CEE 371	November 23, 2009

Exam #2

Please grade the following questions:

1, 2, 3
6, 7, 8

Circle two from each row. You must answer 4, 5, 9 and 10

Closed Book, two sheets of notes allowed
Please answer questions 4, 5, 9 and 10. In addition, answer two questions from 1-3 and two from 6-8. The total potential number of points is 100. Show all work. Be neat, and box-in your answer.

A. Water Quality & Regulations: Answer any 2 of the following 3 questions (5 points each)

1. Standards

What does the multiple barrier approach refer to? Explain. (5 points)

- Use of several methods to protect the public from drinking water contaminants. For example, one can use (1) watershed protection, (2) filtration, and (3) disinfection with chlroine to protect the public from pathogens. Multiple barriers require multiple failure modes to cause excess risk to humans.

2. Definition 1

How are primary and secondary drinking water standards different? Give two examples of each. (5 points)

- Primary standards: enforceable, relate to human health
    - Examples: Crypto, Giardia, Arsenic, Nitrate, Lead
- Secondary standards: not enforceable, not health related, pertain to aesthetics
    - Examples, Taste & Odor, Iron, Manganese, color

3. Definition 2

Define the term "pathogen", and give two examples. (5 points)

- Organisms (or more generally, "infectious agents") that cause disease; human pathogens are then organisms that cause disease in humans. Examples of pathogens are Giardia species, Cryptosporidium species.

B. <u>Disinfection</u>: Answer both question #4 and question #5 (30 points total)

4. Disinfection Effectiveness (7 points)

Name 4 different disinfectants used in drinking water treatment. Discuss the relative efffectivenss of each and the pros and cons of using the 4 you have named. (7 points)

- Chlorine or "free chlorine"
  - Pros: effective with all but protozoan cysts
  - Cons: forms THMs, HAAs,

- Chloramines, or "combined chlorine"
  - Pros: maintains residual, doesn't produce much THMs or HAAs
  - Cons: not effective as a primary disinfectant, can cause tastes & odors, may result in elevated lead levels

- Ozone:
  - Pros: most effective of the disinfectants, has other benefits such as improved filtration, maybe coagulation
  - Cons: doesn't maintain a long lived residual, may stimulate biogrowth (than can be an advantage too), costly, energy intensive, produces bromate in some waters

- Chlorine dioxide:
  - Pros: powerful disinfectant, almost as powerful as ozone, does not produce THMs or HAAs
  - Cons: produces chlorite, can cause some taste & odor problems

- UV light:
  - Pros: doesn not require large contactors or long contact times, very effective with protozoan cysts
  - Cons: doesn't result in a lasting residual, not very effective with viruses

5. Tracer Problem (23 points)

The hydraulics of the disinfection contact tank at a water treatment plant are described by Figure 1 showing continuous (or step) input tracer study results (C_{out}/C_0 vs. time) for a flow of 1.5 MGD at a mean hydraulic detention time of 42 minutes. Some US EPA stipulated requirements for "Ct" values are described in Table 1.

