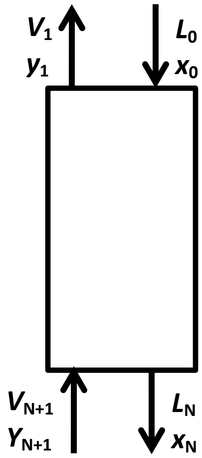
Practice problems in ABSORPTION

1.



Given: V_{N+1} = 100 kmol/h

y_{N+1} = 0.022

x_0 = 0 (pure water feed)

Calculate V':

$$\begin{aligned} V' &= V_{N+1}(1 - y_{N+1}) \\ &= (100 kmol/h)(1-0.022) \\ &= 97.8 kmol/h \end{aligned}$$

Ethanol flows:

Ethanol entering in V_{N+1}: $V_{N+1} y_{N+1} = (100 kmol/h)(0.022) = 2.2 kmol/h$

Ethanol leaving in V_1: $(0.1)(2.2) = 0.22 kmol/h$

Ethanol leaving in L_N: $(0.9)(2.2) = 1.98 kmol/h$

Calculate V_1 and y_1:

$$V_1 = (97.8 + 0.22) kmol/h = 98.02 kmol/h$$

$$y_1 = \frac{0.22}{98.02} = 0.002244$$

At $L'_{\min}$, y_{N+1} and $x_{N,\max}$ are in equilibrium:

$$\begin{aligned} y_{N+1} &= 0.022 = 0.68 x_{N,\max} \\ x_{N,\max} &= 0.03235 \end{aligned}$$

Use the solute balance with $x_{N,\max}$ to calculate $L'_{\min}$, then calculate L':

$$L'_{\min} \frac{x_0}{1-x_0} + V' \frac{y_{N+1}}{1-y_{N+1}} = L'_{\min} \frac{x_{N,\max}}{1-x_{N,\max}} + V' \frac{y_1}{1-y_1}$$

$$L'_{\min} \frac{0}{1-0} + 97.8 \frac{0.022}{1-0.022} = L'_{\min} \frac{0.03235}{1-0.03235} + 97.8 \frac{0.002244}{1-0.002244}$$

$$L'_{\min} = 59.23 kmol/h$$

$$L' = 1.3 L'_{\min} = 1.3(59.23 kmol/h) = 76.99 kmol/h$$

Use the solute balance with L' to calculate x_N:

$$L'\frac{x_0}{1-x_0}+V'\frac{y_{N+1}}{1-y_{N+1}}=L'\frac{x_N}{1-x_N}+V'\frac{y_1}{1-y_1}$$

$$76.99\frac{0}{1-0}+97.8\frac{0.022}{1-0.022}=76.99\frac{x_N}{1-x_N}+97.8\frac{0.002244}{1-0.002244}$$

$$x_N=0.02507$$

Because the system is dilute, the operating and equilibrium lines will be straight. Plot the equilibrium line using the equation given. Plot the operating line from (x_0,y_1) to (x_N,y_{N+1}). Stepping up between the operating and equilibrium lines will give around 5.4 stages.

For the analytical solution, we need the absorption factor:

$$A_{top}=\frac{L_0}{mV_1}=\frac{76.99}{(0.68)(98.02)}=1.155$$

$$A_{bottom}=\frac{L_N}{mV_{N+1}}=\frac{78.97}{(0.68)(100)}=1.161$$

$$A=\sqrt{A_{top}A_{bottom}}=\sqrt{(1.155)(1.161)}=1.158$$

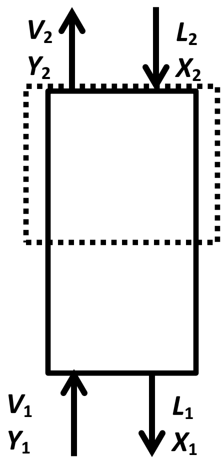
Use the analytical solution for an absorption tray tower to find N:

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

$$=\frac{\ln\left[\frac{0.022-(0.68)(0)}{0.002244-(0.68)(0)}\left(1-\frac{1}{1.158}\right)+\frac{1}{1.158}\right]}{\ln(1.158)}$$

$$=5.38\text{ stages}$$

2.



