1. Problem 22.1-8

   (a)

   Fith polynomial to data in Exmaple 22.1-5

$$y_A(x_A) = 31.5057x_A^4 - 13.8911x_A^3 + 3.2917x_A^2 + 0.2981x_A$$

Solve the system of equations:

$$\begin{aligned}
N_A &= \frac{k'_y}{(1-y_A)_{iM}}(y_{AG} - y_{Ai}) \\
N_A &= \frac{k'_x}{(1-x_A)_{iM}}(x_{Ai} - x_{AL}) \\
(1-y_A)_{iM} &= \frac{y_{AG} - y_{Ai}}{\ln\left(\frac{1-y_{Ai}}{1-y_{AG}}\right)} \\
(1-x_A)_{iM} &= \frac{x_{Ai} - x_{AL}}{\ln\left(\frac{1-x_{AL}}{1-x_{Ai}}\right)} \\
y_{Ai}(x_{Ai}) &= 31.5057x_{Ai}^4 - 13.8911x_{Ai}^3 + 3.2917x_{Ai}^2 + 0.2981x_{Ai}
\end{aligned}$$

Where:

$$\begin{aligned}
y_{AG} &= 0.25 \\
x_{AL} &= 0.05 \\
k'_y &= 1.465 \cdot 10^{-3} \\
k'_x &= 1.967 \cdot 10^{-3}
\end{aligned}$$

$$\boxed{\begin{aligned}
x_{Ai} &= 0.1687 \\
y_{Ai} &= 0.1028 \\
N_A &= 2.625 \cdot 10^{-4} \text{ kg mol/s}\cdot\text{m}^2
\end{aligned}}$$

(b)

$$y_A^* = 31.5057x_{AL}^4 - 13.8911x_{AL}^3 + 3.2917x_{AL}^2 + 0.2981x_{AL}$$
$$y_A^* = 31.5057 \cdot 0.05^4 - 13.8911 \cdot 0.05^3 + 3.2917 \cdot 0.05^2 + 0.2981 \cdot 0.05 = 0.02159$$
$$m' = \frac{y_{Ai} - y_A^*}{x_{Ai} - x_{AL}}$$
$$m' = \frac{0.1028 - 0.02159}{0.1687 - 0.05} = 0.6841$$
$$(1 - y_A)_{*M} = \frac{y_{AG} - y_A^*}{\ln\left(\frac{1-y_A^*}{1-y_{AG}}\right)}$$
$$(1 - y_A)_{*M} = \frac{0.25 - 0.02159}{\ln\left(\frac{1-0.02159}{1-0.25}\right)} = 0.8591$$
$$(1 - y_A)_{iM} = \frac{y_{AG} - y_{Ai}}{\ln\left(\frac{1-y_{Ai}}{1-y_{AG}}\right)}$$
$$(1 - y_A)_{iM} = \frac{0.25 - 0.1028}{\ln\left(\frac{1-0.1028}{1-0.25}\right)} = 0.8893$$
$$(1 - x_A)_{iM} = \frac{x_{Ai} - x_{AL}}{\ln\left(\frac{1-x_{AL}}{1-x_{Ai}}\right)}$$
$$(1 - x_A)_{iM} = \frac{0.1687 - 0.05}{\ln\left(\frac{1-0.05}{1-0.1687}\right)} = 0.8214$$
$$\frac{(1 - y_A)_{*M}}{K_y'} = \frac{(1 - y_A)_{iM}}{k_y'} + \frac{m'(1 - x_A)_{iM}}{k_x'}$$
$$K_y' = (1 - y_A)_{*M}\left(\frac{(1 - y_A)_{iM}}{k_y'} + \frac{m'(1 - x_A)_{iM}}{k_x'}\right)^{-1}$$
$$K_y' = 0.8591 \cdot \left(\frac{0.8893}{1.465 \cdot 10^{-3}} + \frac{0.6841 \cdot 0.8214}{1.967 \cdot 10^{-3}}\right)^{-1}$$
$$\boxed{K_y' = 9.876 \cdot 10^{-4} \text{ kg mol/s·m}^2}$$
$$K_y = \frac{K_y'}{(1 - y_A)_{*M}}$$
$$K_y = \frac{9.876 \cdot 10^{-4}}{0.8591}$$
$$\boxed{K_y = 1.149 \cdot 10^{-3} \text{ kg mol/s·m}^2}$$
$$N_A = K_y(y_{AG} - y_A^*)$$
$$N_A = 1.149 \cdot 10^{-3} \cdot (0.25 - 0.02159)$$
$$\boxed{N_A = 2.625 \cdot 10^{-4} \text{ kg mol/s·m}^2}$$

(c)

$$0.25 = 31.5057 x_A *^4 - 13.8911 x_A *^3 + 3.2917 x_A *^2 + 0.2981 x_A *$$

$$x_A^* = 0.2915$$

$$m'' = \frac{y_{AG} - y_{Ai}}{x_A^* - x_{AL}}$$

$$m'' = \frac{0.25 - 0.1028}{0.2915 - 0.05} = 1.199$$

$$(1 - x_A)_{*M} = \frac{x_A^* - x_{AL}}{\ln\left(\frac{1 - x_{AL}}{1 - x_A^*}\right)}$$

$$(1 - x_A)_{*M} = \frac{0.2915 - 0.05}{\ln\left(\frac{1 - 0.05}{1 - 0.2915}\right)} = 0.8234$$

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

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

$$K'_x = 0.8234 \cdot \left(\frac{0.8893}{1.199 \cdot 1.465 \cdot 10^{-3}} + \frac{0.8214}{1.967 \cdot 10^{-3}}\right)$$

$$\boxed{K'_x = 8.951 \cdot 10^{-4} \text{ kg mol/s}\cdot\text{m}^2}$$

$$K_x = \frac{K'_x}{(1 - x_A)_{*M}}$$

$$K_x = \frac{8.951 \cdot 10^{-4}}{0.8234}$$

$$\boxed{K_x = 1.087 \cdot 10^{-3} \text{ kg mol/s}\cdot\text{m}^2}$$

$$N_A = K_x (x_A^* - x_{AL})$$

$$N_A = 1.087 \cdot 10^{-3} \cdot (0.2915 - 0.02)$$

$$\boxed{N_A = 2.625 \cdot 10^{-4} \text{ kg mol/s}\cdot\text{m}^2}$$

2. Problem 22.5-6

   (a)

$$
\begin{aligned}
x_0 &= 0 \\
y_{N+1} &= 0.04 \\
y_1 &= 0.005 \\
L = L' &= 68 \\
V &= 57.8 \\
D &= 0.747 \\
V' &= V(1 - y_{N+1}) \\
V' &= 57.8 \cdot (1 - 0.04) \\
V' &= 55.5 \\
L' \frac{x_0}{1 - x_0} + V' \frac{y_{N+1}}{1 - y_{N+1}} &= L' \frac{x_N}{1 - x_N} + V' \frac{y_1}{1 - y_1} \\
68 \cdot \frac{0}{1 - 0} + 55.5 \cdot \frac{0.04}{1 - 0.04} &= 68 \cdot \frac{x_N}{1 - x_N} + 55.5 \cdot \frac{0.005}{1 - 0.005} \\
x_N &= 0.029
\end{aligned}
$$

Fit the data from Appendix A in the table below to find the Henry's Law constant.

x_A	y_A
0.0208	0.0158
0.0258	0.0197
0.0309	0.0239
0.0405	0.0328
0.0503	0.0416

$$
\begin{aligned}
H &= 0.8 \\
k'_x a &= 0.169 \\
k'_y a &= 0.0739
\end{aligned}
$$

At the top of the tower:

$$
\begin{aligned}
-\frac{k'_x a}{k'_y a} &= \frac{y_1 - y_i}{x_0 - x_i} \\
y_i &= H x_i
\end{aligned}
$$

Solve the system for the top of the tower:

$$
\begin{aligned}
-\frac{0.169}{0.0739} &= \frac{0.005 - y_i}{0 - x_i} \\
y_i &= 0.8 x_i
\end{aligned}
$$

