In Class Post Quiz 1 Pre-Quiz 2—Environmental Measurements

CENG 340–Introduction to Environmental Engineering
Instructor: Deborah Sills

September 6, 2013

What are PVC pipes made from?

Vinyl Chloride, C_2H_3Cl

The Environmental Protection Agency regulates vinyl chloride (VC) under the Clean Air Act and the Safe Drinking Water Act. VC has an MCL of 0.002 ppm_m and a 3-h outdoor air quality standard of 10 ppm_v.

A manager of a facility that produces polyvinyl chloride (PVC) informs you that a malfunctioning valve caused 60 g of VC to be discharged into an indoor swimming pool. **She wants to know if the resulting concentrations of VC in the water and air violate the MCL and outdoor air quality standard, respectively.**

Since VC is very volatile, assume that 58 g of the VC volatilzed out of the water into the air surrounding the indoor pool, and 2 g remained dissolved in water. (Note that next week you will learn to calculate how volatile compounds like VC partition between air and water.)

Additional useful information:

1. The pool has a volume of 100 m^3 and the indoor pool area has an air volume of 1000 m^3.
2. Temperature and pressure equal 25 ^{0}C and 1 atm, respectively.
3. Temperature in Kelvin (K) = temperature in degrees Celsius (^{0}C) + 273.15;
4. $MW_C = 12$ g/mole; $MW_H = 1$ g/mole; $MW_{Cl} = 35.5$ g/mole
5. The ideal gas constant $R = 8.205 \times 10^{-5} \frac{m^3 \times atm}{mole \times Kelvin}$.

Problem Solving Strategies
Equilibrium

1. Draw a diagram
2. Use key words in the problem statement to figure out which type of equilibrium equation you should use
3. Write down the equations
4. Identify what you need to calculate
5. Identify what you know
6. Iterate, go back, and repeat steps 3 through 6

In Class Problem—Fish Kill

Acid–Base Chemistry

CENG 340–Introduction to Environmental Engineering
Instructor: Deborah Sills
September 11, 2013

Concentrations of NH_3 (a weak acid) that are higher than 0.2 mg/L are toxic to fish.

Effluent from a wastewater treatment plant (WWTP)—with pH = 7 and a total ammonia concentration of 5 **mg-N/L**—is discharged to a stream that is popular with fisherman. Ammonia consists of two species: NH_4^+ (a weak acid) and NH_3 (its conjugate base). The concentrations of NH_4^+ and NH_3 are related to each other through the following equilibrium reaction:

$$[NH_4^+] \overset{K_a}{\rightleftharpoons} [NH_3] + [H^+]$$

where $K_a = 10^{-9.3}$, or $pK_a = 9.3$.

1. You've been asked to use the total ammonia data reported above to calculate the concentration of NH_3 in the WWTP effluent to ensure that $[NH_3]$ is lower than 0.2 mg/L.

In Class Problems
Precipitation–Dissolution Equilibrium & Kinetics
CEng 340–Introduction to Environmental Engineering

Instructor: Deborah Sills

September 16, 2013

1. *Modified from Mihelcic and Zimmerman*

   Ingesting cadmium may lead to kidney damage. According to the EPA, major sources of cadmium in drinking water include corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; and runoff from waste batteries and paints.

   One method to remove metals, such as cadmium, from water is to raise the pH and cause them to precipitate as their metal hydroxides. The precipitation–dissolution equilibrium relationship for cadmium hydroxide is described by the following equation:

$$[\mathrm{Cd(OH)_2}] \overset{K_{sp}}{\rightleftharpoons} [\mathrm{Cd^{2+}}] + 2\,[\mathrm{OH^-}]$$

   where $\mathrm{p}K_{sp} = 13.85$

   (a) In an attempt to remove cadmium from water by precipitating cadmium hydroxide, the pH of water was raised from 6.8 to 8.0. Was the dissolved cadmium concentration reduced to below 100 mg/L at the final pH?

   (b) What pH is required to reduce cadmium concentration to below the MCL of 5 ppb?

2. *Modified from Mihelcic and Zimmerman*

Nitrogen dioxide (NO_2), an air pollutant produced when N_2 in air reacts with O_2 during fuel combustion, can be destroyed via photochemical reactions, which result in the formation of ozone. In one study, NO_2 concentrations decreased from 5 ppm_v to 2 ppm_v in four minutes due to exposure to light.

(a) What is the first-order rate constant for this reaction?

(b) What was the half-life of NO_2 during this study?

In Class Problems
Precipitation–Dissolution Equilibrium for Tara
CENG 340–Introduction to Environmental Engineering
Instructor: Deborah Sills
September 18, 2013

Tara asked a great question about the cadmium hydroxide precipitation problem we worked on in class on Monday. She wanted to know if we could use stoichiometry to calculate the equilibrium concentrations of $[OH^-]$ and $[Cd^{2+}]$ in the following equation, and if not, why?

$$[Cd(OH)_2] \xrightleftharpoons{K_{sp}} [Cd^{2+}] + 2\,[OH^-]$$

where $pK_{sp} = 13.85$

I told her that—within the context of Monday's problem—the answer was no, but that I would try to find a good way to explain why not. I hope that the following problem will help:

If 50 mg of OH^- and 50 mg of Cd^{2+} are present in 1 L of water, what will be the final equilibrium concentration of Cd^{2+}? (Note that to solve this problem you need to use the equilibrium equation above.)