Given: V_1 = 181.4 kmol/h

y_1 = 0.25

y_2 = 0.02

x_2 = 0.005 (inlet liquid)

Calculate V' and V_2:

$$V' = V_1(1-y_1) = (181.4 kmol/h)(1-0.25) = 136.05 kmol/h$$

$$V_2 = V'\frac{1}{1-y_2} = (136.05 kmol/h)\frac{1}{1-0.02} = 138.83 kmol/h$$

At $L'_{\min}$, y_1 and $x_{1,\max}$ are in equilibrium. Plotting the equilibrium data shows that the equilibrium line is curved, and that at y_1 = 0.25, $x_{1,\max}$ = 0.14.

Use the solute balance with $x_{1,\max}$ to calculate $L'_{\min}$, then calculate L':

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

$$L'_{\min}\frac{0.005}{1-0.005} + 136.05\frac{0.25}{1-0.25} = L'_{\min}\frac{0.14}{1-0.14} + 136.05\frac{0.02}{1-0.02}$$

$$L'_{\min} = 269.9 kmol/h$$

$$L' = 1.5L'_{\min} = 1.5(269.9 kmol/h) = 404.8 kmol/h$$

Use the solute balance with L' to calculate x_1:

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

$$404.8\frac{0.005}{1-0.005} + 136.05\frac{0.25}{1-0.25} = 404.8\frac{x_1}{1-x_1} + 136.05\frac{0.02}{1-0.02}$$

$$x_1 = 0.1425$$

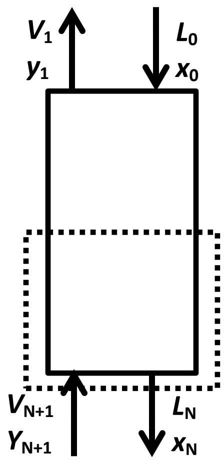
Because the system is not dilute, the operating line will be curved, and we need the operating line equation to plot it. The operating line equation is generated from a solute balance around either the top or the bottom of the column. Using the top of the column (dashed line in figure):

$$L'\frac{x_2}{1-x_2}+V'\frac{y}{1-y}=L'\frac{x}{1-x}+V'\frac{y_2}{1-y_2}$$

$$404.8\frac{0.005}{1-0.005}+136.05\frac{y}{1-y}=404.8\frac{x}{1-x}+136.05\frac{0.02}{1-0.02}$$

Plot the operating line from (x_0,y_1) to (x_N,y_{N+1}), using several (x,y) points calculated using the operating line equation.

3.



Given: L_0 = 300 kmol (basis per unit time)

$x_0 = 0.04$

$x_N = 0.002$

V_{N+1} = 11.42 kmol (basis per unit time)

$y_{N+1} = 0$ (therefore $V_{N+1} = V'$)

Calculate L':

$$\begin{aligned} L' &= L_0(1-x_0) \\ &= (300kmol)(1-0.04) \\ &= 288kmol \end{aligned}$$

Use the solute balance with to calculate y_1:

$$L'\frac{x_0}{1-x_0}+V'\frac{y_{N+1}}{1-y_{N+1}}=L'\frac{x_N}{1-x_N}+V'\frac{y_1}{1-y_1}$$

$$288\frac{0.04}{1-0.04}+11.42\frac{0}{1-0}=288\frac{0.002}{1-0.002}+11.42\frac{y_1}{1-y_1}$$

$$y_1 = 0.50$$

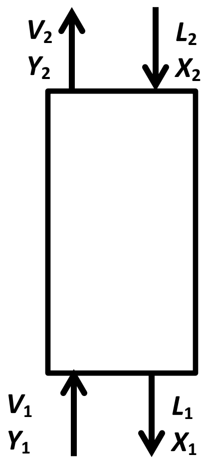
Use a solute balance around the bottom of the column (dotted line in figure) to get the equation of the operating line:

$$L'\frac{x}{1-x}+V'\frac{y_{N+1}}{1-y_{N+1}}=L'\frac{x_N}{1-x_N}+V'\frac{y}{1-y}$$

$$288\frac{x}{1-x}+11.42\frac{0}{1-0}=288\frac{0.002}{1-0.002}+11.42\frac{y}{1-y}$$

