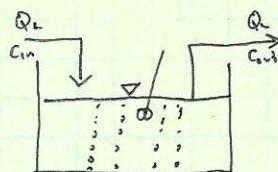


① $C_{w,in} = 2 \text{ mg/L}$
 $C_{w,out} = 7 \text{ mg/L}$
 $V_L = 10000 \text{ L}$
 $Q_g = 15 \text{ L/min}$
 $K_L a_L = 1.2 \text{ min}^{-1}$
 $H_{cc} = 32.3 \frac{\text{L}}{\text{Lg}}$
 $P_{O_2} = 0.21 \text{ atm}$
 $T = 25^\circ\text{C} = 298 \text{ K}$
 $R = 0.08206 \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}}$
 $MW = 32 \frac{\text{g}}{\text{mol}}$

a) CFSTR

Assume:
steady state for CFSTR

$$C_{w,in} = \left(2 \frac{\text{mg}}{\text{L}}\right) \left(\frac{1 \text{ g}}{1000 \text{ mg}}\right) \left(\frac{1 \text{ mol}}{32 \text{ g}}\right) = 6.25 \times 10^{-5} \frac{\text{mol}}{\text{L}}$$

$$C_{w,out} = 2.188 \times 10^{-4} \frac{\text{mol}}{\text{L}}$$

$$V_L \frac{dC_L}{dt} = Q_L C_{L,in} - Q_L C_{L,out} + V_L r_{gt}$$

$$= Q_L (C_{L,in} - C_{L,out}) + V_L K_L (C_L^* - C_{L,out})$$

$$C_L^* = \frac{p_{O_2}}{R T} = \frac{0.21 \text{ atm}}{(0.08206 \frac{\text{L}\cdot\text{atm}}{\text{K}\cdot\text{mol}})(298 \text{ K})} = 0.00859 \frac{\text{mol}}{\text{L}}$$

$$K_L = \frac{Q_g H}{V_L} \left[1 - \exp\left(-\frac{K_L a_L}{Q_g H / V_L}\right)\right]$$

$$0 = Q_L (C_{L,in} - C_{L,out}) + Q_g H \left[1 - \exp\left(-\frac{K_L a_L}{Q_g H / V_L}\right)\right] (C_L^* - C_{L,in})$$

$$\frac{(C_{L,in} - C_{L,out})}{(C_{L,out} - C_L^*)} = \frac{Q_g H}{Q_L} \left[1 - \exp\left(-\frac{K_L a_L}{Q_g H / V_L}\right)\right]$$

$$= \frac{\tau Q_g H}{V_L} \left[1 - \exp\left(-\frac{K_L a_L}{Q_g H / V_L}\right)\right]$$

$$Q_L = \frac{V_L}{\tau}$$

$$\tau = \frac{V_L (C_{L,in} - C_{L,out})}{Q_g H \left[1 - \exp\left(-\frac{K_L a_L}{Q_g H / V_L}\right)\right] (C_{L,out} - C_L^*)}$$

$$= \frac{(10000 \text{ L}) (6.25 \times 10^{-5} \frac{\text{mol}}{\text{L}} - 2.188 \times 10^{-4} \frac{\text{mol}}{\text{L}})}{(15 \frac{\text{L}}{\text{min}}) (32.3) \left[1 - \exp\left(-\frac{1.2 \text{ min}^{-1}}{(15 \frac{\text{L}}{\text{min}}) (32.3) / 10000 \text{ L}}\right)\right] (2.188 \times 10^{-4} \frac{\text{mol}}{\text{L}} - 0.00859 \frac{\text{mol}}{\text{L}})}$$

$$\tau = 0.385 \text{ min}$$

b) batch reactor

$$V_L \frac{dC_L}{dt} = V_L r_{gt}$$

$$\frac{dC_L}{dt} = K_L (C_L^* - C_{L,out})$$

$$\int \frac{dC_L}{(C_L^* - C_{L,out})} = \int K_L dt$$

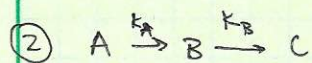
$$-\ln \left[\frac{C_L^* - C_{L,out}(t)}{C_L^* - C_L(0)} \right] = K_L t$$