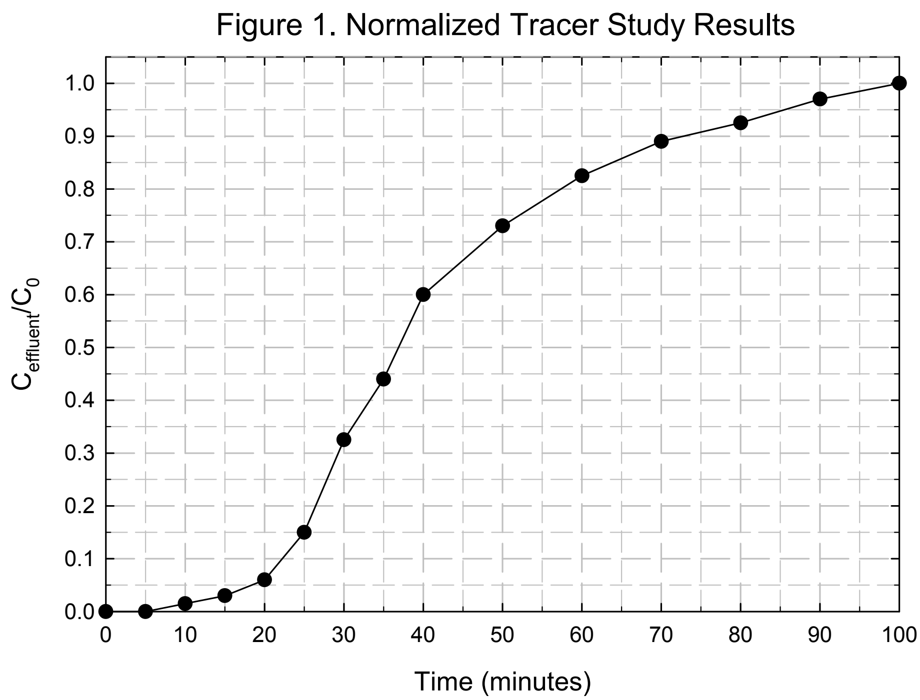

Table 1.

Disinfectant	**Ct values (mg L^{-1} min) for *Giardia* Inactivation, water temp of 5°C**	
	1 log	**3 log**
Free Chlorine, pH=6.0	35	105
Free Chlorine, pH=8.0	72	216
Chlorine Dioxide	8.7	26
Ozone	0.63	1.9
Chloramine	735	2200

(Ignore any chlorine concentration effects on Ct.)

a) **(7 Pts)** Name the two chemical forms of free chlorine. Calculate the ratio of the concentrations of the two forms at pH 6 and also at pH 8.

The two forms of chlorine are **Hypochlorite anion (OCl^-)** and **Hypochlorous Acid (HOCl)**.

The ratios can be readily calcuated from the equilibrium quotient.

$$K_a = 10^{-7.5} = \frac{[H^+][OCl^-]}{[HOCl]}$$

Rearranging, you get:

$$\frac{10^{-7.5}}{[H^+]} = \frac{[OCl^-]}{[HOCl]}$$

So, for pH=6 ($[H^+]=10^{-6}$), we get:

$$\frac{[OCl^-]}{[HOCl]} = 10^{-1.5} = \mathbf{0.0316}$$

And for pH=8 ($[H^+]=10^{-8}$), we get:

$$\frac{[OCl^-]}{[HOCl]} = 10^{+0.5} = \boxed{\mathbf{3.16}}$$

b) **(7 Pts)** If you needed to achieve 1 log inactivation of *Giardia*, how much of a dose would you need if you were going to use chlorine at pH 8. Assume the reactor hydraulics shown in Figure 1 represent those of your contact tank. Also, assume that the chlorine demand is 0.9 mg/L and you're calculating this for a water temperature of 5 ºC.

In this case you'll need 1-log removal, which corresponds to a Ct of 72 min-mg/L. The "t" in Ct is actually the t_{10}. From Figure 1, we can read the t_{10} as about 22 minutes. Therefore the minimum allowable chlorine residual is:

$$C = \frac{Ct}{t_{10}} = \frac{72}{22} = 3.27\ mg/L$$

And with a chlorine demand of 0.9 mg/L, you'll need to add

Dose = 3.27 + 0.9 = **4.17 mg/L**

To overcome the demand and provide adequate residual

c) **(5 Pts)** Assume you're treating a groundwater with 1.2 mg/L of ferrous iron. Also assume you have essentially no other reduced substances, nor any appreciable organic carbon. Estimate the chlorine demand. Show your work.