1. Take a look at the problem we solved on Monday, and describe how this problem is different from Monday's problem. Write down how you think the differences between the two problems will change your approach to this one.

2. Try to solve the problem.

3. Try to answer Tara's question.

Mass Balance–Salt in a Storm Sewer

CENG 340–Introduction to Environmental Engineering
Instructor: Deborah Sills
In Class: September 20, 2013

(adapted from *Environmental Engineering* by Davis and Cornwell)
A storm sewer is carrying snow melt containing 1,200 g/L of sodium chloride into a small stream. The stream has a naturally occurring sodium chloride concentration of 20 mg/L. If the storm sewer flow rate is 2000 L/min and the stream flow rate is 2.0 m^3/s, what is the concentration of the salt in the stream after the discharge point? Assume that the sewer flow and stream flow are completely mixed, and that the salt is a conservative substance (it does not react) and that the system is at steady state?

Step 1:

Underline any words or phrases that are unclear to you–i.e., even if you understand the English, there are a few key phrases in the problem that we have not covered.

Step 2:

Draw a mass balance diagram.

Step 3:

Write a mass balance equation:

Step 4:

Solve the mass balance equation:

Completely Mixed Flow Reactors

CENG 340–Introduction to Environmental Engineering
Instructor: Deborah Sills
In Class: September 25, 2013

Steps for Solving Mass Balance Problems in Completely Mixed Flow Reactors (CMFRs)

(Modified from *Environmental Engineering* by Mihelcic and Zimmerman)
The most difficult part of solving mass balance problems in CMFRs arise from uncertainty of the location of the control volume boundaries, and uncertainty of values of the individual terms in the mass balance equation (e.g., Q_{out}, $\dot{m}_{rxn}$). The following steps will hopefully help solve mass balance problems:

1. Draw a diagram, identify the control volume and all of the influent and effluent flows. All mass flows must cross the control volume and it should be reasonable to assume the control volume is well mixed. (Remember that the significance of "completely mixed" is that $C_{out} = C_{\text{in the reactor}}$.)
2. Write the mass balance equation in general form:
$$\frac{dm}{dt} = \dot{m}_{in} - \dot{m}_{out} + \dot{m}_{rxn}$$
3. Determine whether the problem is at steady state ($\frac{dm}{dt} = 0$) or nonsteady state ($\frac{dm}{dt} = V \times \frac{dC}{dt}$).
4. Determine whether the compound being balanced is conservative ($\dot{m}_{rxn} = 0$) or nonconservative. If the compound is nonconservative, then $\dot{m}_{rxn}$ must be determined based on reaction kinetics as follows:
$$\dot{m}_{rxn} = V \times (\frac{dC}{dt})_{\text{reaction only}}$$
5. Substitute known or required values for each of the terms in the mass balance equation.
6. Solve the problem. You'll need to solve differential equations for nonsteady-state problems and algebraic equations for steady-state problems.

Examples of Mass Balance Problems for CMFRs

Go through the examples in Section 4.1.3 of the textbook (pp.113–120). There are four examples and we've done (including today) two in class.

Mass Balance–CMFR with Conservative Pollutant

CENG 340–Introduction to Environmental Engineering
Instructor: Deborah Sills
In Class: September 23, 2013

(Example 4.5 in *Environmental Engineering* by Mihelcic and Zimmerman)

A completely mixed stirred reactor (CMFR) contains clean water prior to being started. After start-up, a waste stream containing 100 mg/L of a conservative pollutant is added to the reactor at a flow rate of 50 $\frac{\text{m}^3}{\text{day}}$. The volume of the reactor is 500 m^3. What is the concentration exiting the reactor as function of time after it is started.

Step 1:

Determine whether the system is at steady state or not.

Step 2:

Draw a mass balance diagram.

Step 3:

Write a mass balance equation:

Step 4:

Solve the mass balance equation:

Mass Balance–CMFR with Reactive Pollutant

CENG 340–Introduction to Environmental Engineering

Instructor: Deborah Sills

In Class: September 25, 2013

A tanker truck overturns on the highway and leaks 4545 kg of wastewater from a yoghurt production facility into a small lake. The wastewater is immediately and uniformly distributed throughout the lake. The lake has a volume of V = 10,000 m^3. A stream flows into and out of the lake at a flowrate of Q = 1000 $\frac{m^3}{day}$. Assume that bacteria present in the lake can degrade dairy waste with a first order rate coefficient of 0.005 day^{-1}. What is the concentration of the dairy waste in the lake as a function of time? Calculate how long it will take for the concentration of dairy waste in the lake to equal 5 percent of the initial concentration.

Step 1:

Draw a mass balance diagram, and label your diagram with given information and unknowns.

Step 2:

Write a general mass balance equation:

Step 3:

Determine whether the system is at steady state or not.

