ENV 6002: Physical and Chemical Principles of Environmental Engineering

Fall 2021 — University of South Florida

Midterm Examination — Civil & Environmental Eng.

Tues., Oct. 12, 2021 — J. A. Cunningham

Instructions:

1. You may read these instructions, but do not turn the page or begin working until instructed to do so.
2. Answer all questions on your own paper. Make sure you write your name on every page!
3. You are allowed one sheet of 8.5-by-11-inch paper (or A4 paper) with hand-written notes. You may write on both sides of that paper. However, mechanical reproductions (photocopying, laser printing, scanning, etc.) are not allowed; all notes must be hand-written.
4. A calculator is recommended, but it may not be pre-programmed with formulae from the class.
5. Time limit: 65 minutes. Stop working when asked. If you continue working after time has been called, you will be penalized at a rate of 1 point per minute.
6. Show all work and state all assumptions in order to receive maximum credit for your work.
7. Make sure your answers include units if appropriate. ***<u>Watch your units!!</u>***
8. This exam contains 8 short problems, of which you will answer 6. Each problem is worth 10 points. Thus, the total point value for the exam is 60 points – about one point per minute. Gauge your time accordingly!
9. Use a reasonable number of significant digits when reporting your answers. *You are likely to be graded down* if you report an excessive number of significant digits. In some cases, the problem may indicate the precision to which you should report your answer.
10. Don't cheat. Cheating will result in appropriate disciplinary action according to university policy. Also, cheating indicates a lack of personal integrity.
11. Page 2 of this exam (the back of this page) contains background information, data, constants, and conversion factors that might be helpful to you as you complete the exam.

Exam background:

Gasoline (petrol) has been spilled into a pond from a leaking tank. There is a thin layer of gasoline floating on top of the water in the pond. (Gasoline floats on top of the water because it is less dense than water.) The temperature of the system is 25 °C.

- The volume of water in the pond is 5×10^5 m^3, and the density of the water is 998 kg/m^3.
- The volume of sediment at the bottom of the pond is 1.5×10^3 m^3, the density of the sediment is 1500 kg/m^3, and the sediment is 10% organic carbon (by mass).
- The gasoline has a molar mass of 51 g/mol, a density of 950 g/L, and a toluene mass fraction equal to 0.20.

Properties of toluene are given below.

Properties of toluene (taken from your text book):

Atomic formula	C_7H_8
Molar mass (g/mol)	92.14
Aqueous solubility, C^{SL} (mg/L)	530.
logarithm of octanol-water coefficient, $\log_{10}(K_{ow})$	2.73
Vapor pressure, P^{sat} (atm)	37.6×10^{-3}
Henry's constant, H_{PC} (atm·m^3/mol)	6.6×10^{-3}

Some other potentially useful constants:

Ideal gas constant, R: 8.314 Pa·m^3·mol^{-1}·K^{-1} = 8.206×10^{-5} atm·m^3·mol^{-1}·K^{-1}
Molar mass of water, H_2O: 18.01 g/mol
Density of water at 25°C: 0.998 g/mL = 998 kg/m^3
Atomic weights: **C** = 12.011 **Cl** = 35.453 **H** = 1.0079 **N** = 14.007 **O** = 15.999

Potentially useful conversion factors:

Pressure: 1 atm = 760 mm Hg = 760 torr = 101325 Pa
Mass: 1 kg = 1000 g = 1×10^6 mg = 1×10^9 μg
Temperature: 25 °C = 298.15 K
Volume: 1 m^3 = 1000 L = 1×10^6 mL = 1×10^6 cm^3

Answer problems 1–5, then choose <u>any one</u> of problems 6–8.
Each problem is worth 10 points.

1. <u>Show that the *mole fraction* of toluene in the gasoline is 0.11</u>. Hint: if you choose an arbitrary volume of gasoline, such as 1 L, it is not difficult to calculate the mole fraction of toluene in the gasoline. You are given all the information you need on p 2. – but if you don't know how to do this problem, skip it and move on, remembering the final result that the mole fraction of toluene in the gasoline is 0.11.

2. On page 2, you are given the aqueous solubility of toluene, C^{SL}, in units of mg/L. <u>Calculate the aqueous solubility of toluene as a mole fraction</u>, x^{SL}.

3. Assume that the water in the pond is in equilibrium with the gasoline that is floating on top of the pond. Also assume that the gasoline phase acts as an ideal liquid, but the water does not. <u>Estimate/calculate the mole fraction of toluene in the water</u>, x_{tol}^{aq}. Hint 1: use appropriate fugacity relationships. Hint 2: notice something important and useful about your answer to problem 2.

4. Using the mole fraction that you found in problem (3), <u>estimate/calculate the concentration of toluene in the water,</u> C_{tol}^{aq}<u>, in units mg/L</u>. What is the ratio C_{tol}^{aq}/C^{SL}? What do you notice about this ratio? Is this a coincidence?

5. Assume the sediment at the bottom of the pond is in equilibrium with the water in the pond. <u>Estimate/calculate the concentration of toluene in the sediment, in units mg/kg</u>. You will have to make an assumption to perform this calculation (i.e., you are not given quite enough information on page 2). Clearly state whatever assumption(s) you make.

Choose <u>any one</u> of problems 6, 7, 8:

6. Using your answer to problem (5), along with the density of the sediment, express the concentration of toluene in the sediment, in units mg/L (i.e., mg toluene per L sediment). Which compartment has a greater <u>concentration</u> of toluene, the water or the sediment? <u>Explain why</u>, referring to appropriate properties of toluene. Which compartment has a greater <u>mass</u> of toluene, the water or the sediment? <u>Explain</u> how this result can be consistent with your concentration result.

7. Suppose you measure the concentration of toluene in the sediment, and you find that the concentration is only 30% of the value that you had estimated in problem 5. Based on this, we know the water and the sediment are not at equilibrium. Write an equation that expresses the mass flux of toluene between the water and the sediment. Define all terms in your equation. Write your equation in such a way that flux is positive if mass transfer is going from the water to the sediment. Assuming an overall mass-transfer coefficient $K_L = 1.0 \times 10^{-6}$ m/s and a sediment-water contact area of 15,000 m^2, how much mass of toluene (in kg) moves between the water phase and the sediment phase in 1 day? Which way is it moving? – from the water to the sediment, or from the sediment to the water?

8. Assume that the air directly above the pond is in equilibrium with the gasoline that is floating on top of the pond. Estimate/calculate the partial pressure of toluene in the air. Report your answer in units of either atm or Pa (whichever you prefer). Hint: use fugacity relationships, remembering that the gasoline is an ideal liquid. Then, report the concentration of toluene in the air, C_{tol}^{air}, in units mg/m^3.

Don't answer this one, but I wish we had time to do this one too:

9. Based on your answers to questions (4) and (8), estimate/calculate a dimensionless form of Henry's constant, Hcc. Does it agree with the value you would estimate from H_{PC} (which is given on page 2)?

END OF EXAM