

35/35 Really nice job here

$$q = K_F (C_I)^{1/n}$$

+8 1. a) Carbon A:

$$q_A = 101 (C_I)^{.894} = 101 (900 \text{ mg/L})^{.894} = 44,200 \text{ mg/g}$$

$$\text{UR} = C_I / q_{eq} = 900 \text{ mg/L} / 44,200 \text{ mg/g} = 0.02 \text{ g/L}$$
$$= 20.3 \text{ g C/m}^3 \text{ water}$$

Carbon B:

$$q_B = 235 (C_I)^{.702} = 235 (900)^{.702} = 27,860 \text{ mg/g}$$

$$\text{UR} = 900 \text{ mg/L} / 27,860 \text{ mg/g} = 0.032 \text{ g/L}$$

$$\text{UR} = 32.3 \text{ g C/m}^3 \text{ water}$$

Carbon C:

$$q_C = 419 (C_I)^{.513} = 419 (900 \text{ mg/L})^{.513} = 13,730 \text{ mg/g}$$

$$\text{UR} = 900 \text{ mg/L} / 13,730 \text{ mg/g} = 0.066 \text{ g/L}$$

$$= 65.6 \text{ g C/m}^3 \text{ water}$$

Based on the usage rates of the carbon and the amount of contaminant that sorbs onto the carbon, I would put Carbon A in the GAC contactors. (lowest UR, highest q). Although the cost is higher, the reduced UR makes it more economical. ✓

+8 b) Carbon A

$$q_A = 101 (100 \text{ mg/L})^{.894} = 6,200 \text{ mg/g}$$

$$UR = 100 \text{ mg/L} / 6,200 \text{ mg/g} = 0.0162 \text{ g/L} = 16.2 \text{ gC/m}^3$$

Carbon B

$$q_B = 235 (100 \text{ mg/L})^{.702} = 5960 \text{ mg/g}$$

$$UR = 100 \text{ mg/L} / 5960 \text{ mg/g} = 0.0168 \text{ g/L} = 16.8 \text{ gC/m}^3 \text{ Hz}$$

Carbon C

$$q_C = 419 (100 \text{ mg/L})^{.513} = 4450 \text{ mg/g}$$

$$UR = 100 \text{ mg/L} / 4450 \text{ mg/g} = 0.0225 \text{ g/L} = 22.5 \text{ gC/m}^3 \text{ Hz}$$

Cost A:

$$\frac{16.2 \text{ g C}}{\text{m}^3} \times \frac{\text{kg}}{1000 \text{ g}} \times \frac{\$3.49}{\text{kg}} = \$5.7 \times 10^{-2} / \text{m}^3$$

Cost B:

$$\frac{16.8 \text{ g}}{\text{m}^3} \times \frac{\text{kg}}{1000 \text{ g}} \times \frac{\$2.99}{\text{kg}} = \$5.0 \times 10^{-2} / \text{m}^3$$

Cost C:

$$\frac{22.5 \text{ g}}{\text{m}^3} \times \frac{\text{kg}}{1000 \text{ g}} \times \frac{\$3.24}{\text{kg}} = \$7.3 \times 10^{-2} / \text{m}^3$$

b) continued: Yes, there is now reason to switch to carbon B. At the lower influent concentration, q for A and B are pretty close. When the cost is compared per m^3 of water, carbon B is now the more economical choice. ✓

$$+8 \text{ c) } DPAC = \frac{C_I - C_E}{q_E}, \quad q_E = K_F (C_E)^{1/n}$$

$$\text{Carbon A: } q_A = 101 (5 \text{ mg/L})^{0.894} = 426 \text{ mg/g}$$

$$DPAC = \frac{(900 \text{ mg/L} - 5 \text{ mg/L})}{426 \text{ mg/g}} = 2.1 \text{ g/L} = 2100 \text{ g/m}^3$$

$$\text{Cost} = \frac{2100 \text{ g}}{\text{m}^3} \times \frac{\text{kg}}{1000 \text{ g}} \times \frac{\$3.49}{\text{kg}} = \$7.3 / \text{m}^3 \text{ water}$$

$$\text{Carbon B: } q_B = 235 (5 \text{ mg/L})^{0.702} = 727 \text{ mg/g}$$

$$DPAC = \frac{(900 \text{ mg/L} - 5 \text{ mg/L})}{727 \text{ mg/g}} = 1.23 \text{ g/L} = 1230 \text{ g/m}^3 \text{ H}_2\text{O}$$

