ENV 6519: Physical & Chemical Processes for Groundwater Remediation

Spring 2021 — University of South Florida
Homework #7 — Civil & Environmental Engineering
Due Tues., March 9, 2021 — J.A. Cunningham

1. (65 pts) Imagine that you are designing a packed tower to treat a contaminated water stream by air stripping. The contaminated stream contains trichloroethene (TCE), 1,1,1-trichloroethane (TCA), and 1,1-dichloroethene (DCE). The concentrations of the three contaminants, and some other properties of those chemicals, are given in the table below. Assume a temperature of 20 °C.

Compound	Conc. in waste stream, C_0 (mg/L)	Required conc., C_E (mg/L)	Aqueous diffusivity (m^2/s)	Diffusivity in air (m^2/s)	Henry's constant
========	========	========	========	========	========
TCE	16.3	0.005	0.89×10^{-9}	0.99×10^{-5}	0.35
TCA	0.56	0.20	0.85×10^{-9}	0.98×10^{-5}	0.61
DCE	0.27	0.006	1.04×10^{-9}	1.15×10^{-5}	0.91

Other design criteria are as follows.
Volumetric flow rate, Q = 100 gallons per minute (gpm)
Packing type = 2-inch plastic saddles (like those shown in Figure 14-12 of your text)

Answer the questions below. You definitely want to set up an Excel spreadsheet to keep track of your calculations. That will be particularly helpful when you get to the later parts of the problem (parts i, j, k).

a. Find the air flow rate, Q_a, that will give a stripping factor of at least 3 for all the compounds that need to be removed. Report your air flow rate in units of m^3/s. Based on that flow rate, what is the stripping factor for each of the three compounds? To clarify, you are finding one flow rate, which will give a different stripping factor for each chemical, but the lowest value of S should be 3.
b. Based on the given Q and the calculated Q_a, find the gas loading rate, G_M, that will result in a pressure drop of $\Delta P/L$ = 50 Pa/m. Hint: use figure 14-21 in your text and follow the procedure described on pages 1076–1077. Report your answer in $kg/(m^2 \cdot s)$.
c. From G_M, calculate the tower area and the tower diameter that give you $\Delta P/L$ = 50 Pa/m.

problem 1 continues →

1. continued
    d. Is the tower diameter at least 12 times as big as the diameter of the packing material? If not, then choose a bigger diameter -- choose the diameter to be equal to 15 times the packing diameter. Now what is the cross-sectional area, A, of the tower? Why is it important to satisfy this criterion?
    e. Based on your revised estimate of A, calculate the liquid loading rate, L_M, and the gas loading rate, G_M. Report your answers in kg/(m^2•s). Also estimate the gas pressure drop $\Delta P/L$. Do you see any potential problems?
    f. Use the Onda correlation to estimate k_G, k_L, and K_La for each of the three compounds. For each of the three compounds, what fraction of the overall mass-transfer resistance is due to the liquid phase? Is the gas-phase resistance negligible, or must it be included?
    g. Now you have the stripping factor, S, for each of the three compounds; you have the tower area, A; and you have the mass transfer rate constant, K_La, for each of the three compounds. Based on that, calculate the NTU, the HTU, and the required tower height for each of the three compounds. It would be nice if you reported your results in a table. For the purposes of this assignment, you do not need to include any "safety factor" in your estimate of K_La; in your design project, you would probably want to include this.
    h. Overall, what tower height is required to treat the contaminated water stream? Which compound determines the height of the tower? Why? (Hint: there are actually <u>three</u> inter-related reasons why that chemical controls the height of the tower. Try to come up with all three reasons. Look at your answers to parts f and g, above.)

    At this point, we can see that there are a few problems with the design so far. For one thing, the pressure drop in part (e) was low. For another, the tower is too tall – your book recommends no more than 9 m of packing height. Finally, the ratio of L to d is too high – we'd like it to be between 2:1 and 5:1, but we could live with it up to 10:1. So let's do a couple things. First, make the tower 1.0 m wide. Then, we'll turn up the air flow rate to decrease the tower height while increasing the pressure drop.

    i. Based on a tower diameter of 1.0 m, find L_M. Is it reasonably close to our target value of 10 kg/(m^2•s)?
    j. What gas flow rate, Q_a, would be required to ensure that the packing height doesn't exceed 7.5 m? If you have a spreadsheet, you can play with the Q_a value in your spreadsheet until you achieve your objective.
    k. Find the gas loading rate, G_M, based on this value of Q_a. Then, use the Eckert curve to estimate the pressure drop per meter of tower height. Is it in the target range of 50–100 Pa/m? If so, then it is acceptable. If not, then how would you further modify your design to make sure that both the tower height and the pressure drop are within an acceptable range?
    l. Based on all these calculations, do you think air stripping is a technically viable option for treating the contaminated water stream described in this problem? Why or why not?

