CE 111 Midterm Exam 1 – Group A

October 05, 2020

Time: 45 minutes

Name Solution

Please write your name in the space provided above and sign the Berkeley Honor Code at the end.

This is an open-book/open-note exam. Communication with other students in any form is prohibited during the exam.

Answer questions in the space provided following each question. Use extra blank page if you need more room. Please make sure that you write the final answer in the box when provided.

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1. (1 point) The pH of a 20 mg/L NaOH solution is 10.7.

$M_w(NaOH) = 40\ g/mol$

$[NaOH] = 20\ mg/L \times \frac{1}{40\ g/mol} \times 10^{-3}\ g/mg = 5\times10^{-4}\ M$

$[OH^-] = 5\times10^{-4}\ M \quad [H^+] = \frac{10^{-14}}{[OH^-]} = 2\times10^{-11}\ M \quad pH = -\log(H^+) = 10.7$

2. (3 points) Please balance the following denitrification reaction:

5 HS^- + 8 NO_3^- + 3 H^+ → 5 SO_4^{2-} + 4 N_2 + 4 H_2O

1) Balance e^- transfer

HS^- : H +1, S −1−1=−2 $\qquad SO_4^{2-}$: O −2, S −2−4×(−2) = +6

$+6-(-2) = 8e^-$ was lost from each HS^-

NO_3^- : O −2, N −1−(−2×3) = +5 $\qquad N_2$: N 0

$5-0 = 5e^-$ was gained by each NO_3^-. To get N_2, need 2 NO_3^-.

$(HS^- \rightarrow SO_4^{2-} + 8e^-) \times 5$

$(2NO_3^- + 10e^- \rightarrow N_2) \times 4$

$\Rightarrow 5HS^- + 8NO_3^- + H^+ \rightarrow 5SO_4^{2-} + 4N_2 + H_2O$

Now balance charge using H^+ and balance all element:

$$5HS^- + 8NO_3^- + 3H^+ \rightarrow 5SO_4^{2-} + 4N_2 + 4H_2O$$

Approach 2:

Step 1: Write down two half-reactions:

$$HS^- \rightarrow SO_4^{2-}$$
$$NO_3{}^- \rightarrow N_2$$

Step 2: Balance the atoms that are oxidized/ reduced

$$HS^- \rightarrow SO_4^{2-}$$
$$2NO_3{}^- \rightarrow N_2$$

Step 3: For each of the half reactions

1) Balance the oxygen with H_2O

$$4H_2O + HS^- \rightarrow SO_4^{2-}$$
$$2NO_3{}^- \rightarrow N_2 + 6H_2O$$

2) Balance hydrogen with H^+

$$4H_2O + HS^- \rightarrow SO_4^{2-} + 9H^+$$
$$12H^+ + 2NO_3{}^- \rightarrow N_2 + 6H_2O$$

3) Balance charge with e^-

$$4H_2O + HS^- \rightarrow SO_4^{2-} + 9H^+ + 8e^-$$
$$10e^- + 12H^+ + 2NO_3{}^- \rightarrow N_2 + 6H_2O$$

Step 4: Multiply each half equation by an integer to make the number of e- in the two half reactions equal

$$(4H_2O + HS^- \rightarrow SO_4^{2-} + 9H^+ + 8e^-) \times 5$$
$$(10e^- + 12H^+ + 2NO_3{}^- \rightarrow N_2 + 6H_2O) \times 4$$

Step 5: Add up the two half reactions

$$\mathbf{5HS^- + 8NO_3{}^- + 3H^+ \rightarrow 5SO_4^{2-} + 4N_2 + 4H_2O}$$

3. (4 points) You have a bottle of carbonated water, which is manufactured by bubbling gaseous CO_2 through pure water. When it is bottled, the gas space in the bottle above the water contains only CO_2 at a pressure of 2 atm.

(a) What is the equilibrium pH of your carbonated water?
Note: $[H_2CO_3^*]$ in water is equivalent to $[CO_2]_{aq}$.

