ENV 6002

Physical and Chemical Principles of Environmental Engineering

Fall 2006 University of South Florida

Midterm Examination Civil & Environmental Eng.

Wed., Oct. 18, 2006 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 in the exam booklet provided, and write your name conspicuously on the exam booklet.
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: 70 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. ***Watch your units!!***
8. This exam contains 3 questions, the third of which contains multiple parts. Complete all three problems. The total point value for the exam is 70 points -- 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.
11. Page 2 of this exam (the back of this page) contains constants and conversion factors that might be helpful to you as you complete the exam.

Properties of TCE and PCE:

This exam contains questions dealing with the contaminants trichloroethene (also called trichloroethylene, or TCE) and tetrachloroethene (also called perchloroethylene, or PCE). These are common environmental contaminants. Below is information on the physical-chemical properties of these contaminants at 20 °C.

	TCE	PCE
Atomic formula	C_2Cl_3H	C_2Cl_4
Molecular weight (g/mol)	131.4	165.8
Liquid density, ρ (g/cm^3)	1.46	1.62
Aqueous solubility, C^{SL} (mole/L)	8.3×10^{-3}	8.5×10^{-4}
Octanol-water coefficient, K_{ow}	265	760
Vapor pressure, P^{sat} (Pa)	7770	1970
Aqueous diffusivity, D (m^2/sec)	8.9×10^{-10}	8.2×10^{-10}

Some other potentially useful constants:

Ideal gas constant, R: 8.314 Pa•m^3•mol^{-1}•K^{-1} = 82.06×10^{-6} atm•m^3•mol^{-1}•K^{-1}

Molecular weight of water, H_2O: 18.01 g/mole

Density of water at 20°C: 0.998 g/mL

Aqueous diffusivity of oxygen at 20°C, D_{O2}^{L}: 2.0×10^{-9} m^2/sec

Henry's constant for oxygen at 20°C, H_{CC}: 30

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

Temperature: 20 °C = 293.15 K

Volume: 1 m^3 = 1000 L = 1×10^6 mL = 1×10^6 cm^3

1. (10 pts) Pick ***one*** of the following questions to answer. Be thorough but concise in your answer.

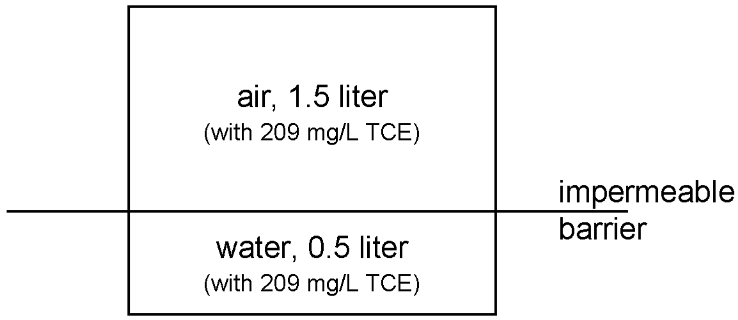
   (a) State Henry's Law as it pertains to the partitioning of non-dissociating organic compounds between air and water. Over what aqueous concentration range (approximately) should Henry's Law be valid? Why? Explain in terms of the concentration dependence of the contaminant's activity coefficient in water.

   (b) Define or explain the terms *maximum contaminant level* (MCL) and *maximum contaminant level goal* (MCLG). Under what piece of major environmental legislation are these terms relevant? What is the relationship between MCL and MCLG, and what are the most important differences between the two?

   (c) Killer whales, also called Orca whales, are meat-eating whales that live in the arctic. They have been found to be highly contaminated by toxic chemicals even though they do not live close to major sources of contamination. Why? Hint: think about the diet and the physiology of these animals (both play an important role).

Exam continues →

2. (10 pts) Suppose that you have a system containing 0.5 L of water and 1.5 L of air. The two compartments are separated by an impermeable barrier, as in the figure shown here.



