

Midterm 1

CENG 340—Introduction to Environmental Engineering

Instructor: Deborah Sills

October 9, 2013

Name:

As you work through the exam, please write down what you know (in equation form when possible), write down any questions you have (since I'm in Chicago). And, please, **SHOW YOUR WORK!**

1. Alkalinity

(a) 5pts What is alkalinity (in words)?

Ability of water to neutralize acid.

(b) 5pts Why is alkalinity important—Name one phenomena or system (natural or engineered) where alkalinity may play a role.

① Life works well at neutral pH

② Acid rain, aerobic digesters, drinking water treatment

(c) 10pts How many milliliters of a sulfuric acid (H_2SO_4) solution (concentration = 0.1 equivalents/liter) are needed to consume the alkalinity of 200 milliliters of lake water, which has an alkalinity of 250 mg/liter as CaCO_3 ? Remember, sulfuric acid is a strong acid.

$$\begin{aligned}\text{Alk of Lake water} &= 250 \text{ mg/L} \times \frac{1 \text{ eq}}{50} = 5 \text{ meq/L} \times \frac{1 \text{ eq}}{1000 \text{ meq}} = \\ &= 5 \times 10^{-3} \text{ eq/L}\end{aligned}$$

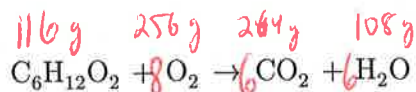
$$\text{Eq-Lake} = \text{Eq-acid}$$

$$C_{\text{Lake}} V_{\text{Lake}} = C_{\text{acid solution}} V_{\text{acid solution}}$$

$$200 \text{ mL} \times 5 \times 10^{-3} \text{ eq/L} = 0.1 \text{ eq/L} \times V_{\text{acid solution}}$$

$$\begin{aligned}V_{\text{acid sol}} &= \frac{200 \text{ mL} \times 5 \times 10^{-3} \text{ eq/L}}{0.1 \text{ eq/L}} = \underline{10 \text{ mL}}\end{aligned}$$

2. During a hydrofracking operation, the surfactant 2-butoxyethanol was accidentally released into a stream that is 2 meters deep. The gas company—*Energy Land*—claims that no clean up is necessary, since 2-butoxyethanol will be broken down by microbes. However, because these microbes are aerobic, they also consume oxygen in proportion to the 2-butoxyethanol consumed, as shown in the following reaction:



- (a) **15 pts** Calculate the mass of 2-butoxyethanol (in kg) that spilled within an enclosed area of 10,000 m², if the dissolved oxygen (D.O.) concentration in this region was reduced by the microbes to 0.5 $\frac{mg O_2}{L}$. Assume that the normal "background" D.O. (outside the spill area) is 8 $\frac{mg O_2}{L}$, and that all of the spilled 2-butoxyethanol remains in the aqueous phase (i.e., no water-gas or water-solid partitioning).

$$[O_2]_{consumed} = 8 - 0.5 = 7.5 \text{ mg/L}$$

$$V_{\text{enclosed area}} = 10,000 \text{ m}^2 \times 2 \text{ m} = 20,000 \text{ m}^3$$

$$\text{mass } O_2 \text{ consumed} = 7.5 \text{ mg/L} \times 20,000 \text{ m}^3 \times \frac{1000 \text{ L}}{1 \text{ m}^3} = 1.5 \times 10^8 \text{ mg} \times \frac{1 \text{ kg}}{10^6 \text{ mg}} = 150 \text{ kg } O_2$$

$$\text{mass 2-butoxy} = 150 \text{ kg } O_2 \times \frac{116 \text{ g 2-butoxy}}{256 \text{ g } O_2} = \underline{68.1 \text{ kg of 2-butoxy ethanol}}$$

- (b) **10 pts** To avoid creating a "Dead Zone" (i.e., a region with very low dissolved oxygen levels), you have been asked to design an oxygen delivery system that will provide all of the oxygen needed by the microbes to break down the spilled surfactant. Assume that 40 kg of 2-butoxyethanol is the total mass released in the spill (it's not). Calculate the volume of a tank that would be required to store the total oxygen needed to break down all of the pollutant. Assume that the oxygen is stored under pressure with $P = 50 \text{ atm}$, at a temperature, $T = 25^\circ \text{C}$.