$H_2CO_3^* \Leftrightarrow H^+ + HCO_3^-$	pKa=6.35

pH= 3.24

$K_H = \frac{C_{CO_2}}{P_{CO_2}}$ $[H_2CO_3^*] = k_H \cdot P_{CO_2} = 0.37 \times 2$ atm $= 0.74$
mol/L·atm

$K_a = \frac{[H^+][HCO_3^-]}{[H_2CO_3^*]} = \frac{[H^+]^2}{[H_2CO_3^*]} = 10^{-6.35}$

$[H^+] = 5.75 \times 10^{-4}$

$pH = -\log(H^+) = 3.24$

(b) If you leave your unfinished carbonated water on a picnic table for a few hours, will you expect the pH of your water to increase, decrease, or remain the same? No need of quantitative calculation; please briefly explain.

The pH will increase because the water is now equilibrate with atmosphere. P_{CO_2} in air is much smaller than P_{CO_2} in bottle, thus $[H_2CO_3^*]$ will decrease and $[H^+]$ will decrease.

4. (5 points) The influent water to a drinking water treatment plant contains 24 mg/L of Mg^{2+}. In a softening process, the pH of the water was adjusted to 11.
(a) Will $Mg(OH)_2$ precipitate out of the solution? If it does, please estimate the equilibrium concentration of Mg^{2+} at pH 11.

Magnesium hydroxide	$Mg(OH)_2$ (s) ⇔ $Mg^{2+} + 2OH^-$	pKs=11.25

at pH 11 $[OH^-] = \frac{10^{-14}}{[H^+]} = \frac{10^{-14}}{10^{-11}} = 10^{-3}$

0.135 mg/L

$K_s = 10^{-pK_s} = [Mg^{2+}] \cdot [OH^-]^2$

$[Mg^{2+}] = \frac{10^{-11.25}}{(10^{-3})^2} = 10^{-5.25}$ M

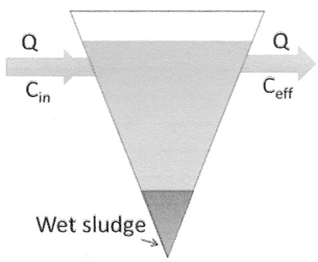
Yes it will precipitate

$M_w(Mg) = 24$ g/mol

$[Mg^{2+}] = 24 \times 10^{-5.25} = 0.135$ mg/L $\ll 24$ mg/L

(b) Assuming the $Mg(OH)_2$ precipitate completely settled to the bottom of a settling tank as illustrated below, it forms a wet sludge accumulated in the bottom contains 20% (w/w) $Mg(OH)_2$ (s). The settling tank operates with a steady flow of 20 m^3/h, and the effluent Mg^{2+} concentration remains constant at the equilibrium concentration. If the maximum sludge capacity of the tank is 1000 kg of wet sludge, how often does the operator need to remove sludge from the tank?

173.4 h



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Sludge accumulation rate:

$$\dot{M}_{Sludge} = \frac{dM_{Mg(OH)_2}}{dt} \cdot \frac{1}{20\%} = (Q_{in}C_{in} - Q_{out}C_{out})/0.2$$

$$Q_{out} = Q_{in}$$

$$M_w(Mg(OH)_2) = 24 + (16+1) \times 2 = 58g/mol$$

$$C_{in} - C_{out} = Mg(OH)_{2(s)} = \left(\frac{24mg/L \times 10^{-3}g/mg}{24g/mol} - 10^{-5.25}M\right) \times 58g/mol = 0.058g/L$$

$$\dot{M}_{Sludge} = 20m^3/h \times \frac{0.058g/L}{0.2} \times 10^3 L/m^3 = 5768g/h$$