Step 4:

Determine whether reactions occur or if conservative.

Step 5:

Rewrite the mass balance equation based on your answers in Step 3 and Step 4, and solve for C = f(t):

Graphical Representation–PFR with Conservative Tracer

CENG 340–Introduction to Environmental Engineering
Instructor: Deborah Sills
In Class: September 25, 2013

This handout will help you in lab and with your lab assignment.

Graph (in a qualitative manner) the effluent concentration (as a function of time) that you expect to observe coming out of (a) an ideal PFR (**now**), (b) a real PFR (**after class**), and (c) a CMFR (**after class**), as a result of a pulse input of a conservative tracer as depicted in Figure 1. Note that to draw the effluent concentration from a **CMFR**, you need to write a mass balance equation and follow the steps outlined in the handout titled, "Completely Mixed Flow Reactors; Steps for solving mass balance problems in CMFRs"—which was handed out last week on Wednesday, 25 September.

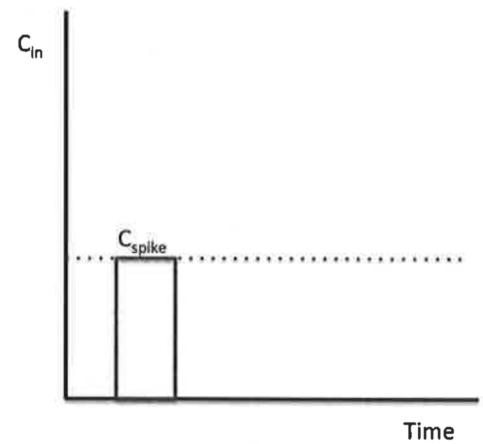

Figure 1: Influent concentration of a conservative tracer as a function of time.

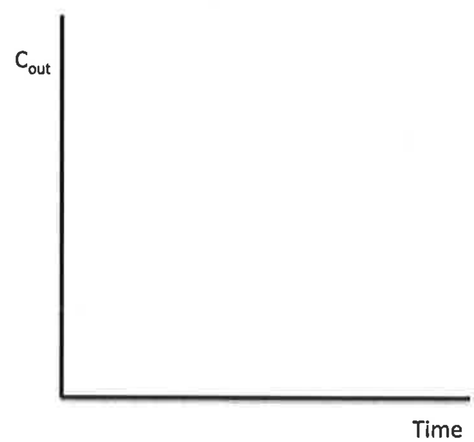

Figure 2: Effluent concentration of a conservative tracer from an ideal PFR as a function of time.

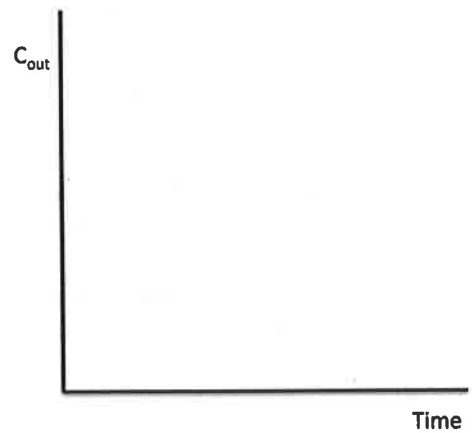

Figure 3: Effluent concentration of a conservative tracer from a real PFR as a function of time.

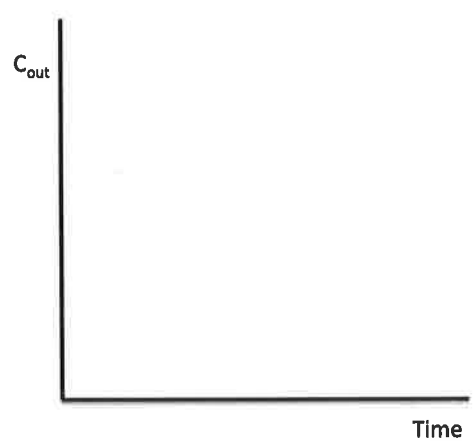

Figure 4: Effluent concentration of a conservative tracer from a CMFR as a function of time.

Mass Balance–PFR with Reactive Pollutant

CENG 340–Introduction to Environmental Engineering
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In Class: September 25, 2013

Preface: Biological Oxygen Demand (BOD) represents the potential effect of biodegradable organic carbon on oxygen depletion in natural and engineered systems.

Problem Statement: The concentration of BOD in a river just downstream of a sewage treatment plant's effluent pipe is 75 mg/L. If the BOD is destroyed through a first-order reaction with a rate constant equal to 0.05 day^{-1} what is the BOD concentration 50 km downstream. The velocity of the river is 15 km/day, and you can assume that the river behaves like a plug flow reactor.

Step 1:

Draw a mass balance diagram, ***draw and label the appropriate control volume for analyzing a PFR***, and label your diagram with given information and unknowns.

Step 2:

Write a general mass balance equation:

Step 3:

Determine whether there is flow in and out of the control volume, and whether reactions occur or if conservative.

Step 4:

Rewrite the mass balance equation based on your answer in Step 3, and solve for C_{BOD} 50 km downstream: