CE 111 Midterm Exam 2

November 13, 2020

Time: 45 minutes

Name Solution

12:50 - 1:20

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.

For problems that require calculations, you must clearly show the steps that you used in arriving at the answer. For such problems, presenting only the final answer without relevant steps will not be given any credit.

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1. (4 points) Please calculate the hardness and alkalinity of the following water.

(a) Total Hardness: 150 mg/L as $CaCO_3$.

Component	C (mg/L)
Ca^{2+}	40
Mg^{2+}	12
HCO_3^-	183
Cl^-	71
K^+	19.5
pH7	

$TH = N_{Ca} + N_{Mg}$

$= 50 \frac{mg\ CaCO_3}{meq} \times \left(\frac{40\ mg/L}{40\ g/mol} \times 2\ eq/mol + \frac{12\ mg/L}{24\ g/mol} \times 2\ eq/mol\right)$

$= 150\ mg/L$ as $CaCO_3$

(b) Alkalinity: 150 mg/L as $CaCO_3$.

$Alk = [OH^-] + [HCO_3^-] + 2[CO_3^{2-}] - [H^+] = \left(10^{-7} - 10^{-7} + \frac{183\ mg/L}{61\ g/mol} \times 1\ eq/mol\right) \times 50 \frac{mg\ CaCO_3}{meq}$

$= 150\ mg/L$

(c) There is one major common ion missing from the table. It is Na^+, and the concentration is 34.5 mg/L.

$Anion = N_{HCO_3^-} + N_{Cl^-} = \frac{183}{61} \times 1 + \frac{71}{35.5} \times 1 = 5\ meq/L$

$Cation = N_{Ca^{2+}} + N_{Mg^{2+}} + N_{K^+} = \frac{40}{40} \times 2 + \frac{12}{24} \times 2 + \frac{19.5}{39} \times 1 = 3.5\ meq/L$

$Anion - Cation = 1.5\ meq/L$. Missing cations

$C_{Na^+} = \frac{1.5\ meq/L}{1\ eq/mol} \times 23\ g/mol = 34.5\ mg/L$

2. (5 points) Wastewater containing BOD = 150 mg/L is discharged at a rate of 1.5 m^3/s into a river that flows at a rate of 8 m^3/s. Upstream of the discharge, the river is saturated with dissolved oxygen (DO = 10.8 mg/L) and contains no BOD. The wastewater has the same temperature of the river water and is also saturated with dissolved oxygen. The deoxygenation rate constant due to BOD degradation in the river is 0.2 day^{-1}. The reoxygenation rate constant for the river is 0.3 day^{-1}.

(a) Downstream of the discharge, can the river still provide a healthy environment (i.e., DO > 5 mg/L) for fish? Please use quantitative calculation to support your conclusion.

$Q_1 = 8\ m^3/s$ →, $BOD_1 = 0$, $DO_1 = 10.8\ mg/L$

↓ $Q_2 = 1.5\ m^3/s$, $BOD_2 = 150\ mg/L$, $DO_2 = 10.8\ mg/L$

$k_1 = 0.2/d$, $k_2 = 0.3/d$

$DO_0 = 10.8\ mg/L$

$BOD_0 = \frac{0 \times 8 + 150 \times 1.5}{8 + 1.5} = 23.68\ mg/L$

$D_0 = 0$ (saturated state)

$D = \frac{k_1 BOD_0}{k_2 - k_1} \times (e^{-\frac{k_1 x}{u}} - e^{-\frac{k_2 x}{u}})$

Solve for $\frac{x}{u}$:

$-\frac{k_1}{u} e^{-k_1 x/u} + \frac{k_2}{u} e^{-k_2 x/u} = 0$

$\frac{k_1}{k_2} = e^{-k_2 x/u} / e^{-k_1 x/u} = e^{\frac{x}{u}(k_1 - k_2)}$

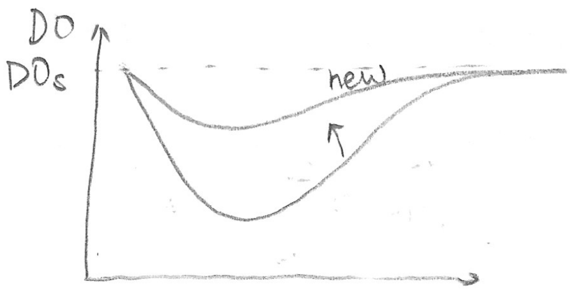
$\ln(\frac{k_1}{k_2}) = \frac{x}{u}(k_2 - k_1)$, $\frac{x}{u} = \frac{\ln\frac{0.2}{0.3}}{0.2 - 0.3}$