Initially, both the air and the water contain trichloroethene, TCE. The concentration of TCE is 209 mg/L in both compartments. The temperature of both compartments is 20 °C and the pressure of both compartments is 1 atm. Suppose you then remove the barrier between the two compartments so that the air and the water come into contact with each other. Which of the following four statements is correct?:

(a) After removing the barrier, TCE will move from the air to the water until equilibrium is reached.

(b) After removing the barrier, TCE will move from the water to the air until equilibrium is reached.

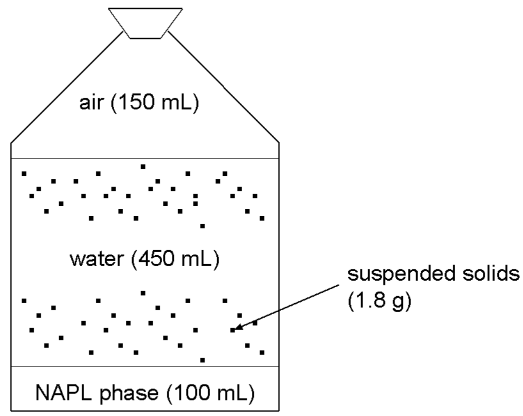
(c) The system is already at equilibrium because the concentration of TCE is equal in the two compartments.

(d) The answer can't be determined from the information given in this exam.

Explain your answer. Show any calculations that you deem necessary.

Exam continues →

3. (50 pts total) Consider a closed beaker as shown in the figure below. The total volume in the closed beaker is 700 mL. The system is at 20 °C and 1 atm.



The system contains four compartments:

- 150 mL air
- 450 mL water
- 1.8 g of sediment suspended in the water. The density of the sediment is 1.01 g/cm^3, the sediment is 3.7% organic carbon by mass, and the average diameter of the suspended sedminent particles is 0.10 mm (i.e., 1.0×10^{-4} m).
- 100 mL of non-aqueous-phase liquid, or NAPL. The NAPL consists of two contaminants, TCE and PCE. The mole fraction of TCE in the NAPL phase is $x_{\mathrm{TCE}}^{\mathrm{NAPL}} = 0.25$ and the mole fraction of PCE in the NAPL phase is $x_{\mathrm{PCE}}^{\mathrm{NAPL}} = 0.75$.

You may assume that the system is at equilibrium. Answer the following.

a. (2 pts) Give the relationship between the fugacity of TCE in the water ($\hat{f}_{\mathrm{TCE}}^{\mathrm{water}}$) and the fugacity of TCE in the NAPL ($\hat{f}_{\mathrm{TCE}}^{\mathrm{NAPL}}$).

Exam continues →

3. continued

b. (8 pts) Show that the concentration of TCE in the water phase is approximately 270 mg/L. Hint: start with the fugacity relationship from part (a).

c. (4 pts) Estimate/calculate the mole fraction of TCE in the water.

d. (6 pts) Estimate/calculate the activity coefficient of TCE in the water. In one or two sentences, explain what the activity coefficient tells you qualitatively.

e. (6 pts) Estimate/calculate the concentration of TCE in the air phase, in units mg/L (i.e., mg of TCE per L of air). Be sure you report you answer in the requested units!

f. (6 pts) Estimate/calculate the concentration of TCE in the solid phase, in units mg/kg (i.e., mg of TCE per kg of suspended solid).

g. (12 pts) How do you think the concentration of PCE compares to the concentration of TCE in the air phase, in the water phase, and in the solid phase? Will the PCE concentration be higher or lower than the TCE concentration in each of these three phases, and by approximately how much? (e.g., by a factor of 2, by a factor of 10, by a factor of 100, etc.?) *Explain* in terms of the *chemical properties* of TCE and PCE. It is OK to explicitly calculate the concentration of PCE in each phase if you wish, but you can probably answer the question pretty well without actually performing any calculations.

h. (6 pts) Suppose I now lower the temperature of the entire system by 10 °C. What will happen to concentration of TCE in the water phase? In the solid phase? In the air phase? Explain in terms of the chemical properties of TCE and their temperature dependence.

END OF EXAMINATION