1. Problem 22.1-2

   From Appendix A.3

$$
\begin{aligned}
H_{\mathrm{CO_2}} &= 0.186 \cdot 10^4 \\
C_{\mathrm{CO_2}} &= 0.9 \cdot 10^{-4} \\
x_A &= \frac{C_A/M_A}{1/M_B + C_A/M_A} \\
M_{\mathrm{CO_2}} &= 44 \\
M_{\mathrm{Water}} &= 18 \\
P_{\mathrm{CO_2}} &= H_{\mathrm{CO_2}} x_{\mathrm{CO_2}} \\
P_{\mathrm{CO_2}} &= 0.186 \cdot 10^4 \cdot \frac{0.9 \cdot 10^{-4}/44}{1/18 + 0.9 \cdot 10^{-4}/44} \\
&\boxed{P_{\mathrm{CO_2}} = 0.0685 \text{ atm}}
\end{aligned}
$$

2. Problem 22.1-4

Diagram:

$$L'\frac{x_0}{1-x_0}+V'\frac{y_2}{1-y_2}=L'\frac{x_1}{1-x_1}+V'\frac{y_1}{1-y_1}$$
$$x_0=0$$
$$y_0=\frac{1.52\cdot 10^4}{2.026\cdot 10^5}=0.075$$
$$L'=2.2$$
$$V'=(1-y_0)V$$
$$V'=(1-0.075)\cdot 5.7=5.27$$

From Figure 22.1-1:

$$H_{SO_2}=29.6$$
$$P_A=Hx_A$$
$$y_A=\frac{H}{P}x_A$$
$$H'=\frac{29.6}{2.026\cdot 10^5}\cdot 101325=14.8$$
$$5.27\cdot\frac{0.075}{1-0.075}=2.2\cdot\frac{x_1}{1-x_1}+5.27\frac{14.8x_1}{1-14.8x_1}$$
$$0=2.2\cdot\frac{x_1}{1-x_1}+5.27\frac{14.8x_1}{1-14.8x_1}-5.27\cdot\frac{0.075}{1-0.075}$$

Solve for x_1

$$\boxed{x_1=0.00495}$$
$$y_1=14.8\cdot 0.00495$$
$$\boxed{y_1=0.0733}$$
$$L_1=\frac{L'}{1-x_1}=\frac{2.2}{1-0.00495}$$
$$\boxed{L_1=2.21\text{ kg mol}}$$
$$V_1=\frac{V'}{1-y_1}=\frac{5.7}{1-0.0733}$$
$$\boxed{V_1=5.69\text{ kg mol}}$$

3. Problem 22.5-1

Stage balances:

$$
\begin{aligned}
L'\frac{x_0}{1-x_0}+V'\frac{y_2}{1-y_2} &= L'\frac{x_1}{1-x_1}+V'\frac{y_1}{1-y_1}\\
L'\frac{x_1}{1-x_1}+V'\frac{y_3}{1-y_3} &= L'\frac{x_2}{1-x_2}+V'\frac{y_2}{1-y_2}\\
L'\frac{x_2}{1-x_2}+V'\frac{y_4}{1-y_4} &= L'\frac{x_3}{1-x_3}+V'\frac{y_3}{1-y_3}
\end{aligned}
$$

