

ENV 6519: Physical and Chemical Processes in Environmental Engineering

Spring 2010  
**Examination**  
Tues., March 30, 2010

University of South Florida  
Civil & Environmental Eng.  
J. A. Cunningham

**Instructions:**

1. You may read these instructions, but do not turn the page or begin working until instructed.
2. Answer all questions in the exam booklet provided, and write your name conspicuously on the exam booklet. (APEX students taking the exam off-site should provide their own paper.)
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, all with multiple parts. **Choose any two of the three problems.** If you attempt all three, you will be given credit for the two on which you score highest. However, this is probably not a good strategy; you are probably better off concentrating on two problems and trying to do them well, rather than attempting all three.
9. The total point value for the exam is 70 points -- one point per minute. Gauge your time accordingly!
10. 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.
11. Don't cheat. Cheating will result in appropriate disciplinary action according to university policy. More importantly, cheating indicates a lack of personal integrity.
12. 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. I recommend that you read page 2 carefully, as it is likely that you will need some of that information to complete the problems on the exam.
13. Additional pages, photocopied from your course text, are provided to give you additional information. You might or might not find the information useful.

## Background Information

1,2-Dibromoethane is also called commonly called ethylene dibromide (EDB). The name EDB isn't actually chemically accurate, but it is what people call it in practice, so we're stuck with it. EDB is a soil fumigant, formerly used a lot in strawberry production, which is a big deal here in Florida. Use of EDB has been phased out because EDB causes a variety of health effects – in fact, the drinking water MCL for EDB is very low, 0.05 µg/L. (For comparison, the MCL for TCE is 5 µg/L, one hundred times higher.) However, many sites remain where the soil and/or groundwater are contaminated with EDB. In this exam, we will consider the possible removal of EDB from water by the three physical/chemical processes we have looked at during the semester.

### Properties of EDB at 25 °C:

Molecular formula:	C <sub>2</sub> H <sub>4</sub> Br <sub>2</sub>
Molecular weight:	187.86 g/mole
Liquid density:	2.18 g/cm <sup>3</sup> = 2180 kg/m <sup>3</sup>
Vapor pressure, P <sup>sat</sup> :	1620 Pa
Aqueous solubility:	0.0234 mol/L = 4.4 g/L
Octanol-water partition coefficient:	10 <sup>1.96</sup> = 91
Reaction rate constant with •OH:	not given in your book's appendix
Heat of vaporization, ΔH:	not given in your book's Table 14-3

### Potentially useful constants:

Ideal gas constant, R:	8.314 Pa•m <sup>3</sup> •mol <sup>-1</sup> •K <sup>-1</sup> = 82.06×10 <sup>-6</sup> atm•m <sup>3</sup> •mol <sup>-1</sup> •K <sup>-1</sup>
Molecular weight of water, H <sub>2</sub> O:	18.01 g/mole
Density of water at 25 °C:	0.9970 g/mL = 997 kg/m <sup>3</sup>
Viscosity of water at 25 °C:	0.890×10 <sup>-3</sup> Pa•sec
Density of air at 25 °C:	1.18 kg/m <sup>3</sup>
Viscosity of air at 25 °C:	1.85×10 <sup>-5</sup> Pa•sec

### Potentially useful conversion factors:

Pressure:	1 atm = 760 mm Hg = 760 torr = 101325 Pa
Mass:	1 kg = 1000 g = 10 <sup>6</sup> mg = 10 <sup>9</sup> µg
Temperature:	25 °C = 298.15 K
Volume:	1 m <sup>3</sup> = 1000 L = 10 <sup>6</sup> mL = 10 <sup>6</sup> cm <sup>3</sup>
Other :	1 Pa = 1 N/m <sup>2</sup> = 1 kg/(m•sec <sup>2</sup> )

### Atomic Masses:

H = 1.008 g/mole	C = 12.011 g/mole	N = 14.007 g/mole	O = 15.999 g/mole
Cl = 35.453 g/mole	Br = 79.904 g/mole		

1. (35 pts) Imagine that you are going to use **adsorption onto activated carbon** to remove EDB from water at 25 °C. You have to choose from three different types of activated carbon. EDB exhibits a different sorption isotherm for each of the three carbons. Also, the price of the carbons differs slightly. Here are the three choices for carbon, along with the costs and the Freundlich isotherm parameters for EDB.