From Lecture #14, we have the following mass-based calculation:

$$\begin{aligned} Inorganic-Demand &= 1.3(Mn^{+2}) + 0.63(Fe^{+2}) + 8.8(HS^-) + 7.6(NH_4^+) \\ &= 0.63(1.2) \\ &\boxed{= 0.76mg/L} \end{aligned}$$

d) **(2 Pts)** What are the two most commonly used secondary disinfectants?.

Chlorine or "Free chlorine" and **Chloramines** or "Combined Chlorine"

e) **(2 Pts)** Name two specific treatment processes that can be used to provide a barrier against pathogen contamination of drinking water without the addition of treatment chemicals.

Examples:

- Coagulation & settling
- flotation
- Granular media Filtration
- Membrane filtration
- UV light

C. Coagulation and Flocculation: Answer any 2 of the following 3 questions (6 points each)

6. Coagulants (6 points)

The design flow for a water treatment plant (WTP) is 0.5 MGD (1.9×10^3 m^3/d). Jar testing shows that the best alum dosage will be 40 mg/L. What is the quantity of alum needed on a daily basis in kg/d? Name one other common coagulant that you might want to test with this water.

First, recall that mg/L is the same as g/m^3, because there are 1000 milligrams in a gram and 1000 liters in a cubic meter.

$$\text{Mass} = QxC = 1.9 \times 10^3\ m^3/d\ (40 g/m^3)$$
$$= 75{,}700\ g/d$$
$$= \underline{\mathbf{75.7\ kg/d}}$$

Other coagulants:

- Ferric Sulfate
- Ferric Chloride
- PACl (poly aluminum chloride)

7. Power (6 points)

What power input (in kW) is required to achieve a mixing intensity (G) of 550 sec^{-1} in a mechanical rapid mixing tank with a mean hydraulic detention time of 50 seconds at a water flow of 0.5 MGD (1.9×10^3 m^3/d)? Assume a water temperature of 10 ºC.

Recall that:

$$P = \mu V G^2$$

So first we need to calculate the tank volume from the flow and detention time.

$$V = Qt_R = 1900\frac{m^3}{d}50sec\left(\frac{1min}{60sec}\right)\left(\frac{1hr}{60min}\right)\left(\frac{1d}{24hr}\right) = 1.10m^3$$

Now plug into the power equation

$$P = 0.001307\frac{Kg}{m-s}1.10m^3(550s^{-1})^2 = 434.7\frac{Kg-m^2}{s^2}$$

And note that these units are identical to those of Watts, so the answer is:

P = 434.7 watts

or

P = 0.435 KW

8. Flocculation Design (6 points)

Consider the flocculation process used in drinking water treatment:

a) What is the main objective of this treatment process, and what is a typical design value for the mean hydraulic detention time of the process?

- Contact opportunities for interparticle attachment and particle growth
- 30 minutes is typical

b) Name three different ways you can increase the degree of mixing in a flocculation tank with horizontal shaft paddle flocculators

- higher rotational speed
- more paddles per arm
- longer hydraulic residence time
- larger paddles

D. <u>Settling and Filtration</u>: Answer both question #9 and #10 (48 points total)

9. Settling (30 points)

A single rectangular sedimentation basin is to be designed to treat a water flow of 0.5 MGD at the design overflow rate of 800 gpd/ft^2 .

a) (10 Pts) Determine the basin dimensions (width, length, depth) for a detention time of 5 hours and a length to width ratio of 3 to 1. (use English units)

First calculate area from overflow rate (V_o or OFR) and flow (Q)

$$A = \frac{Q}{V_o} = \frac{0.5x10^6\frac{gal}{d}}{800\frac{gal}{day-ft^2}} = 625ft^2$$

The depth is determined by the area just calculated and the volume, which we can get from the flow and retention time.

$$V = Qt_R = 0.5x10^6 \frac{gal}{d} 5hr \left(\frac{0.133ft^3}{gal}\right)\left(\frac{1d}{24hr}\right) = 13{,}854ft^3$$

$$Depth = \frac{V}{A} = \frac{13{,}854ft^3}{625ft^2} = 22.17ft$$

So the area is just W*L or $3W^2$, because L/W =3, and

$$Width = \sqrt{\frac{A}{3}} = \sqrt{\frac{625ft^2}{3}} = 14.43ft$$

And

Length = 3*Width = 3*14.43ft = 43.30 ft.

