Problem Set 3

CEEG 340–Introduction to Environmental Engineering

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September 2, 2019

Due Date

Friday 13 September 2019

Learning Goals

1. Calculate chemical concentration in common constituent units such as "As N" for nitrogen.
2. Apply Henry's Law to calculate concentrations of volatile chemicals in air and water.
3. Calculate concentrations and pH of strong acids.
4. Apply equilibrium to calculate concentrations of weak acids and bases.
5. Calculate concentrations of alkalinity in units of eq/L and as $CaCO_3$.

Questions

1. **(8 pts) Working with units of "as N"**
   A small stream adjacent to a poultry farm, polluted with nitrogen, contains the following: 70 mg/L of NO_3^-, 100 mg/L of NH_4^+, and 0.5 mg/L of NH_3.

   (a) Calculate concentrations of the following chemicals present in the stream in units of mole/L
      i. NO_3^-
      ii. NH_4^+
      iii. NH_3
      iv. $NO_3^- + NH_4^+ + NH_3$

   (b) Calculate concentrations of the following chemicals present in the stream in units of $\frac{\text{mg-N}}{\text{L}}$:
      i. NO_3^-
      ii. NH_4^+
      iii. NH_3
      iv. $NO_3^- + NH_4^+ + NH_3$

   (c) Calculate concentrations of the following chemicals present in the stream in units of $\frac{\text{mole-N}}{\text{L}}$:

i. NO_3^-
ii. NH_4^+
iii. NH_3
iv. $NO_3^- + NH_4^+ + NH_3$

(d) Compare the values you calculated in parts (a) and (c) and explain similarities and/or differences.

2. **(8 points)** At 20 degrees C, the Henry's Constant for oxygen (O_2) is 769 $\frac{\text{atm•L}}{\text{mole}}$. What is the saturation concentration of O_2 (in units of mg/L) in a healthy stream? Note that the saturation concentration is the aqueous concentration at equilibrium.

3. **(8 points)** Researchers who study microbial degradation of vinyl chloride (VC) use small sealed glass bottles to keep VC from partitioning into the room air during experiments. Once, while I was working in a lab, a new master's student walked up to me to show me that her sealed bottle was open (true story). After the seal broke the bottle contained 3 mg of vinyl chloride in 60 mL of water.

   Assume the volume of air in the lab equaled 100 m^3 and that there was no ventilation (luckily that was not true), the temperature and pressure in the lab were 25 ^{0}C and 1 atm, respectively. In addition, Henry's Law Constant equals 26.8 $\frac{\text{L}\times\text{atm}}{\text{mole}}$.

   - Compare the equilibrium concentration of VC in the air to the 3-h air quality standard of $[VC]_{std} = 10$ ppm_v.
   - What should the new master's student have done, when she noticed the seal on the bottle that contained VC was open?

4. **(8 points)** Acid-Base Chemistry

   (a) What is the pH of of a 100 mL solution with 10 mg/L of sulfuric acid (H_2SO_4)?

   (b) What is the normality of the sulfuric acid solution (note that 1 normal (N) equals 1 eq/L)?

5. **(10 points)** (modified based on Mihelcic and Zimmerman) When Cl_2 gas is added to water during the disinfection of drinking water, it hydrolyzes water to form HOCl, a weak acid. The disinfection power of HOCl is 88 times better than its conjugate base OCl^-. The pK_a for HOCl is 7.5. If 15 mg of total HOCl was added per every liter of water being treated, what fraction of the HOCl is not dissociated to its conjugate base OCl^- and H^+?

6. **(9 pts)** Express 50 mg/L of HCO_3^- as:

   - equivalents/liter
   - moles/liter
   - milligram/liter as $CaCO_3$

7. **(8 points) FE Exam Formatted Problem** Estimate the approximate alkalinity, in mg/L as $CaCO_3$, of water with a carbonate ion concentration of 17.0 mg/L and a bicarbonate ion concentration of 111.0 mg/L.

(a) 119 mg/L as $CaCO_3$

(b) 128 mg/L as $CaCO_3$

(c) 148 mg/L as $CaCO_3$

(d) 146 mg/L as $CaCO_3$

Note that "approximate alkalinity" means that you should ignore $[OH^-]$ and $[H^+]$. Show your work even though you wouldn't have to for the FE.

8. **(9 pts)** (adapted from Mihelcic and Zimmerman) A researcher from ETH Zurich recently discovered a microbe that can degrade methylcylclohexanemethanol (MCHM). This microbe destroys MCHM with a rate that follows a first-order reaction with a rate constant of 0.01 day^{-1}.

   (a) How many days will it take for 90 percent of the MCHM to be destroyed?

   (b) How long will it take for 99 percent of the MCHM to be destroyed?

   (c) How long will it take for 99.9 percent of the MCHM to be destroyed?

9. **(12 pts)** A storage facility was abandoned 19 years ago. During its active life, oil was routinely spilled and historical records estimate that the oil concentration in the soil was as high as 400 mg/kg at the time the facility closed. Now a fast food chain wants to build a restaurant at this location. Soil samples indicate that the soil is still contaminated with 20 mg/kg of oil. A local engineer concludes that the oil is still being biodegraded by soil microbes at a rate of 20 mg/kg each year, and that in one more year, the site will be "oil–free."

   (a) *If* correct, what would be the technical basis for the engineer's conclusion? Note that you'll need to provide calculations to support your answer.

   (b) Now assume the engineer is wrong, provide appropriate "worst–case" calculations and determine how long it could take (from the time of facility shut–down) to reach a concentration of 1 mg/kg.

10. **(8 pts)** Derive the integrated form of a second order rate equation starting with the following differential form:

$$\frac{dC}{dt} = -kC^2 \tag{1}$$