At the top of the tower:

$$
\begin{aligned}
x_i &= 0.0016 \\
y_i &= 0.0013
\end{aligned}
$$

At the bottom of the tower:

$$-\frac{k'_x a}{k'_y a} = \frac{y_{N+1} - y_i}{x_N - x_i}$$
$$y_i = Hx_i$$

Solve the system for the bottom of the tower:

$$-\frac{0.169}{0.0739} = \frac{0.04 - y_i}{0.029 - x_i}$$
$$y_i = 0.8x_i$$

At the bottom of the tower:

$$x_i = 0.034$$
$$y_i = 0.028$$

Tower height:

$$z = H_L N_L$$
$$N_L = \frac{x_N - x_0}{(x_{i,N} - x_N) - (x_{i,0} - x_0)} \ln\left(\frac{x_{i,N} - x_N}{x_{i,0} - x_0}\right)$$
$$N_L = \frac{0.029 - 0}{(0.034 - 0.029) - (0.0016 - 0)} \ln\left(\frac{0.034 - 0.029}{0.0016 - 0}\right)$$
$$N_L = 9.25$$

H_L at the bottom of the tower:

$$H_L = \frac{L}{k'_x a S(1 - x_N)} \frac{(1 - x_{i,N}) - (1 - x_N)}{\ln\left(\frac{1 - x_{i,N}}{1 - x_N}\right)}$$
$$H_L = \frac{68/(1 - 0.029)/3600}{0.169 \cdot \pi/4 \cdot 0.747^2 \cdot (1 - 0.029)} \frac{(1 - 0.034) - (1 - 0.029)}{\ln\left(\frac{1 - 0.034}{1 - 0.029}\right)}$$
$$H_L = 0.2548$$

H_L at the bottom of the tower:

$$H_L = \frac{L}{k'_x a S(1 - x_0)} \frac{(1 - x_{i,0}) - (1 - x_0)}{\ln\left(\frac{1 - x_{i,0}}{1 - x_0}\right)}$$
$$H_L = \frac{68/3600}{0.169 \cdot \pi/4 \cdot 0.747^2 \cdot (1 - 0.0016)} \frac{(1 - 0.0016) - (1 - 0)}{\ln\left(\frac{1 - 0.0016}{1 - 0}\right)}$$
$$H_L = 0.2543$$

Average H_L across the tower

$$H_L = 0.2546$$
$$z = 0.2546 \cdot 9.25$$
$$\boxed{z = 2.35 \text{ m}}$$

(b)

Top of the tower calculations:

$$
\begin{aligned}
y^* &= Hx_0 \\
y^* &= 0 \\
m' &= \frac{y_i - y^*}{x_i - x_0} \\
m' &= 0.802 \\
(1-y)_{*M} &= \frac{y_1 - y^*}{\ln\left(\frac{1-y^*}{1-y_1}\right)} \\
(1-y)_{*M} &= 0.997 \\
(1-x)_{iM} &= \frac{x_i - x_0}{\ln\left(\frac{1-x_0}{1-x_i}\right)} \\
(1-x)_{iM} &= 0.999 \\
(1-y)_{iM} &= \frac{y_i - y_1}{\ln\left(\frac{1-y_1}{1-y_i}\right)} \\
(1-y)_{iM} &= 0.997 \\
K'_y a &= \frac{(1-y)_{*M}}{\frac{(1-y)_{iM}}{k'_y a} + \frac{m'(1-x)_{iM}}{k'_x a}} \\
K'_y a &= 0.0547
\end{aligned}
$$

Bottom of the tower calculations:

$$
\begin{aligned}
y^* &= Hx_N \\
y^* &= 0.0233 \\
m' &= \frac{y_i - y^*}{x_i - x_N} \\
m' &= 0.803 \\
(1-y)_{*M} &= \frac{y_{N+1} - y^*}{\ln\left(\frac{1-y^*}{1-y_{N+1}}\right)} \\
(1-y)_{*M} &= 0.968 \\
(1-x)_{iM} &= \frac{x_i - x_N}{\ln\left(\frac{1-x_N}{1-x_i}\right)} \\
(1-x)_{iM} &= 0.968 \\
(1-y)_{iM} &= \frac{y_i - y_{N+1}}{\ln\left(\frac{1-y_{N+1}}{1-y_i}\right)} \\
(1-y)_{iM} &= 0.966 \\
K_y'a &= \frac{(1-y)_{*M}}{\frac{(1-y)_{iM}}{k_y'a} + \frac{m'(1-x)_{iM}}{k_x'a}} \\
K_y'a &= 0.0548 \\
N_{OG} &= \frac{y_N - y_1}{(y_1 - y_1^*) - (y_N - y_N^*)} \ln\left(\frac{y_1 - y_1^*}{y_N - y_N^*}\right) \\
N_{OG} &= 3.61 \\
V_{avg} &= \frac{V'}{2}\left(\frac{1}{1-y_N} + \frac{1}{y_{N+1}}\right) \\
V_{avg} &= 56.8
\end{aligned}
$$

$K_y'a$ average over tower:

$$
\begin{aligned}
K_y'a &= 0.0547 \\
H_{OG} &= \frac{V}{SK_y'a} \\
H_{OG} &= 0.657 \\
z &= H_{OG}N_{OG} \\
&\boxed{z = 2.37 \text{ m}}
\end{aligned}
$$

3. Problem 22.5-12

$$\Delta P_{flood} = 0.115 F_P^{0.7}$$

Intalox Packing:

$$F_P = 41$$
$$\Delta P_{flood} = 0.115 \cdot 41^{0.7} = 1.55 \text{ in. } H_2O\text{/ft packing}$$
$$\text{flow param.} = \frac{G_L}{G_G}\left(\frac{\rho_G}{\rho_L}\right)^{0.5}$$

From Example 22.3-1

$$\rho_G = 0.07309$$
$$\rho_L = 62.25$$
$$\nu = 0.8963$$
$$\frac{G_L}{G_G} = 2.2$$
$$\text{flow param.} = 2.2 \cdot \left(\frac{0.07309}{62.25}\right)^{0.5} = 0.0754$$

From Figure 22.3-1:

$$\text{y-axis} = 1.65$$
$$\text{y-axis} = v_G\left(\frac{\rho_G}{\rho_L - \rho_G}\right)^{0.5} F_P^{0.5}\nu^{0.05}$$
$$v_G = 1.65 \cdot \left[\left(\frac{0.07309}{62.25 - 0.07309}\right)^{0.5} \cdot 41^{0.5} \cdot 0.8963^{0.05}\right]^{-1}$$
$$v_G = 7.56$$
$$G_G = v_G \rho_G$$
$$G_G = 7.56 \cdot 0.07309 = 0.552$$

At 60% flood:

$$G_{G,flood} = 0.552 \cdot 0.6 = 0.331$$
$$A_c = \frac{G_G}{G_{G,flood}}$$
$$A_c = \frac{\pi}{4}D^2$$
$$D = \sqrt{\frac{4}{\pi}\frac{G_G}{G_{G,flood}}}$$
$$D = \sqrt{\frac{4}{\pi} \cdot \frac{2000/3600}{0.331}}$$
$$\boxed{D = 1.46 \text{ ft}}$$

For pressure drop at 60% flood:

$$\text{New capacity param} = 1.65 \cdot 0.6 = 0.99$$

From Figure 22.3-1:

$$\boxed{\Delta P_{flood} = 0.25 \text{ in. } H_2O/\text{ft packing}}$$

4. Problem 22.7-1

Data from Table 22.7-1, and calculated values

x	L	$k'_x a$	x_i	$(1-x_i)_M$	$\frac{L(1-x_i)_M}{k'_x aS(1-x)(x_i-x)}$
0.0	0.042	0.848	0.00046	0.9998	1158.72
0.000332	0.04201	0.849	0.00103	0.9993	762.82
0.000855	0.04203	0.85	0.00185	0.9986	534.67
0.00201	0.04208	0.853	0.00355	0.9972	344.55
0.00355	0.04215	0.857	0.00565	0.9954	251.84

Evaluate the following at different values of x

$$(1-x_i)_M = \frac{(1-x_i)-(1-x)}{\ln\left(\frac{1-x_i}{1-x}\right)}$$

$$z = \int \frac{L(1-x_i)_M}{k'_x aS(1-x)(x_i-x)} dx$$

Evaluate the integrand of the above integral at various values of x

$$S = 0.0929$$

Estimate the integral with trapezoids

$$\boxed{z = 1.62 \text{ m}}$$