$$
\begin{aligned}
V'\frac{y_2}{1-y_2} &= L'\frac{x_1}{1-x_1}+V'\frac{y_1}{1-y_1}-L'\frac{x_0}{1-x_0}\\
V'y_2 &= \left(L'\frac{x_1}{1-x_1}+V'\frac{y_1}{1-y_1}-L'\frac{x_0}{1-x_0}\right)\\
&\quad - y_2\left(L'\frac{x_1}{1-x_1}+V'\frac{y_1}{1-y_1}-L'\frac{x_0}{1-x_0}\right)\\
V'y_2+y_2\left(L'\frac{x_1}{1-x_1}+V'\frac{y_1}{1-y_1}-L'\frac{x_0}{1-x_0}\right) &= \left(L'\frac{x_1}{1-x_1}+V'\frac{y_1}{1-y_1}-L'\frac{x_0}{1-x_0}\right)\\
y_2 &= \frac{\left(L'\frac{x_1}{1-x_1}+V'\frac{y_1}{1-y_1}-L'\frac{x_0}{1-x_0}\right)}{V'+\left(L'\frac{x_1}{1-x_1}+V'\frac{y_1}{1-y_1}-L'\frac{x_0}{1-x_0}\right)}\\
y_2 &= \left(\frac{V'}{L'\frac{x_1}{1-x_1}+V'\frac{y_1}{1-y_1}-L'\frac{x_0}{1-x_0}}+1\right)^{-1}\\
y_3 &= \left(\frac{V'}{L'\frac{x_2}{1-x_2}+V'\frac{y_2}{1-y_2}-L'\frac{x_1}{1-x_1}}+1\right)^{-1}\\
y_4 &= \left(\frac{V'}{L'\frac{x_3}{1-x_3}+V'\frac{y_3}{1-y_3}-L'\frac{x_2}{1-x_2}}+1\right)^{-1}
\end{aligned}
$$

Fit VLE data in Appendix A.3-19 to 4^{th} order polynomial

$$
\begin{aligned}
y_A(x_A) &= Ax_A^4+Bx_A^3+Cx_A^2+Dx_A+E\\
A &= 2.99092125\cdot 10^5\\
B &= -2.26812714\cdot 10^4\\
C &= 642.305650\\
D &= 26.9838344\\
E &= -2.85407304\cdot 10^{-3}\\
y_A(x_A) &= 2.99\cdot 10^5 x_A^4-2.27\cdot 10^4 x_A^3+642.31x_A^2+26.98x_A-2.85\cdot 10^{-3}
\end{aligned}
$$

Constants:

$$x_0 = 0$$
$$L' = \frac{6000}{18}$$
$$L' = 333.33$$
$$V' = \frac{150}{28.97}$$
$$V' = 5.178$$
$$y_4 = 0.2$$

Algorithm to solve for y_1:

(1) Guess y_1

(2) Solve for x_1 using:

$$y_1(x_1) = 2.99 \cdot 10^5 x_1^4 - 2.27 \cdot 10^4 x_1^3 + 642.31 x_1^2 + 26.98 x_1 - 2.85 \cdot 10^{-3}$$

(3) Solve for y_2 using:

$$y_2 = \left(\frac{V'}{L'\frac{x_1}{1-x_1} + V'\frac{y_1}{1-y_1} - L'\frac{x_0}{1-x_0}} + 1 \right)^{-1}$$

(4) Solve for x_2 using:

$$y_2(x_2) = 2.99 \cdot 10^5 x_2^4 - 2.27 \cdot 10^4 x_2^3 + 642.31 x_2^2 + 26.98 x_2 - 2.85 \cdot 10^{-3}$$

(5) Solve for y_3 using:

$$y_3 = \left(\frac{V'}{L'\frac{x_2}{1-x_2} + V'\frac{y_2}{1-y_2} - L'\frac{x_1}{1-x_1}} + 1 \right)^{-1}$$

(6) Solve for x_3 using:

$$y_3(x_3) = 2.99 \cdot 10^5 x_3^4 - 2.27 \cdot 10^4 x_3^3 + 642.31 x_3^2 + 26.98 x_3 - 2.85 \cdot 10^{-3}$$

(7) Solve for y_4 using:

$$y_4 = \left(\frac{V'}{L'\frac{x_3}{1-x_3} + V'\frac{y_3}{1-y_3} - L'\frac{x_2}{1-x_2}} + 1 \right)^{-1}$$

(8) Check that the y_4 calculated equals the y_4 specification from the problem. If they are not equal, return to step 1. Once they are equal, y_1 is solved for.

Using this algorithm, $\boxed{y_1 = 0.01127107}$.