	Carbon A	Carbon B	Carbon C
$K_F (\mu\text{g/g})/(\mu\text{g/L})^{1/n}$	101	235	419
$1/n$	0.894	0.702	0.513
cost (per kg)	\$ 3.49	\$ 2.99	\$ 3.24

- (8 pts) Suppose that you are going to treat a stream of water that is contaminated with EDB at a concentration of 900  $\mu\text{g/L}$ . The flow rate of the contaminated stream is 100 gpm = 380 L/min = 550  $\text{m}^3/\text{d}$ . You want to reduce the concentration to 5  $\mu\text{g/L}$  or lower. You are going to treat the stream in a fixed bed of granular activated carbon (GAC) – actually, with two fixed beds operating in series, so that you don't have to worry about the width of the mass-transfer zone. Which of the three types of carbon do you choose to put in your GAC contactors? Why? Show whatever calculations are necessary to support your decision.
- (8 pts) Now suppose that the stream of contaminated water drops in concentration from 900  $\mu\text{g/L}$  to 100  $\mu\text{g/L}$ . The flow rate does not change. Is there any reason to switch to a different carbon, or would you keep using the same one? If you switch, to which one? Why? Show whatever calculations are necessary to support your decision.
- (8 pts) Now suppose that you wanted to treat the stream with powdered activated carbon (PAC) instead of GAC. You might do this, for instance, if the EDB contamination were an intermittent problem rather than a continuous problem. You will add the PAC to the contaminated water in a completely-mixed flow reactor (CMFR). You may assume that the residence time in the CMFR is long enough that the water and the carbon reach full equilibrium. Suppose that, as in part (a) of this problem, the influent concentration is 900  $\mu\text{g/L}$  and you want to treat it to no higher than 5  $\mu\text{g/L}$ . Which carbon would you select? (Assume that the isotherms and the costs given in the table are valid for both the granular form and the powdered form of the carbon.) Show whatever calculations are necessary to support your decision.
- (6 pts) Continue the PAC operation as you did in part (c). Now, however, suppose that the influent concentration of the water drops from 900  $\mu\text{g/L}$  to 100  $\mu\text{g/L}$ . Is there any reason to switch to a different carbon, or would you keep using the same one? If you switch, to which one? Why?
- (5 pts) Briefly explain the choices you made in parts (a)–(d). Did you make similar choices for the GAC and the PAC? Why or why not?

2. (35 pts) Imagine that you are investigating whether **air stripping** is a good treatment technique for the removal of EDB from water at 25 °C. You will use packed-tower aeration to treat the contaminated water. The concentration of EDB in the contaminated water is 200 µg/L.

The air stripping tower has the following parameters (all of which are quite reasonable or typical):

Tower diameter, $d = 1.0$ m	Packing type = 2" plastic saddles
Packing height, $L = 8.0$ m	Packing diameter, $d_p = 0.0508$ m
Liquid loading rate, $L_M = 10.0$ kg/(m <sup>2</sup> •s)	Packing factor, $C_f = 20$
Gas loading rate, $G_M = 0.50$ kg/(m <sup>2</sup> •sec)	Packing specific surface area, $a_t = 110$ m <sup>2</sup> /m <sup>3</sup>
Pressure drop, $\Delta P/L < 50$ Pa/m	Packing surface tension, $\sigma_c = 0.033$ N/m

Mass transfer properties for EDB in the air stripper under these conditions:

$$k_L = 2.2 \times 10^{-4} \text{ m/sec} \quad k_G = 1.0 \times 10^{-2} \text{ m/sec} \quad a_w = 58 \text{ m}^2/\text{m}^3$$