Plot the operating line from (x_0,y_1) to (x_N,y_{N+1}) using the equation above (will be curved). Plot the equilibrium line using the equation given. Stepping up between the operating and equilibrium lines will give around 5.6 stages.

4.



Given solute-free fluxes:
$$\frac{V'}{S} = 95 lb_m / h \cdot ft^2$$
$$\frac{L'}{S} = 987 lb_m / h \cdot ft^2$$

Given film mass transfer coefficients:
$$k_y a = 4.03 lbmol / h \cdot ft^3$$
$$k_x a = 57.0 lbmol / h \cdot ft^3$$

Given equilibrium relationship: $c_A\left[lbmol / ft^3\right] = 1.37 p_A [atm]$

For dilute solutions, assume: $k_y a \approx k'_y a$ and $k_x a \approx k'_x a$
$$\frac{V'}{S} \approx \frac{V}{S} \text{ and } \frac{L'}{S} \approx \frac{L}{S}$$

(a) Calculate H_G and H_L:
$$H_G = \frac{V}{S}\frac{1}{k'_y a} = \left(\frac{95 lb_m / h \cdot ft^2}{29 lb_m / lbmol}\right)\left(\frac{1}{4.03 lbmol / h \cdot ft^3}\right) = 0.813\, ft$$
$$H_L = \frac{L}{S}\frac{1}{k'_x a} = \left(\frac{987 lb_m / h \cdot ft^2}{18 lb_m / lbmol}\right)\left(\frac{1}{57.0 lbmol / h \cdot ft^3}\right) = 0.962\, ft$$

(b) To find H_{OG}, we need the overall volumetric gas mass transfer coefficient. To calculate this we first need the equilibrium relationship in terms of mole fractions:

For the liquid:
$$x_A = \frac{c_A\left[lbmolA / ft^3\right]}{C\left[lbmol(A+B) / ft^3\right]}$$

Since the system is dilute:
$$C(A+B) \approx C(B) = \frac{\rho_{water}}{MW_{water}} \frac{61.8 lb_m / ft^3}{18 lb_m / lbmol}$$

Therefore:
$$c_A = C(A+B)x_A = \frac{61.8}{18} x_A$$

For the gas:

$$y_A = \frac{p_A[atm(A)]}{P[atm(total)]} = \frac{p_A[atm]}{1.0atm}$$

$$p_A = 1.0 y_A$$

Substituting and rearranging the equilibrium equation gives the slope of the equilibrium line, *m*:

$$c_A[lbmol/ft^3] = 1.37 p_A[atm]$$

$$\frac{61.8}{18} x_A = 1.37(1.0 y_A)$$

$$y_A = 2.506 x_A$$

$$m = 2.506$$

Calculate the overall mass transfer coefficient:

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

For a dilute system, $(1\text{-}y_A)_{*M}$, $(1\text{-}y_A)_{iM}$ and $(1\text{-}x_A)_{iM}$ are all ~1:

$$\frac{1}{K'_y a} = \frac{1}{k'_y a} + \frac{m'}{k'_x a}$$

$$= \frac{1}{4.03 lbmol/h\cdot ft^3} + \frac{2.506}{57.0 lbmol/h\cdot ft^3}$$

$$K'_y a = 3.423 lbmol/h\cdot ft^3$$

Calculate H_{OG}:

$$H_G = \frac{V}{S}\frac{1}{K'_y a} = \left(\frac{95 lb_m/h\cdot ft^2}{29 lb_m/lbmol}\right)\left(\frac{1}{3.423 lbmol/h\cdot ft^3}\right) = 0.957\, ft$$