$$t = - \frac{\ln \left[\frac{C_L^* - C_L(t)}{C_L^* - C_L(0)} \right]}{\frac{Q_g H}{V_L} \left[1 - \exp\left(-\frac{K_L a_L}{Q_g H / V_L}\right)\right]} = - \frac{\ln \left[\frac{0.00859 \frac{\text{mol}}{\text{L}} - 2.188 \times 10^{-4} \frac{\text{mol}}{\text{L}}}{0.00859 \frac{\text{mol}}{\text{L}} - 6.25 \times 10^{-5} \frac{\text{mol}}{\text{L}}} \right]}{\frac{(15 \frac{\text{L}}{\text{min}}) (32.3)}{10000 \text{ L}} \left[1 - \exp\left(-\frac{1.2 \text{ min}^{-1}}{(15 \frac{\text{L}}{\text{min}}) (32.3) / 10000 \text{ L}}\right)\right]}$$

$$t = 0.382 \text{ min}$$

→ since a sequential batch reactor is ~~basically~~ a plug flow reactor and a PFR can be treated as a batch reactor w/ a moving window, t represents τ
 $C_L(t) = C_{L,out}$
 $C_L(0) = C_{L,in}$

→ the batch reactor is slightly more efficient than the CFSTR



$$r_A = -k_A C_A$$

$$r_B = k_A C_A - k_B C_B$$

$$r_C = +k_B C_B$$

a)

$$\begin{aligned} V \frac{dC_A}{dt} &= Q C_{A,0} - Q C_A + V r_A \\ &= Q C_{A,0} - Q C_A - V k_A C_A \\ &= Q C_{A,0} - C_A (Q + V k_A) \end{aligned}$$

Assume
steady-state

$$C_A = \frac{Q C_{A,0}}{(Q + V k_A)}$$

b)

$$V \frac{dC_B}{dt} = Q C_{B,0} - Q C_B + V r_B$$

$$0 = -Q C_B + V k_A C_A - V k_B C_B$$

$$= V k_A C_A - C_B (Q + V k_B)$$

$$C_B = \frac{V k_A C_A}{(Q + V k_B)}$$

c)

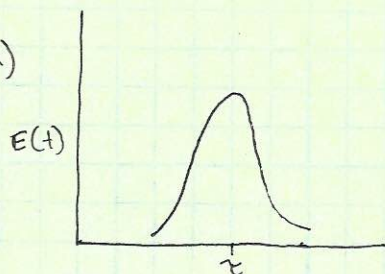
$$V \frac{dC_C}{dt} = Q C_{C,0} - Q C_C + V r_C$$

$$0 = -Q C_C + V k_B C_B$$

$$C_C = \frac{V k_B C_B}{Q}$$

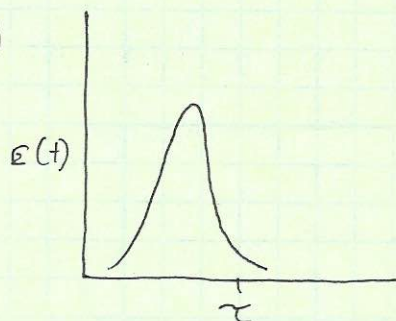
③

a)



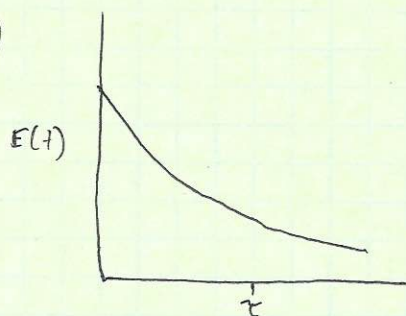
→ this $E(t)$ represents a single plug flow reactor with a dispersion coefficient $\frac{D}{VL} = 0.01$ for a reactor w/ closed boundaries

b)