4. Problem 22.5-4

Table of data from Appendix A.3-22, VLE data for Ammonia in water at 293 K

x_A	y_A
0.137	0.235
0.175	0.342

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

$$x_0 = 0.005$$

$$y_1 = 0.02$$

$$y_{N+1} = 0.25$$

$$x_N = \frac{0.175 - 0.137}{0.342 - 0.235} \cdot (0.25 - 0.235) + 0.137$$

$$x_N = 0.142$$

$$L'_{min} = L'$$

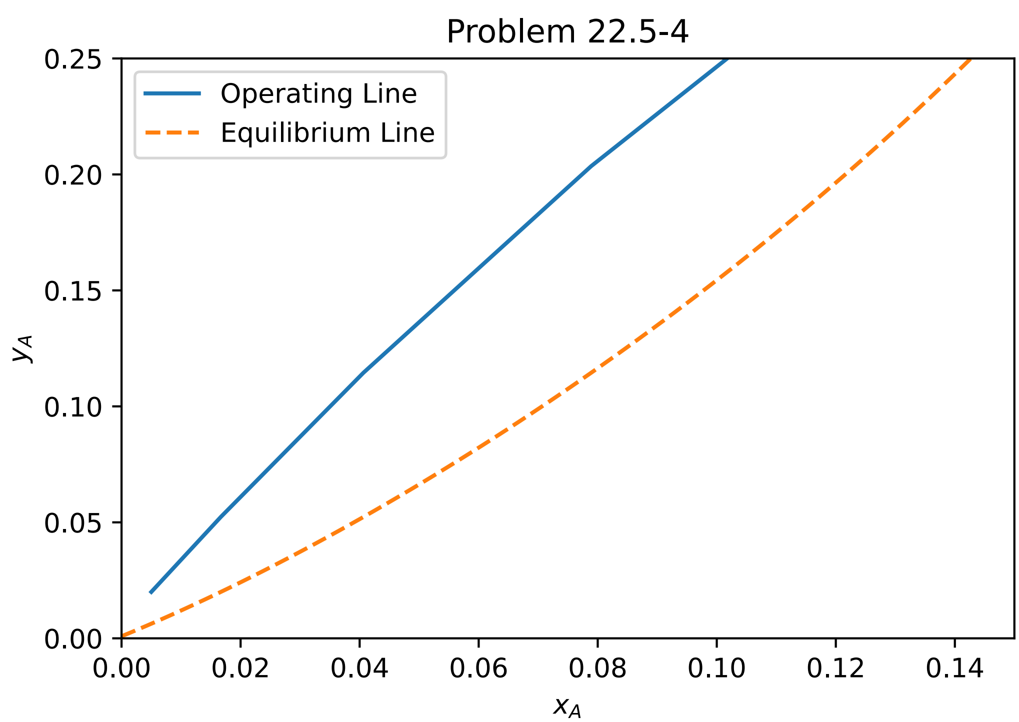
$$V' = 181.4 \cdot (1 - 0.25)$$

$$L'_{min} \frac{0.005}{1-0.005} + 181.4 \cdot (1-0.25) \cdot \frac{0.25}{1-0.25} = L'_{min} \frac{0.142}{1-0.142} + 181.4 \cdot (1-0.25) \cdot \frac{0.02}{1-0.02}$$

Solve for L'_{min}

$$\boxed{L'_{min} = 264.56 \text{ kg mol/h}}$$

Plot:



5. Problem 22.5-5

$$
\begin{aligned}
x_0 &= 0.04 \\
y_{N+1} &= 0 \\
y &= 25x \\
x_N &= 0.002 \\
y &= 25 \cdot x \\
V &= 11.42 \\
L &= 300
\end{aligned}
$$