So in summary:

depth =	**22.17**	**ft**	**~23**
width =	**14.43**	**ft**	**~15**
length =	**43.30**	**ft**	**~44**

b) (10 Pts) Assuming the sedimentation tank behaves like an ideal plug flow reactor, determine the diameter that corresponds to a particle that will be 50% removed by this tank. Assume your particle has a density of 1100 kg/m^3 and tha the water temperature is 10 ºC.

Recognize that to be 50% removed, the particle has to settle at a rate of 2xOFR or less. This is because when a particle of a given size settles at the OFR, even those particles that enter at the top of the tank will reach the bottom by the time the flow reaches the outlet. Particles that are 50% removed are those that just make it to the bottom by the time they reach the end when they enter at 50% depth. Particles of this critical size that enter below the 50% depth point will be completely removed, and those that enter above will be swept over the effluent weir.

So the critical settling velocity will be:

$$v = 2xOFR = 2x800 \frac{gal/day}{ft^2}\left(\frac{0.133ft^3}{gal}\right)\left(\frac{1day}{24x60x60sec}\right)\left(\frac{m}{3.28084ft}\right) = 7.507x10^{-4}\frac{m}{sec}$$

And the Stokes Equation:

$$D_p = \sqrt{\frac{v18\mu}{g(\rho_p - \rho_w)}}$$

$$= \sqrt{\frac{7.507x10^{-4}\ {}^{m}\!/_{s}\,(18)0.001307\ {}^{kg}\!/_{m-s}}{9.80665\ {}^{m}\!/_{s^2}\,(1100-999.7)\,{}^{kg}\!/_{m^3}}}$$

$$= \sqrt{\frac{1.766x10^{-5}\ {}^{kg}\!/_{s^2}}{983.6\ {}^{kg}\!/_{m^2s^2}}}$$

$$= \sqrt{1.796x10^{-8}m^2}$$

$$= 1.34x10^{-4}m$$

$$= 0.134mm$$

Note: be careful not to confuse the velocity with kinematic viscosity. They commonly use the same symbol.

c) **(5 Pts)** If the flow rate to the sedimentation tank doubled, and if the depth of the tank was doubled as well, would the particle removal efficiency decrease, stay the same, or increase? Briefly explain.

This would cause a **decrease in efficiency**, because of the increase in OFR. Depth by itself doesn't have an impact.

d) **(5 Pts)** Suppose you decided to convert the gravity settling tank to a dissolved air flotation process, incorporating a flotation tank the same size as the settling tank. Would the efficiency of particle removal, increase, decrease or stay the same. Explain your answer.

This would result in an **increase in efficiency**, because DAF uses air with a density of zero to float particles. Therefore the density difference with water is of a much greater magnitude as compared to most particles that settle. Note that the density difference is of the opposite sign. This is why it floats, instead of settles.

10. Filtration (18 points)

Consider the design and use of a dual media filter for drinking water treatment with the following characteristics:

- Anthracite Layer
  24 inch depth
  Effective Size (ES): 1.1 mm
  d_{60} size: 1.45 mm
  Porosity: 0.40

  Sand layer
  12 inch depth
  ES: 0.50 mm
  d_{60} size: 0.60 mm
  Porosity: 0.38

a) (2 Pts) What is the value of the Uniformity Coefficient for the anthracite media?