→ this $E(t)$ represents a reactor very similar to part (a), w/ a dispersion coefficient, $\frac{D}{VL} = 0.01$ w/ closed boundaries. However, the $E(t)$ distribution indicates that there is dead space in the reactor as $t_{eff} < \tau$ for the majority of the distribution, the effective volume of the tank has likely been reduced. The ~~more~~ similarity to the previous dist., (a), leads me to believe it is dead space rather than short-circuiting as short circuiting would be represented by a more erratic dist.

c)



→ this $E(t)$ represents a single ideal CSTR

- ④ a) design an adsorption system to remove compound A w/ GAC
 ↳ two batch reactors in series

a) adsorption isotherm can be given by Freundlich Isotherm $\rightarrow q = k c^n$
 find k and n

linear form: $\log(q) = \log(k) + n \log(c)$

from model generated in R (code generated)

$$\boxed{\begin{matrix} k = 4.385 \\ n = 0.538 \end{matrix}}$$

b) Tank 1

$$C_{in} = 50 \frac{\text{mol}}{\text{L}}$$

$$C_{out} = 20 \frac{\text{mol}}{\text{L}}$$

$$q_{in} = 0$$

MB:

change in total
adsorbable mass
in system due to
adsorption

= change in dissolved
adsorbate mass + change in adsorbed
adsorbate mass

$$0 = V_L (C_{in} - C_{out}) + W (q_{in} - q_{out})$$

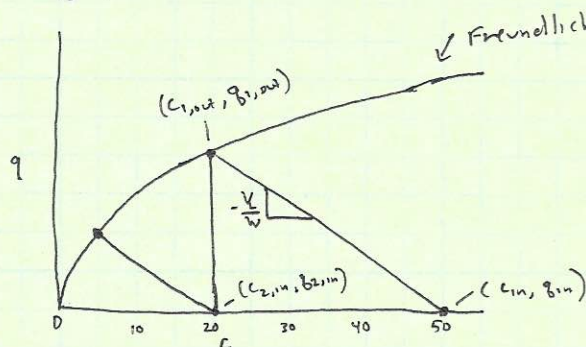
$$\frac{W}{V_L} = ?$$

$$\frac{W_a}{V_L} = \frac{C_{in} - C_{out}}{q_{out}} = \frac{C_{in} - C_{out}}{k C_{out}^n}$$

$$\frac{W}{V_L} = \frac{50 \frac{\text{mol}}{\text{L}} - 20 \frac{\text{mol}}{\text{L}}}{\left(4.385 \frac{\text{mol/gAC}}{(\text{mol/L})^{0.538}}\right) \left(20 \frac{\text{mol}}{\text{L}}\right)^{0.538}}$$

$$\boxed{\frac{W}{V_L} = 1.37 \frac{\text{g AC}}{\text{L}}}$$

c) use graphical representation to determine the final conc. of A



$$-\frac{V_L}{W} \approx -0.73 \approx \frac{4 \text{ block lengths over}}{6 \text{ block lengths up}}$$

↳ from graph $C_{2, out} \approx 5 \frac{\text{mol}}{\text{L}}$

- ⑤ stripping column designed to remove chloroform from drinking water
 ↳ goal: $120 \mu\text{g/L} \rightarrow 30 \mu\text{g/L}$

a) calculate $c_{g,\text{out}}$

$$c_{g,\text{in}} = 0$$

$$Q_L = 0.1 \text{ m}^3/\text{s}$$

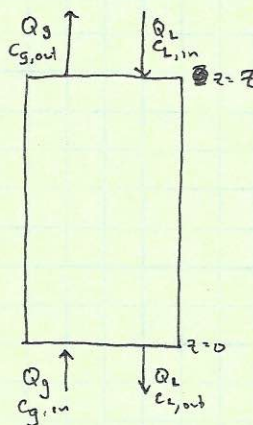
$$Q_g = 0.9 \text{ m}^3/\text{s}$$

$$H = 0.16 \text{ L/L}_g$$

$$K_L a_L = 0.08 \text{ s}^{-1}$$

$$C_{L,\text{in}} = 120 \mu\text{g/L}$$

$$C_{L,\text{out}} = 30 \mu\text{g/L}$$



MB)

$$\text{rate of change of chloroform stored in column} = \text{net (in-out) liquid phase advection} + \text{net (in-out) gas phase advection}$$