Solve for y_1 from overall mass balance

$$
\begin{aligned}
L'\frac{x_0}{1-x_0} + V'\frac{y_{N+1}}{1-y_{N+1}} &= L'\frac{x_N}{1-x_N} + V'\frac{y_1}{1-y_1} \\
300 \cdot (1-0.04) \cdot \frac{0.04}{1-0.04} + 11.42\frac{0}{1-0} &= 300 \cdot (1-0.04) \cdot \frac{0.002}{1-0.002} + 11.42\frac{y_1}{1-y_1} \\
y_1 &= 0.5
\end{aligned}
$$

Finding number of stages

Calculate x_n from y_n starting at y_1

$$
x_n = \frac{y_n}{25}
$$

Then calculate y_{n+1} from

$$
L'\frac{x_{n-1}}{1-x_{n-1}} + V'\frac{y_{n+1}}{1-y_{n+1}} = L'\frac{x_n}{1-x_n} + V'\frac{y_n}{1-y_n}
$$

Repeat the above steps until x_n is less than the x_N specification, $x_N = 0.002$

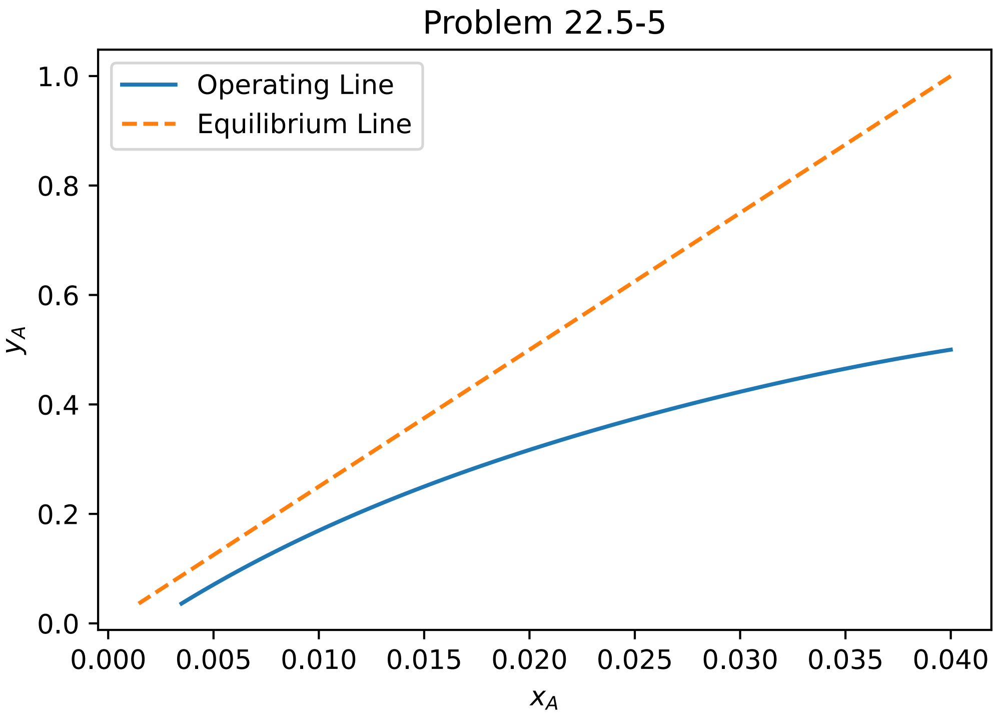
Find intermediate stage

$$
\begin{aligned}
N_i &= \frac{x_N - x_{n-1}}{x_n - x_{n-1}} \\
N_i &= \frac{0.002 - 0.003481}{0.001448 - 0.003481} = 0.728
\end{aligned}
$$

Add N_i to the stage for x_{n-1}

$$
\begin{aligned}
N &= 5 + 0.728 \\
&\boxed{N = 5.728}
\end{aligned}
$$

Plot:



Problem 22.5-5
Operating Line
Equilibrium Line
1.0
0.8
0.6
0.4
0.2
0.0
y_A
0.000
0.005
0.010
0.015
0.020
0.025
0.030
0.035
0.040
x_A