2. (15 pts) Look again at problem 1. Perhaps it might be possible to treat this contaminated stream with a low-profile air stripper instead of a packed tower. Low-profile air strippers are nice because they are small (hence the name "low-profile"), and they are often suitable for low water flow rates, such as we have here. For now, let's consider only removal of TCE -- don't worry about the other two contaminants -- and we'll try to decide if a low-profile air stripper might be a good option worth further investigation.
   a. Suppose I want a maximum of 6 trays to keep the system compact (which is one of its main advantages). If each tray is 50% efficient, then that means my number of *theoretical* trays is 3. Use equation 14-66 in your text book to determine what value of S is required such that I can achieve my treatment objective with no more than 3 theoretical trays.
   b. What is the required flow rate of air in units of m^3/s? In units of standard cubic feet per minute (scfm)? How does this air flow rate compare to the air flow rate that you would use for the packed tower in problem 1?
   c. Do you think low-profile air stripping might be a viable option? You don't have very much information to go on, so I do not expect a definitive answer…but based on what you have so far, do you think it would be worth further investigation as a treatment option? Or can we rule it out based on what we know so far?

3. (20 pts) **NOT REQUIRED FOR 2021**
   In problem 1, above, you were given values of aqueous diffusivity, air diffusivity, and Henry's constant for each contaminant. In your design project this semester, you will have to deal with the compound 1,1,2,2-tetrachloroethane (TeCA).
   a. Find, calculate, or estimate values of aqueous diffusivity, air diffusivity, and Henry's constant for this contaminant at 20 °C. Explain your estimation method(s), and/or give the reference for any information that you look up somewhere. (Give a complete citation.)
   b. Based on your estimated values, do you think this chemical is likely to be amenable to treatment by air stripping? Why or why not?

4. (20 pts) **Choose problem 4 *OR* problem 5**

   Look again at your results from problem 1.

   a. Calculate the power required for the water pump and the air blower. Perform the calculations for both the low air flow rate and the high flow rate. How much does the overall power requirement increase if you use the higher air flow rate?

      Hints:

      - Assume that the structural height of the air-stripping tower is 40% greater than the packing height. You must lift the water to the top of the tower.
      - Assume 80% efficiency for the water pump and 35% efficiency for the air blower.
      - For the air blower, use formulae 14-60 through 14–62 in your text.
      - Watch out for the units…I think you might need to use R in units of J/(kg•K) instead of J/(mol•K)…but check me on that to be sure.

   b. For the higher air flow rate, re-calculate the blower power required using a simplified formula (instead of eqn 14-60):

$$P_{\text{blower}} = \frac{\left(G_m\ A_{\text{tower}}\right) R\,T}{\text{blower efficiency}} \frac{\Delta P_{\text{total}}}{P_{\text{out}}}$$

      where $\Delta P_{\text{total}} = \Delta P + \Delta P_{\text{losses}} = P_{\text{in}} - P_{\text{out}}$. How does your new estimate compare to that which you derived using equation 14-60? Do you think the simplified formula is acceptable?

5. (20 pts) **Choose problem 4 *OR* problem 5**

A contaminated water stream is treated with air stripping. For this problem, the *top* of the tower is designated $z = 0$, and the influent concentration is C_0. The concentration at a position z (i.e., distance from the top of the tower) is given by equation 14-65 in your text:

$$C(z) = C_0 \frac{S-1}{S\exp\left[\dfrac{z\,K_L a\,(S-1)}{S\,(Q/A)}\right]-1}$$

To simplify this equation somewhat, we define a dimensionless concentration and a dimensionless position in the tower:

$$\overline{C} = \frac{C}{C_0} \qquad \overline{z} = \frac{z\,K_L a}{Q/A}$$

Therefore, in dimensionless terms, the concentration varies with position according to:

$$\overline{C}(\overline{z}) = \frac{S-1}{S\exp\left[\dfrac{(S-1)}{S}\overline{z}\right]-1}$$

Now we can see how the concentration in the tower varies with position.

a. Graph $\overline{C}(\overline{z})$ vs $\overline{z}$ for the cases $S = 2$, $S = 5$, $S = 20$, and $S = 200$. Consider values of $\overline{z}$ between $\overline{z}=0$ and $\overline{z}=10$. (Note that $\overline{z}=10$ corresponds to a distance of 10 HTUs, i.e., NTU = 10.) Put all four lines on the same graph and label them as clearly as you can. Prepare your graph in the following way. Put $\overline{C}(\overline{z})$ on the abscissa (x-axis) with a range of $\overline{C}=0$ to $\overline{C}=1$. Put $\overline{z}$ on the ordinate (y-axis) with $\overline{z} = 0$ at the top of the graph and $\overline{z}=10$ at the bottom of the graph. That way, the graph shows visually how the concentration varies from the top of the tower to the bottom of the tower – i.e., the top of the graph represents the top of the tower.

b. Make another copy of the same graph from part (a), but make the abscissa logarithmic so we can see what happens at low concentrations.

c. Use your graphs to discuss how concentration depends upon stripping factor at a fixed position within the tower -- pick $\overline{z} = 5$ for the sake of discussion. Does there appear to be some optimum range for S?

6. (50 pts) **NOT REQUIRED FOR 2021**

Answer text book problems 14-8, 14-10, 14-12, 14-16, and 14-20.