$\frac{x}{u} = 4.05$

max. $D = \frac{dD}{dx} = 0$ $\quad \frac{dD}{dx} = \frac{k_1 BOD_0}{k_2 - k_1} \times (-\frac{k_1}{u} e^{-\frac{k_1 x}{u}} + \frac{k_2}{u} e^{-\frac{k_2 x}{u}}) = 0$

$\Rightarrow \frac{x}{u} = 4.05$. $D_{max} = \frac{0.2 \times 23.68}{0.3 - 0.2} \times (e^{-0.2 \times 4.05} - e^{-0.3 \times 4.05}) = 7.02$ $\quad DO_{min} = DO_s - D_{max} = 3.78 < 5 \Rightarrow$ No

(b) Please sketch the oxygen sag curve with Time and DO as the x-axis and y-axis, respectively. If a wastewater treatment facility is installed to remove half of the BOD before discharging the wastewater into the river, how will the new oxygen sag curve shift? You only need to illustrate the relative positions of the two curves. No need of quantitative calculation.



DO will not decrease as much for new sag curve (DO_{min}-new curve < DO_{min}-old curve

3. (4 points) A wastewater treatment facility has a flowrate of 0.3 m^3/s through a sedimentation tank with L=30m (length), W=5m (width), and H=3.0m (depth). (a) For spherical particles with a density of 2.4 g/cm^3 and a diameter of 50 μm, what is the removal efficiency? Here are some parameters that you could use: gravity $g = 980$ cm/s^2, dynamic viscosity of water $\mu = 0.01$ g/cm/s, and water density of 0.998 g/cm^3.

95 %

From stock's law:

$$V_{(50\mu m)} = \frac{d_p^2 \cdot g (\rho - \rho_f)}{18\mu} = \frac{(50\times10^{-6}m)^2 \times 9.8 m/s^2 \times (2.4 - 0.998)\times10^3 kg/m^3}{18 \times 0.01 g/cm/s \times 10^{-3} kg/g \times 10^2 m/cm}$$

$$V_{(50\mu m)} = 1.9\times10^{-3} m/s$$

$$V_c = \frac{Q}{A_s} = \frac{Q}{L\times W} = \frac{0.3 m^3/s}{30\times5 m^2} = 2\times10^{-3} m/s$$

$$\eta = \frac{V}{V_c} = \frac{1.9\times10^{-3}}{2\times10^{-3}} = 95\%$$

(b) If the depth of the reactor is increased to 5 m, will the particle removal efficiency be improved?

No. Because Vc is independent of tank depth

4. (6 points) A contaminated ground water aquifer contains 5 mg/L TCE. A drinking water facility plans to use powdered activated carbon (PAC) in a well-mixed reactor to treat the groundwater. The maximum contaminant level (MCL) established by EPA for TCE in drinking water is 0.01 mg/L. The equilibrium adsorption isotherm for TCE on PAC1 is $q = 34C^{0.65}$, where q is in mg-TCE per gram of carbon, and C is in mg/L.

(a) Please calculate the PAC1 dosage to treat the ground water in order to meet EPA requirement.

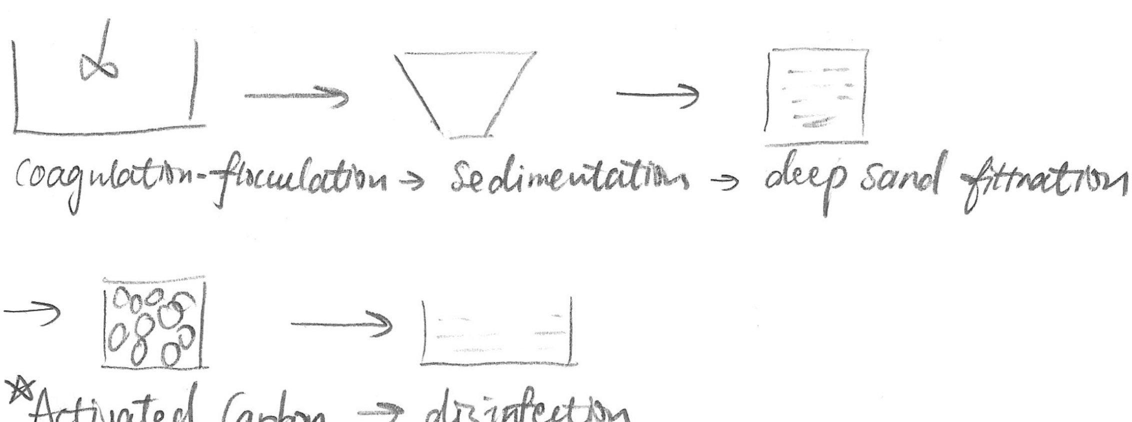
$C_{fin} = 0.01$ mg/L

$q_{fin} = 34 \times C_e^{0.65} = 34 \times 0.01^{0.65} = 1.7$ mgTCE/gPAC

From mass balance:

$$\frac{W}{V} = \frac{C_{init} - C_{fin}}{-(q_{init} - q_{fin})} = \frac{(5 - 0.01)\ \text{mgTCE/L}}{-(0 - 1.7)\ \text{mgTCE/gPAC}} = 2.93\ \text{gPAC/L}$$

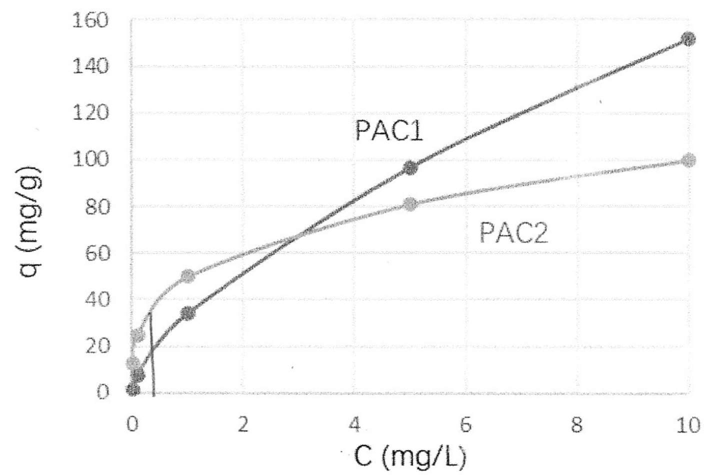
(b) Please draw a diagram to illustrate the typical drinking water treatment process and explain how and where you would apply the PAC for TCE removal.



PAC will be dosed into the coagulation tank, and the PAC would be removed in the sedimentation tank and media filtration

Or: PAC will be used in “”Activated Carbon” step which will be added to water as a slurry upstream of the granular filter

(c) If you get another activated carbon (PAC2) and its isotherm for TCE removal is plotted in the following graph together with the isotherm of PAC1. Which PAC will demand less activated carbon dosage? Just briefly explain. No need to show any calculation.



PAC₂ is better than PAC₁ because at C = 0.01 mg/L, $q_{PAC_2} > q_{PAC_1}$

since $\frac{W}{V} = \frac{\Delta C}{-\Delta q}$, PAC₂ will require less dosage to treat the ground water

5. (1 point) Algal bloom has been causing dead zones in Chesapeake Bay every Spring. Researchers have found that the algal bloom is nitrogen limited. Which of the following measure would be effective in controlling the algal bloom. Please choose all that apply.

   (a) Enhancing the nitrogen removal efficiency in a wastewater treatment plant that discharge wastewater to the Bay.

   (b) Enhancing the phosphorous removal efficiency in a wastewater treatment plant that discharge wastewater to the Bay.

   (c) Enhancing the BOD removal efficiency in a wastewater treatment plant that discharge wastewater to the Bay.

   (d) Installing stormwater treatment process to reduce fertilizer runoff from farms around the Bay.

Signature:____________________________________

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

This is the end of the exam.