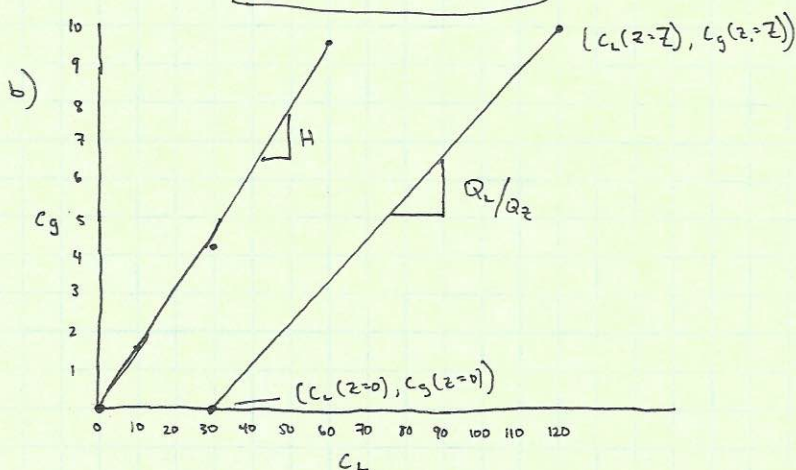
Assume
 steady-state
 no reaction, diffusion, or dispersion

$$0 = Q_L (C_{L,\text{in}} - C_{L,\text{out}}) + Q_g (C_{g,\text{in}} - C_{g,\text{out}})$$

$$C_{g,\text{out}} = \frac{Q_L}{Q_g} (C_{L,\text{in}} - C_{L,\text{out}}) + C_{g,\text{in}}$$

$$C_{g,\text{out}} = \frac{0.1 \frac{\text{m}^3}{\text{s}}}{0.9 \frac{\text{m}^3}{\text{s}}} (120 \frac{\mu\text{g}}{\text{L}} - 30 \frac{\mu\text{g}}{\text{L}}) + 0$$

$$C_{g,\text{out}} = 10 \frac{\mu\text{g}}{\text{L}}$$



Eg line eg:
 $c_g = H c_L$

c) $r_L(z=Z) = ?$

$$r_L = K_L a_L (C_L^*(z=Z) - C_L(z=Z))$$

$$r_L = (0.08 \text{ s}^{-1}) (62.5 \mu\text{g/L} - 120 \mu\text{g/L})$$

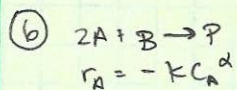
$$r_{L,\text{top}} = -4.6 \frac{\mu\text{g}}{\text{L} \cdot \text{s}}$$

↳ transfer from liquid phase to gas phase

$$C_L^* = \frac{c_g}{H} = \frac{C_{g,\text{out}}}{H} = \frac{10 \frac{\mu\text{g}}{\text{L}}}{0.16}$$

$$C_L^* = 62.5 \mu\text{g/L}$$

$$C_{L,\text{top}}(z=Z) = C_{L,\text{in}} = 120 \mu\text{g/L}$$



time (min)	C_A (mol/L)
0	10
1	4.0
2	1.65

- a) \rightarrow data was plotted as ~~0.2~~ C_A vs t (zero-order), $\ln(C_A)$ vs t (first order), and $\frac{1}{C_A}$ vs t (second order) in R, code attached. The first order reaction was the closest to linearity w/ $R^2 = 0.999$ and is given by the following equation:

$$\ln[C_A(t)] = \ln[C_A(0)] - kt$$

getting the slope of the line gives k as:

$$k = 0.90 \frac{1}{\text{min}}$$

b) $C_A(0) = 75 \frac{\text{mol}}{\text{L}}$
 $C_B(0) = 60 \frac{\text{mol}}{\text{L}}$
 $C_B(t=305) = ?$

$$\begin{aligned} C_A(t=0.5 \text{ min}) &= C_A(0)e^{-kt} \\ &= \left(75 \frac{\text{mol}}{\text{L}}\right) e^{-(0.9 \frac{1}{\text{min}})(0.5 \text{ min})} \\ &= 47.82 \frac{\text{mol}}{\text{L}} \\ C_A(t=0.5 \text{ min}) &= 47.82 \frac{\text{mol}}{\text{L}} \end{aligned}$$

for every 2 moles of C_A consumed, 1 mol of C_B is consumed

$$2\Delta C_A = \Delta C_B$$

$$\left(75 \frac{\text{mol}}{\text{L}} - 47.82 \frac{\text{mol}}{\text{L}}\right) = 2 \left(60 \frac{\text{mol}}{\text{L}} - C_B(t=0.5 \text{ min})\right)$$

$$C_B(t=0.5 \text{ min}) = 60 \frac{\text{mol}}{\text{L}} - \frac{27.18 \frac{\text{mol}}{\text{L}}}{2}$$

$$C_B(t=0.5 \text{ min}) = 46.41 \text{ mol/L}$$

	Hexane (H)	Nonane (N)
(7) X_L	0.5	0.5
MW (g/mol)	86	128
P° (kPa)	20.2	0.57
$C_{w, sol}$ (g/m ³)	9.5	0.02 0.12
K_{ow}	1.3×10^4	6×10^6

* non aqueous phase liquid composed of hexane and nonane ($\Sigma X_L = 0.5$ each) is spilled into the subsurface.

a) what is initial contaminant concentration if groundwater is used to recover contaminants?

Assume: rapid attainment of equilibrium

$\rightarrow C_{Aw} = C_{Aw, sol} X_{AL}$ \rightarrow where A represents any given contaminant

Hexane: $C_{Hw} = C_{Hw, sol} X_{HL} = (9.5 \text{ g/m}^3)(0.5) \left(\frac{1 \text{ mol}}{86 \text{ g}} \right)$

$$C_{Hw} = 0.552 \frac{\text{mol}}{\text{m}^3}$$

Nonane: $C_{Nw} = C_{Nw, sol} X_{NL} = (0.12 \text{ g/m}^3)(0.5) \left(\frac{1 \text{ mol}}{128 \text{ g}} \right)$

$$C_{Nw} = 4.688 \times 10^{-4} \frac{\text{mol}}{\text{m}^3}$$

b) what is initial contaminant concentration in gas if air is used to volatilize the contaminants?

\rightarrow ideal gas

Assume: rapid attainment of equilibrium; STP $\rightarrow T = 273 \text{ K}$

$$C_{Ag} = \frac{n_A}{V} = \frac{P_A}{RT}$$

$$R = 0.08206 \frac{\text{L} \cdot \text{atm}}{\text{K} \cdot \text{mol}} \left(\frac{1 \text{ m}^3}{1000 \text{ L}} \right) \left(\frac{1 \text{ kPa}}{0.00987 \text{ atm}} \right)$$

$$R = 0.008314 \frac{\text{m}^3 \cdot \text{kPa}}{\text{K} \cdot \text{mol}}$$

$$P_A = P_A^\circ X_L$$

$$C_{Ag} = \frac{P_A^\circ X_L}{RT}$$

Hexane: $C_{Hg} = \frac{P_H^\circ X_{HL}}{RT} = \frac{(20.2 \text{ kPa})(0.5)}{(0.008314 \frac{\text{m}^3 \cdot \text{kPa}}{\text{K} \cdot \text{mol}})(273 \text{ K})}$

$$C_{Hg} = 4.45 \frac{\text{mol}}{\text{m}^3}$$

Nonane: $C_{Ng} = \frac{P_N^\circ X_{NL}}{RT} = \frac{(0.57 \text{ kPa})(0.5)}{(0.008314 \frac{\text{m}^3 \cdot \text{kPa}}{\text{K} \cdot \text{mol}})(273 \text{ K})}$