The UC is simply calculated as the ratio of the d_{60} to the d_{10} (or ES)

$$UC = \frac{1.45}{1.1} = 1.32$$

b) (3 Pts) If the design hydraulic loading rate is 5 gpm/ft^2, what is the approach, or superficial, velocity? Express in units of ft/min.

$$v_o = 5\frac{gal/min}{ft^2}\left(0.133\frac{ft^3}{gal}\right) = 0.667\frac{ft}{min} = 0.0111\frac{ft}{s}$$

c) (4 Pts) Calculate the detention time (in minutes) throught the entire depth of the filter at the design hydraulic loading rate of 5 gpm/ft^2.

Note; Actual "pore velocity" is equal to the superficial velocity divided by the porosity

Anthracite layer

$$t_R = \frac{depth}{velocity} = \frac{2ft}{0.667\frac{ft}{min}/0.40} = 1.20\ min$$

Sand layer

$$t_R = \frac{depth}{velocity} = \frac{1ft}{0.667\frac{ft}{min}/0.38} = 0.57\ min$$

Entire Filter

$$t_R = 1.20\ min + 0.57\ \text{min} = 1.77\ min$$

d) (7 Pts) At the design hydraulic loading rate, what is the clean bed head loss for the for the entire filter for a water temperature of 60 ºF? Use the Carmen-Kozeny equation with k = 5, and use the d_{60} value for media size.

The Carmen-Kozeny equation is:

$$\frac{\Delta H}{L} = \frac{36k(1-\varepsilon)^2 \nu V_0}{\varepsilon^3 d_c^2 g}$$

where ε = porosity, ν=kinematic viscosity, V_0 = filtration rate, d_c = mean media diameter, ΔH=clean bed head loss, L = bed depth, k= constant (4-5)

$$\Delta H = L\frac{36k(1-\varepsilon)^2 \nu V_0}{\varepsilon^3 d_c^2 g}$$

First the anthracite layer:

$$\Delta H = 2\,ft\,\frac{36(5)(1-0.40)^2 1.217x10^{-5}\,{}^{ft^2}\!/_{s}\left(0.01111\,{}^{ft}\!/_{s}\right)}{(0.40)^3(0.004757\,ft)^2\,32.2\,{}^{ft}\!/_{s^2}}$$

ΔH = <u>0.376</u> ft

Or if you kept metric units, it is:

$$\Delta H = 0.6096m\,\frac{36(5)(1-0.40)^2 1.1306x10^{-6}\,{}^{m^2}\!/_{s}\left(0.003386\,{}^{m}\!/_{s}\right)}{(0.40)^3(0.00145m)^2\,9.81\,{}^{m}\!/_{s^2}}$$

ΔH = 0.1146 m

Next the sand layer:

$$\Delta H = 1\,ft\,\frac{36(5)(1-0.38)^2 1.217x10^{-5}\,{}^{ft^2}\!/_{s}\left(0.01111\,{}^{ft}\!/_{s}\right)}{(0.380)^3(0.001969\,ft)^2\,32.2\,{}^{ft}\!/_{s^2}}$$

ΔH = <u>1.368</u> ft

And finally, the sum:

ΔH = 0.376 ft + 1.368 ft = <u>**1.744**</u> ft

e) (2 Pts) What is the unit filter run volume (UFRV) if the filter run length is 48 hours?

$$UFRV = 5\frac{\frac{gal}{min}}{ft^2}x48hr\frac{60min}{hr} = 14{,}400\frac{gal}{ft^2}$$

Good stuff to know

Conversions
7.48 gallon = 1.0 ft^3 1 gal = $3.7854x10^{-3}$ m^3
1 MGD = 694 gal/min = 1.547 ft^3/s = 43.8 L/s
1 ft^3/s = 449 gal/min
g = 32 ft/s^2
W=γ = 62.4 lb/ft^3 = 9.8 N/L
1 hp = 550 ft-lbs/s = 0.75 kW
1 mile = 5280 feet 1 ft = 0.3048 m
1 watt = 1 N-m/s
1 psi pressure = 2.3 vertical feet of water (head)
At 60 ºF, $\nu = 1.217 \times 10^{-5}$ ft^2/s