Time when sludge reached capacity:

$$\frac{1000kg}{5768g/h} \times 10^3 g/kg = 173.4h$$

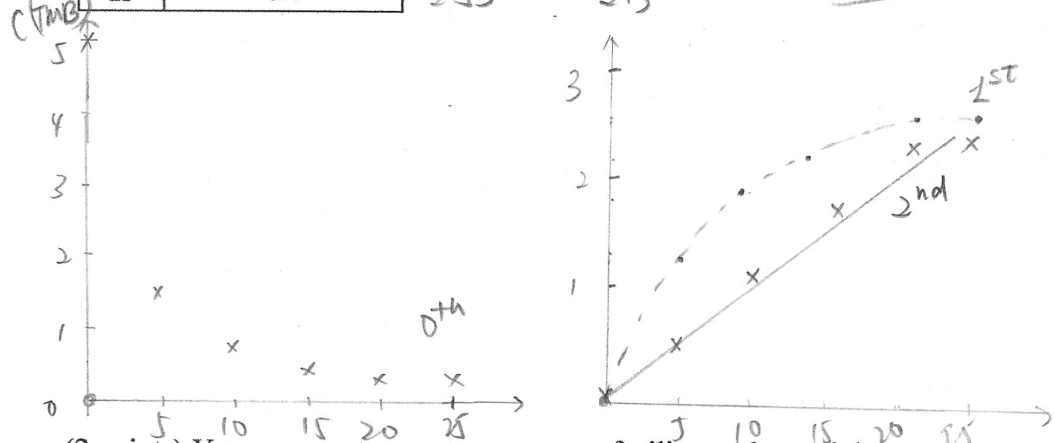
5. (3 points) A batch reactor experiment was performed to characterize the kinetics of TMB removal by oxidation. The data are listed in the following table. Please graphically determine order of reaction and the rate constant with clearly labeled unit.

Time (Min)	Concentration of TMB (mg/L)	$\ln(C_0/C)$	$\frac{1}{C}-\frac{1}{C_0}$
0	5.0	0	0
5	1.4	1.27	0.51
10	0.8	1.83	1.05
15	0.6	2.12	1.47
20	0.4	2.53	2.3
25	0.4	2.53	2.3

k = 0.099 $(mg/L)^{-1} \cdot min^{-1}$

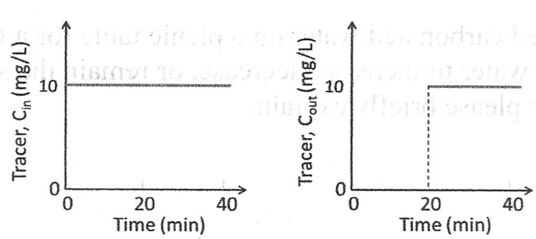
or L/(mg·min)

2nd order



6. (2 points) You are new to a water treatment facility, and your job is to operate a reactor for TMB removal. You know the flowrate through your reactor is 2500 L/min. However, the dimension or volume of the reactor was nowhere to find. So, you decided to run a tracer test by continuously dosing a tracer into the influent and monitoring tracer concentration in the effluent. After obtaining the data, you plotted them in the following graph. Can you calculate your reactor volume based on the tracer results?

50 m^3



This is a PFR with non-reactive tracer

$\theta = 20\,min = \frac{V}{Q}$

$V = 20\,min \times 2500\,L/min \times 10^{-3}\,m^3/L = 50\,m^3$

7. (3 point) With the information on kinetics from Problem 5 and reactor from Problem 6, could you please predict if the effluent concentration would be able to meet the EPA regulation of [TMB] < 1 mg/L? The TMB concentration in the influent is 20 mg/L.

PFR with 2nd order reaction:

$$\frac{1}{C_{out}} - \frac{1}{C_0} = k \cdot \theta$$

$\theta = 20$ min $k = 0.099\ (mg/L)^{-1} min^{-1}$

$C_{in} = 20 mg/L$

Solve for Cout: $C_{out} = \frac{1}{(0.099 \times 20)(mg/L)^{-1} + \frac{1}{20 mg/L}} = \boxed{0.49\ mg/L} < 1 mg/L$

Yes it meets the EPA regulation

Signature:______________________________

I pledge my honor that I have not violated the Berkeley Honor Code during this examination.

This is the end of the exam.