$$C_{Ng} = 0.126 \frac{\text{mol}}{\text{m}^3}$$

⑧ 1 g of compound ^A to reactor

$$V_g = 1 \text{ m}^3$$

$$V_w = 10^{-3} \text{ m}^3$$

$$M_s = 100 \text{ g}$$

$$P = 1 \text{ atm}$$

$$T = 293 \text{ K}$$

$$MW_A = 110 \frac{\text{g}}{\text{mol}}$$

$$C_{A,g} = 0.40 \text{ g/m}^3 \text{ @ eq.}$$

$$C_{A,w} = 250 \text{ g/m}^3 \text{ @ eq.}$$

a) what is H_{CA}

Assume ideal gas

$$P_A = H_{CA} C_{A,w}$$

$$C_{A,g} = \frac{P_A}{RT}$$

$$P_A = C_{A,g} RT = (0.40 \text{ g/m}^3) \left(\frac{1 \text{ mol}}{110 \text{ g}} \right) (293 \text{ K}) \left(0.08206 \frac{\text{L} \cdot \text{atm}}{\text{K} \cdot \text{mol}} \right) \left(\frac{1 \text{ m}^3}{1000 \text{ L}} \right)$$

$$P_A = 8.743 \times 10^{-5} \text{ atm}$$

$$H_{CA} = \frac{P_A}{C_{A,w}} = \frac{8.743 \times 10^{-5} \text{ atm}}{(250 \frac{\text{g}}{\text{m}^3}) \left(\frac{1 \text{ mol}}{110 \text{ g}} \right)}$$

$$H_{CA} = 3.847 \times 10^{-5} \frac{\text{atm}}{\text{mol/m}^3}$$

b) adsorption b/t water and solid phase is linear:

$$g = kC$$

$$g = \frac{\text{mass adsorbate}}{\text{mass adsorbent}} = \frac{M_{Ad}}{M_s} [=] \frac{\text{mg}}{\text{g}}$$

$$M_t = M_g + M_w + M_{Ad}$$

$$M_{Ad} = M_t - M_g - M_w$$

$$= 1 \text{ g} - (0.4 \frac{\text{g}}{\text{m}^3})(1 \text{ m}^3) - (250 \frac{\text{g}}{\text{m}^3})(10^{-3} \text{ m}^3)$$

$$M_{Ad} = 0.35 \text{ g} = 350 \text{ mg}$$

$$g = \frac{350 \text{ mg}}{100 \text{ g}} = 3.5 \frac{\text{mg adsorbate}}{\text{mg adsorbent}}$$

$$3.5 \frac{\text{mg}}{\text{g}} = k C_{A,w} = k (250 \times 10^3 \frac{\text{mg}}{\text{m}^3})$$

$$k = 1.4 \times 10^{-5} \frac{\text{m}^3}{\text{g}}$$

c) solid is removed and put into $V_w = 10^{-3} \text{ m}^3$ clean water, what is C_{fin}

$$C_{init} = 0$$

$$g_{init} = 3.5 \frac{\text{mg}}{\text{g}}$$

$$g_{fin} = k C_{fin}$$

$$W = 100 \text{ g}$$

$$k = 1.4 \times 10^{-5} \frac{\text{m}^3}{\text{g}}$$

$$0 = V_L (C_{init} - C_{fin}) + W (g_{init} - g_{fin})$$

$$V_L C_{fin} = W (g_{init} - W (k C_{fin}))$$

$$C_{fin} (V_L + W k) = W g_{init}$$

$$C_{fin} = \frac{W g_{init}}{V_L + W k} = \frac{(100 \text{ g}) (3.5 \frac{\text{mg}}{\text{g}})}{(10^{-3} \text{ m}^3) + (100 \text{ g}) (1.4 \times 10^{-5} \frac{\text{m}^3}{\text{g}})}$$

$$C_{fin} = 145833 \frac{\text{mg}}{\text{m}^3}$$

$$C_{fin} = 145.8 \frac{\text{g}}{\text{m}^3}$$