- (5 pts) Estimate/calculate the water flow rate and the air flow rate, both in units of m<sup>3</sup>/s.
- (5 pts) Estimate/calculate Henry's constant,  $H$ , for EDB at a temperature of 25 °C. Report  $H$  in its dimensionless form. Hint: watch your units!!
- (4 pts) Estimate/calculate the value of the stripping factor,  $S$ , for EDB in this air stripping unit.
- (5 pts) Estimate/calculate the height of a transfer unit, HTU, under these conditions.
- (8 pts) Estimate/calculate  $C_e$ , the concentration of EDB in the water stream that exits the bottom of the air stripper. How much fractional removal of EDB do we get in this air stripping unit? Hint: you are given the packing height  $L = 8.0$  m.
- (8 pts) Suppose we want to achieve a treatment objective of 5 µg/L. Is it achieved under the conditions given above? If not, what appears to be the main impediment to achieving the treatment objective? Based on that, is there some process change that might enable us to achieve the treatment objective? Try to be specific if possible.

3. (35 pts) Imagine that you are employing **oxidation by ozone with hydrogen peroxide** for the removal of EDB from water. The process is taking place in a completely-mixed flow reactor (CMFR) through which the contaminated water flows. Ozone is bubbled into the bottom of the reactor, and hydrogen peroxide is added to the contaminated water just before it enters the reactor. This enhances the formation of the  $\cdot\text{OH}$  radical to destroy the EDB. The conditions in the reactor are as follows.

Temperature,  $T = 25\text{ }^\circ\text{C}$

Hydraulic residence time,  $\tau = 5\text{ min}$

Influent EDB concentration,  $C_1 = 200\text{ }\mu\text{g/L}$

Partial pressure of ozone in gas stream,  $P_{\text{O}_3} = 0.030\text{ atm}$

Henry's constant for ozone gas at  $25\text{ }^\circ\text{C}$ ,  $H_{\text{PC}} = 89.1\text{ atm}\cdot\text{L/mol}$

Overall mass transfer coefficient for ozone,  $K_{\text{L}}a = 3.0 \times 10^{-4}/\text{sec}$

pH of contaminated water = 7.0

Concentration of bicarbonate,  $[\text{HCO}_3^-] = 183\text{ mg/L} = 3.0 \times 10^{-3}\text{ mol/L}$

Concentration of dissolved organic carbon,  $[\text{NOM}] = 0.24\text{ mg/L} = 2.0 \times 10^{-5}\text{ mol/L}$

Concentration of peroxide,  $[\text{H}_2\text{O}_2] = 0.34\text{ mg/L} = 1.0 \times 10^{-5}\text{ mol/L}$

Concentration of hydroxyl radicals,  $[\cdot\text{OH}] = 2.2 \times 10^{-12}\text{ mol/L}$

Under these conditions, the effluent concentration of EDB is  $C_E = 50\text{ }\mu\text{g/L}$ . That is, we are removing 75% of the incoming EDB.

- a. (5 pts) Estimate/calculate the value of  $k$ , the apparent first-order rate constant for the destruction of EDB. Report  $k$  in units of  $\text{min}^{-1}$ . Hint: what is  $C_E/C_1$  for a CMFR?

Unfortunately, it has been determined that this is unacceptable and better removal of the EDB is required. A number of possible process modifications have been suggested. For parts (b)–(d) below, *estimate the effluent concentration of EDB* that will result if the proposed process modification is implemented. (Note: you probably can't get an exact answer without going through a complicated iterative process like you did on HW 8, and that is not feasible for this exam; so instead, make your best estimates, show your calculations, and/or explain your logic/reasoning.)

- b. (8 pts) The ceramic diffusers in the reactor are upgraded so that the overall mass transfer coefficient doubles to  $K_{\text{L}}a = 6.0 \times 10^{-4}/\text{sec}$ .
- c. (10 pts) A softening system is put in upstream of the reactor, which reduces the bicarbonate concentration to  $12.2\text{ mg/L} = 2.0 \times 10^{-4}\text{ mol/L}$ .
- d. (8 pts) The ozone generation system is upgraded so that the partial pressure of ozone in the gas stream increases to 0.060 atm.
- e. (4 pts) Which option offers the best improvement? Why? Briefly (a few sentences) explain the principle behind this improvement and why it is superior to the other two options.