$$\text{Cost} = \frac{1230 \text{ g}}{\text{m}^3} \times \frac{\text{kg}}{1000 \text{ g}} \times \frac{\$2.99}{\text{kg}} = \$3.68 / \text{m}^3 \text{ water}$$

$$\text{Carbon C: } q_C = 419 (5 \text{ mg/L})^{0.513} = 957 \text{ mg/g}$$

$$DPAC = \frac{(900 \text{ mg/L} - 5 \text{ mg/L})}{957 \text{ mg/g}} = 0.935 \text{ g/L} = 935 \text{ g/m}^3 \text{ H}_2\text{O}$$

$$\text{Cost} = \frac{935 \text{ g}}{\text{m}^3} \times \frac{\text{kg}}{1000 \text{ g}} \times \frac{\$3.24}{\text{kg}} = \$3.03 / \text{m}^3 \text{ water}$$

✓ I would select Carbon C as it has the highest q (mg contaminant/g PAC), the lowest dose of PAC (so least amount of carbon) and lowest cost.

46 d) There is no reason to switch carbons because in a CMFR the carbon equilibrates with the effluent concentration ($q = K_F (C_E)^{1/n}$). Therefore, the calculations in part (c) will not change. ✓

45 e) The choices made for GAC and PAC were different because with GAC, the carbon equilibrates with C_I , so when C_I changes, the choice of carbon may change. In a CMFR, (the PAC) the carbon equilibrates with the C_E , so changing the influent had no effect on the choice of carbon.

$$\text{GAC: } q = K_F (C_I)^{1/n} \quad \text{PAC: } q = K_F (C_E)^{1/n}$$

Choices were made based on which carbon is most economical in terms of the LR and cost.

35/35 very nice job here

2. a. $C_{i0} = 200 \frac{mg}{L}$ $T_{water} = 298K$

+5 $Q = \frac{LmA}{\rho_L} = \frac{(10.0 \frac{kg}{m^2 \cdot s})(\frac{\pi}{4})(1.0m)^2}{997 \frac{kg}{m^3}} = 0.0079 \frac{m^3}{s} = Q$

$\frac{Q_a}{Q} = 42$

$Q_a = \frac{G_m A}{\rho_g} = \frac{(0.50 \frac{kg}{m^2 \cdot s})(\frac{\pi}{4})(1.0m)^2}{1.18 \frac{kg}{m^3}} = 0.33 \frac{m^3}{s} = Q_a$

b. Henry's Const. @ 25°C by using $H = \frac{p_{sat}}{RTc^{SL}}$

+5

$H = \frac{(1620 Pa)}{(8.314 \frac{Pa \cdot m^3}{mol \cdot K})(298K)(0.0234 \frac{mol}{L})(\frac{1000L}{1m^3})}$

$H = 0.028$ ✓

c. Stripping Factor = $S \equiv \frac{H}{Q/Q_a} = \frac{0.028}{(0.0079 \frac{m^3}{s}) / (0.33 \frac{m^3}{s})}$

+4

$S = 1.2$ ✓

d. $HTU = \frac{Q}{A K_L a}$ where estimate $K_L a = \frac{1}{k_{L,w}} + \frac{1}{H k_{L,g}}$ ✓

+5

$= \frac{(0.0079 \frac{m^3}{s})}{(\frac{\pi}{4})(1.0m)^2 (.0071/s)}$

$HTU = 1.4m$ ✓

$= \frac{1}{(2.2 \times 10^{-4} \frac{1}{s})(58/m) + \frac{1}{(1.0 \times 10^{-2} \frac{1}{s})(58/m)(0.028)}}$

$K_L a = 0.0071/s$ ✓

e. Estimate c_e given $L=8.0\text{m}$ We know $L=(HTU)(NTU)$ ✓

So $NTU = \frac{L}{HTU}$ but $NTU = \frac{S}{S-1} \ln \left[1 + \frac{(C_0/c_e)(S-1)}{S} \right]$

+8

try to solve for c_e ? ✓

$$\frac{L}{HTU} = \frac{S}{S-1} \ln \left[1 + \frac{(C_0/c_e)(S-1)}{S} \right]$$

$$\frac{(S-1)L}{S(HTU)} = \ln \left[\quad \right]$$

$$\exp \left[\quad \right] = 1 + \frac{(C_0/c_e)(S-1)}{S}$$

$$1 + \frac{C_0}{c_e}(S-1) = S \exp \left[\frac{(S-1)L}{S(HTU)} \right]$$

$$\frac{C_0}{c_e}(S-1) = S \exp \left[\quad \right] - 1$$

$$c_e = \frac{C_0(S-1)}{S \exp \left[\frac{(S-1)L}{S(HTU)} \right] - 1}$$

$$c_e = \frac{(200 \frac{\mu\text{g}}{\text{L}})(1.2 - 1)}{(1.2) \exp \left[\frac{(1.2-1)(8.0\text{m})}{(1.2)(1.4\text{m})} \right] - 1}$$

$$c_e = 19 \frac{\mu\text{g}}{\text{L}} \quad \checkmark$$

The fractional removal of EDB is $1 - \frac{c_e}{C_0} = 1 - \frac{19 \frac{\mu\text{g}}{\text{L}}}{200 \frac{\mu\text{g}}{\text{L}}}$

$$\text{fractional removal} = 90\% \quad \checkmark$$

F. These conditions do not meet treatment objective of $5 \frac{\mu\text{g}}{\text{L}}$ EDB. ✓

+8

The main impediment to using air stripping is that this compound isn't especially amenable to leaving the water phase and entering the gas phase (low $H = 0.028$). ✓

... or you could say low $S = 1.2$

If we needed to use air stripping anyway, we wouldn't be too keen on making the tower higher, since it is already 8 m high (of the working space, packing height). ✓

We could increase Q_a , say to establish $S = 4$. ✓

This makes $Q_a = \frac{SQ}{H} = \frac{4(1.0079 \text{ m}^3/\text{s})}{0.028} = 1.1 \frac{\text{m}^3}{\text{s}}$

which gives $C_e = \frac{(200 \frac{\mu\text{g}}{\text{L}})(4-1)}{(4) \exp\left[\frac{(4-1)(8.0 \text{ m})}{H(1.4 \text{ m})}\right] - 1}$

$$C_e = 2.1 \frac{\mu\text{g}}{\text{L}}$$

This calculation indicates that we could use the same tower specs, but increase Q_a . ✓

turns out
 $S=2$ will
work but
this is
fine

PROBLEM: Removal of EDB by O_3/H_2O_2 AOP

(a) Estimate k , the apparent first-order rate constant

$$CMFR = C_E / C_I = 1 / (1 + k\tau)$$

$$C_E = 50 \text{ mg/L} \quad C_I = 200 \text{ mg/L} \quad \tau = 5 \text{ min}$$

$$\frac{50 \text{ mg/L}}{200 \text{ mg/L}} = \frac{1}{1 + k(5 \text{ min})} \Rightarrow \underline{k = 0.6/\text{min}}$$

(b) What will be C_E if $K_L a$ doubles?

$$[\cdot OH] = \frac{K_L a (P_{O_3}/H_{PC} - [O_3])}{\text{denominator}}$$

So if $K_L a$ doubles, then the numerator about doubles

Perhaps not exactly because $[O_3]$ may increase some

But as an estimate, the numerator doubles

Thus $[\cdot OH]$ doubles

$$\text{And } k = k_R [\cdot OH] \Rightarrow k \text{ doubles} \Rightarrow k = 1.2/\text{min}$$

$$C_E = C_I \frac{1}{1 + k\tau} = (200 \text{ mg/L}) \frac{1}{1 + (1.2/\text{min})(5 \text{ min})}$$

$$C_E \approx \underline{29 \text{ mg/L}}, \text{ down from } 50 \text{ mg/L}$$

(c) What will be C_E if $[HCO_3^-]$ is reduced to 12.2 mg/L ?

$$[\cdot OH] = \frac{K_L a (P_{O_3}/H_{PC} - [O_3])}{\text{denominator}}$$

$$\text{denominator} = k_{\text{Nom}} [\text{Nom}] + k_{H_2O_2} [H_2O_2] + k_{HCO_3^-} [HCO_3^-] + k_{EDB} [EDB] + k_{HO_2^-} [HO_2^-]$$

ignore $k_{EDB} [EDB]$ and $k_{HO_2^-} [HO_2^-]$... these should be small

$$\text{denominator} \approx k_{\text{Nom}} [\text{Nom}] + k_{H_2O_2} [H_2O_2] + k_{HCO_3^-} [HCO_3^-]$$

