N+1} + \left(\frac{1 - x_N}{1 - x_0} - 1 \right) L_N},$$

or,

$$y_1 = \frac{y_{N+1} + \left(\frac{1 - x_N}{1 - x_0} x_0 - x_N \right) \frac{L_N}{V_{N+1}}}{1 + \left(\frac{1 - x_N}{1 - x_0} - 1 \right) \frac{L_N}{V_{N+1}}}.$$

In this example, $x_0 = 0$, thus,

$$y_1 = \frac{y_{N+1} - \frac{x_N L_N}{V_{N+1}}}{1 - \frac{x_N L_N}{V_{N+1}}}.$$

$x_N L_N / V_{N+1}$ may be solved for,

$$\frac{x_N L_N}{V_{N+1}} = 0.98 y_{N+1} = (0.98)(0.04) = 0.0392,$$

giving,

$$y_1 = \frac{0.04 - 0.0392}{1 - 0.0392} = 0.0008.$$

The operating line may now be plotted since $(x_0, y_1) = (0, 0.0008)$ and $(x_N, y_{N+1}) = (0.0195, 0.04)$ are known.

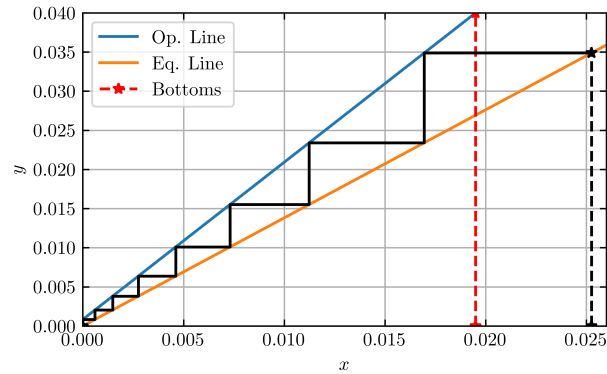
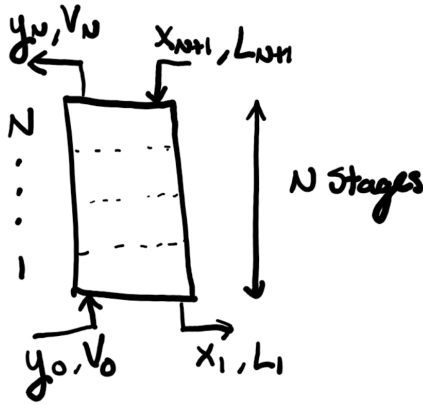


Figure 2: $\text{NH}_3 - \text{H}_2\text{O}$ Absorption

Thus, at least $\boxed{N = 8}$ stages are required (Kremser gives $N = 7.20$).

3)

a.



$$y_0 \approx 0$$

Water in : 600 ppm TCA

$$P = 110000 \text{ Pa}$$

$$T = 25 \text{ }^\circ\text{C}$$

$$\dot{V}_{TCA, out} / \dot{V}_{tot, out} \leq 0.025$$

$$N_A = 8, E = 0.4$$

TCA equilibrium:

$$K' = 0.204 + 0.0182\theta + 0.000174\theta^2 \left[\frac{\text{mg/L air}}{\text{mg/L water}} \right],$$

where θ is the temperature in $^\circ\text{C}$.

Solve:

Since the pressure is 1.1 bar, we will assume we have ideal gasses. We will also assume the total moles of the mixture is approximately the moles of air. The moles of air is then given by,

$$\begin{aligned} \frac{1 \text{ L}}{n_{air}} &= \frac{R(\theta + 273.15)}{P} \\ &= \frac{(8.3145 \text{ Pa} \cdot \text{m}^3/\text{mol} \cdot \text{K})(1000 \text{ L/m}^3)}{110000 \text{ Pa}} (\theta + 273.15) \\ &= 0.07559(\theta + 273.15) \text{ L/mol air.} \end{aligned}$$

The moles in 1 L of water is,

$$\frac{1 \text{ L}}{n_w} = \frac{M_w}{\rho_w} = \frac{18.02 \text{ g/mol}}{997 \text{ g/L}} = 0.01807 \text{ L/mol water.}$$

Thus the Henry's Law constant, K , in mole fractions is,

$$\begin{aligned} K &= K' \frac{0.07559(\theta + 273.15)}{0.01807} \left[\frac{\text{mol TCA/mol air}}{\text{mol TCA/mol water}} \right] \\ &= 4.182(\theta + 273.15) K' \left[\frac{\text{mol TCA/mol air}}{\text{mol TCA/mol water}} \right]. \end{aligned}$$

With $\theta = 25 \text{ }^\circ\text{C}$,

$$\boxed{K = 956}.$$

(Seems wrong..., can't figure it out)

b.

x_{N+1} may be solved for,

$$x_{N+1} = 600 \times 10^{-6} \frac{\text{g TCA}}{\text{g water}} \left(\frac{18.02 \text{ g/mol water}}{133.4 \text{ g/mol TCA}} \right) = 0.00008.$$

The inlet solution is *very* dilute, thus, we may assume CMO as a first approximation¹. With this, the material balances become,

$$y_0 V + x_{N+1} L = y_N V + x_1 L,$$

Using $y_0 \approx 0$,

$$\frac{V}{L} = \frac{x_{N+1} - x_1}{y_N}.$$

Since we have assumed ideal gasses, the volume fraction of the outlet vapor is the equal to the mole fraction, i.e. $y_N = 0.025$. Thus, we have,

$$S = \frac{KV}{L} = \frac{K(x_{N+1} - x_1)}{y_N} = \frac{956(0.00008 - x_1)}{0.025}.$$

The number of ideal stages, N , is given by,

$$N = E \cdot N_A = (0.4)(8) = 3.2.$$

The Kremser equation with $y_0 = 0$ is,

$$N = \frac{\ln \left(\left[\frac{x_{N+1}}{x_1} \right] \left[1 - \frac{1}{S} \right] + \frac{1}{S} \right)}{\ln(S)}.$$

The only unknown in the above is x_1 , therefore, we let,

$$f(x_1) = \ln \left(\left[\frac{x_{N+1}}{x_1} \right] \left[1 - \frac{1}{S} \right] + \frac{1}{S} \right) - N \ln(S),$$

and root solve for $f(x_1) = 0$, giving $x_1 = 1.56 \times 10^{-6}$. This is less than x_{N+1} , so the root is reasonable. The percent removal is thus,

$$\% \text{ Removal} = \frac{\text{TCA removed}}{\text{TCA in}} = \frac{(x_{N+1} - x_1)L}{x_{N+1}L} = 98\%.$$

¹Its possible to solve this problem without assuming CMO for the material balances, but the resulting answer for x_1 is 1.62×10^{-6} and the removal is still 98 %. Thus, the result is negligibly different and the math is much less nice.