$$\text{Mass of } O_2 = 40 \text{ kg 2-butoxy} \times \frac{256 \text{ g } O_2}{116 \text{ g 2-butoxy}} = 88 \text{ kg } O_2$$

$$\text{moles } O_2 = 88 \text{ kg } O_2 \times \frac{1 \text{ mole}}{32 \text{ g}} \times \frac{1000 \text{ g}}{1 \text{ kg}} = 2759 \text{ mole } O_2$$

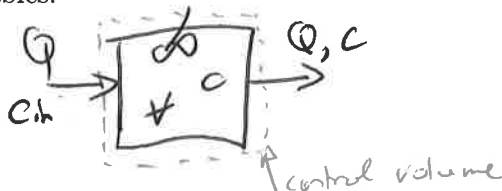
$$PV = nRT$$

$$V = \frac{nRT}{P} = \frac{2759 \text{ mole} \times 8.205 \times 10^{-5} \frac{\text{m}^3 \cdot \text{atm}}{\text{mole} \cdot \text{K}} \times 298.15 \text{ K}}{50 \text{ atm}} = \underline{1.35 \text{ m}^3}$$

3. For this problem, only use your calculator for the final steps of parts (c) and (e).

To prevent future problems, the same gas company—*Energy Land*—hired you to design a reactor with a first-order reaction rate, that will remove 99 percent of the surfactant, 2-butoxyethanol, from frack flow-back water, at steady state. You are considering a completely-mixed flow reactor (CMFR) and a plug-flow reactor (PFR). The design volumetric flow rate (Q), and the reaction rate coefficient (k) are known.

- (a) 5 pts For the CMFR, draw a schematic that includes an appropriate reactor, control volume, and all known and unknown variables.



- (b) 10 pts Write the *complete* mass balance equation, including all variables. Then, clearly indicate which terms (if any) should not be considered for this problem. Clearly state all assumptions made to simplify the mass balance equation.

$$\frac{dn}{dt} = m_{in} - m_{out} - m_{rxn}$$

$$V \frac{dc}{dt} = QC_{in} - QC - kCV$$

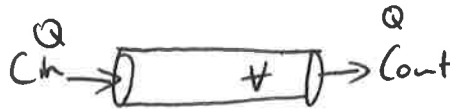
Steady
state

- (c) 10 pts Solve the mass balance equation for the CMFR volume needed to achieve 99% removal of 2-butoxyethanol in terms of volumetric flow rate and the reaction rate coefficient.

$$0 = Qc_{in} - Q(0.01)c_{in} - k \cdot 0.01c_{in} V$$

$$V = \frac{0.99Q}{0.01K} = 99 \frac{Q}{K}$$

- (d) **2 pts** For the PFR, draw a schematic that includes an appropriate reactor and all known and unknown variables.



- (e) **10 pts** Use the equation we developed in class for a PFR (or write a complete mass balance equation) and solve for the volume needed to achieve 99% removal of 2-butoxyethanol in terms of volumetric flow rate and the reaction rate coefficient.

$$C_{out} = C_{in} \cdot e^{-kt} = C_{in} e^{-k \frac{V}{Q}}$$

$$e^{-k \frac{V}{Q}} = \frac{0.01 C_{in}}{C_{in}}$$

$$-k \frac{V}{Q} = \ln 0.01$$

$$\boxed{V = 4.6 \frac{Q}{k}}$$

- (f) **5 pts** Provide a **brief** statement regarding the relative sizes of the reactors. Should the volumes be the same or different? Why?

For first order reactions & same k , Q , and pollutant removal — volume of PFR is smaller than volume of CMFR.

Reason: Reaction rate is a function of concentration & $C_{PFR} > C_{CMFR}$.

4. **13 pts** A PFR and CMFR are in series as shown below. The CMFR and PFR each has an initial concentration $C_0 = 0$. And each reactor has the same volume, V . A pulse input (mass = M) of a conservative material is introduced at the influent end of the PFR at $t=0$, and is immediately followed by a continuous flow, Q , with $C=0$. Sketch the concentration of the conservative material, C , vs. time in the effluent from the CMFR. For your convenience, time intervals on the x-axis are given in multiples of the hydraulic retention time, $\theta = \frac{V}{Q}$.