Continued \rightarrow

© continued

So before we put the softening process in,

$$\text{denominator} \approx (3.9 \times 10^8 \frac{\text{L}}{\text{mol}\cdot\text{s}})(2.0 \times 10^5 \frac{\text{mol}}{\text{L}}) + (2.7 \times 10^7 \frac{\text{L}}{\text{mol}\cdot\text{s}})(1.0 \times 10^5 \frac{\text{mol}}{\text{L}}) \\ + (8.5 \times 10^6 \frac{\text{L}}{\text{mol}\cdot\text{s}})(3.0 \times 10^3 \frac{\text{mol}}{\text{L}})$$

$$\text{denominator} \approx 7800 \text{ s}^{-1} + 270 \text{ s}^{-1} + 25,500 \text{ s}^{-1}$$

$$\text{denominator} \approx 33,570$$

Then after the softening,

$$\text{denominator} \approx 7800 \text{ s}^{-1} + 270 \text{ s}^{-1} + (8.5 \times 10^6 \frac{\text{L}}{\text{mol}\cdot\text{s}})(2.0 \times 10^4 \frac{\text{mol}}{\text{L}}) \\ \approx 7800 \text{ s}^{-1} + 270 \text{ s}^{-1} + 1700 \text{ s}^{-1} \\ \approx 9,770 \text{ s}^{-1}$$

So the denominator decreases by a factor 3.44

Thus $[\text{OH}^-]$ should increase by approximately that factor

Thus k should increase by about that factor

$$k \approx (0.6 \text{ min}^{-1})(3.44) = 2.0 \text{ min}^{-1}$$

$$C_E = (200 \frac{\text{mg}}{\text{L}}) \frac{1}{1 + (2.0 \text{ min}^{-1})(5 \text{ min})} = \underline{\underline{18 \text{ mg/L}}}, \quad \text{improved from } 50 \text{ mg/L}$$

④ What will be C_E if P_{O_2} doubles?

If P_{O_2} doubles then the numerator of $[\text{OH}^-]$ should roughly double -- just like in part (b)

So I expect this one to have about the same effect as part (b)

$$\therefore C_E \approx 29 \text{ mg/L}, \quad \text{improved from } 50 \text{ mg/L}$$

e) Which option is best? Explain why.

Doubling K_{La} or doubling P_{O_3} both help to get more ozone in the water, and thereby double (approximately) $[^{\cdot}OH]$. However, softening is the best choice. By removing HCO_3^- , we remove the ions that scavenge the $^{\cdot}OH$ radicals. Thus $[^{\cdot}OH]$ does better than doubling -- it more than triples! Hence softening offers the best improvement over the original design.

NOTE: To check if I was right, I actually built the spreadsheet for the original scenario and for each of the modified scenarios. I did this after I wrote my answers (above). Here is what I found out:

b) Improve $K_{La} \Rightarrow [^{\cdot}OH]$ increases from 2.2×10^{-12} to 3.0×10^{-12} $\frac{mol}{L}$
 $[O_3]$ increases from 0.75×10^{-4} to 1.6×10^{-4} $\frac{mol}{L}$
[EDB] decreases from 50 mg/L to 39 mg/L ✓
(predicted 29 mg/L ok)

c) softer water $\Rightarrow [^{\cdot}OH]$ increases from 2.2×10^{-12} to 1.2×10^{-11} $\frac{mol}{L}$!
Why so much? Because $[NO_3^-]$ also decreases when there is less $[HCO_3^-]$ scavenging the $^{\cdot}OH$ radicals ... so the denominator term is even lower than I had predicted
 \therefore [EDB] decreases from 50 mg/L to 11 mg/L ✓
(predicted 18 mg/L ok)

d) improve $P_{O_3} \Rightarrow [O_3]$ increases from 0.75×10^{-4} to 2.7×10^{-4} $\frac{mol}{L}$
 $[^{\cdot}OH]$ increases from 2.2×10^{-12} $\frac{mol}{L}$ to 3.5×10^{-12} $\frac{mol}{L}$
[EDB] decreases from 50 mg/L to 35 mg/L ✓