Water Properties:
At 60 ºF, $\nu = 1.217 \times 10^{-5}$ ft^2/s , $\mu = 2.359 \times 10^{-5}$ lb-sec/ft^2 , γ = 62.4 lb/ft^3
At 10 ºC, $\nu = 1.306 \times 10^{-6}$ m^2/s , $\mu = 1.307 \times 10^{-3}$ kg/m-s , ρ = 999.7 kg/m^3

Chemistry
K_a for free chlorine is $10^{-7.5}$

PHYSICAL AND CHEMICAL CONSTANTS

Avogadro's number	$\mathcal{N} = 6.022 \times 10^{23}\ \text{mol}^{-1}$
Elementary charge	$e = 1.602 \times 10^{-19}\ \text{C}$
Gas constant	$R = 8.314\ \text{J mol}^{-1}\ \text{K}^{-1}$
	$= 1.987\ \text{cal mol}^{-1}\ \text{K}^{-1}$
	$= 0.08205\ \text{L atm mol}^{-1}\ \text{K}^{-1}$
Planck's constant	$h = 6.626 \times 10^{-34}\ \text{J s}$
Boltzmann's constant	$\mathbf{k} = 1.381 \times 10^{-23}\ \text{J K}^{-1}$
Faraday's constant	$F = 9.649 \times 10^{4}\ \text{C mol}^{-1}$
Speed of light	$c = 2.998 \times 10^{8}\ \text{m s}^{-1}$
Vacuum permittivity	$\varepsilon_0 = 8.854 \times 10^{-12}\ \text{J}^{-1}\ \text{C}^2\ \text{m}^{-1}$
Earth's gravitation	$g = 9.806\ \text{m s}^{-2}$

CONVERSION FACTORS

1 cal	= 4.184 joules (J)
1 eV/molecule	$= 96.485\ \text{kJ mol}^{-1}$
	$= 23.061\ \text{kcal mol}^{-1}$
1 wave number (cm^{-1})	$= 1.1970 \times 10^{-2}\ \text{kJ mol}^{-1}$
1 erg	$= 10^{-10}\ \text{kJ}$
1 atm	$= 1.01325 \times 10^{5}\ \text{Pa}$
1 Å	$= 10^{-10}\ \text{m}$
1 L	$= 10^{-3}\ \text{m}^3$

PROPERTIES OF WATER

T(°C)	ρ, Density ($\text{kg} \cdot \text{m}^{-3}$)	μ Viscosity ($\text{kg} \cdot \text{m}^{-1} \cdot \text{s}^{-1}$)	σ, Surface Tension against Air ($\text{J} \cdot \text{m}^{-2}$)	ε Dielectric Constant ($\text{C} \cdot \text{V}^{-1} \cdot \text{m}^{-1}$)	pK_w, Ionization Constant ($\text{mol}^2 \cdot \text{L}^{-2}$)
0	999.868	0.001787	0.0756	88.28	14.9435
5	999.992	0.001519	0.0749	86.3	14.7338
10	999.726	0.001307	0.07422	84.4	14.5346
15	999.125	0.001139	0.07349	82.5	14.3463
20	998.228	0.001002	0.07275	80.7	14.1669
25	997.069	0.0008904	0.07197	78.85	13.9965
30	995.671	0.0007975	0.07118	77.1	13.8330

SI PREFIXES

Multiplication Factor	Prefix	Symbol	Multiplication Factor	Prefix	Symbol
10^{12}	tera	T	10^{-2}	centi	c
10^{9}	giga	G	10^{-3}	milli	m
10^{6}	mega	M	10^{-6}	micro	μ
10^{3}	kilo	k	10^{-9}	nano	n
10^{2}	hecto	h	10^{-12}	pico	p
10^{1}	deka	da	10^{-15}	femto	f
10^{-1}	deci	d	10^{-18}	atto	a