1.85 WATER AND WASTEWATER TREATMENT ENGINEERING
TAKE-HOME MID-TERM EXAM
DUE TUESDAY APRIL 5, 2005 AT 1:00 PM

This is an open-book exam, with the exception that you are asked to restrict your use of Internet sources to the links included on the 1.85 course webpage and to routine information sources like unit conversions. Unlike the homework, collaboration is not permitted—please do not work with others on this exam.

1. A surface water with the water-quality characteristics listed below is being considered for a municipal water supply.
   a. Which water-quality constituents are problematic and why (short answer)? (10 points)
   b. Identify a set of treatment technologies (unit processes) to make this water suitable for drinking water. (10 points) ____

Turbidity	170 NTU
Iron	13.0 mg/L
Calcium	50.8 mg/L
Magnesium	0.9 mg/L
Sodium	6.9 mg/L
Potassium	0.4 mg/L
Taste & odor	Unacceptable in summer

Manganese	1.0 mg/L
Carbonate	0 mg/L
Bicarbonate	116 mg/L
Sulfate	31.0 mg/L
Chloride	10.8 mg/L
Nitrate	1.9 mg/L as NO_3

See attached spreadsheet. Note that treatment for hardness is not considered necessary for a public water supply below about 250 mg/L.

Scoring:

- Part a:
  - -1 point for including hardness
  - -2 points each for leaving out turbidity, iron, manganese, or taste & odor
- Part b:
  - -2 points for leaving out disinfection
  - -2 points each for not specifying acceptable technology for turbidity, iron, manganese, and taste & odor

Problem 1

	Reported conc.	MCL	
Turbidity	170 NTU	~0	**Too high**
Iron	13.0 mg/L	0.3	**Too high**
Manganese	1.0 mg/L	0.05	**Too high**
Taste & odor	Unacceptable in summer		**Too high**

		Conc	MW	Equiv	Eq Wt	Equiv conc	Conc	Sum Eq
		mg/L				meq/L	mg/L as $CaCO_3$	meq/L
Calcium	50.8 mg/L	50.8	40	2	20	2.5	127.0	
Magnesium	0.9 mg/L	0.9	24.4	2	12.2	0.1	3.7	
Sodium	6.9 mg/L	6.9	23	1	23	0.3	15.0	
Potassium	0.4 mg/L	0.4	39.1	1	39.1	0.0	0.5	2.9
Carbonate	0 mg/L	0	60	2	30	0.0	0.0	
Bicarbonate	116 mg/L	116	61	1	61	1.9	95.1	
Sulfate	31.0 mg/L	31	96	2	48	0.6	32.3	
Chloride	10.8 mg/L	10.8	35.5	1	35.5	0.3	15.2	
Nitrate	1.9 mg/L as NO_3	1.9	62	1	62	0.0	1.5	2.9

Hardness	130.7	**OK**
Alkalinity	95.1	

Treatment technologies:

Turbidity	Sedimentation with coagulant addition, followed by rapid filtration
Iron and manganese	Oxidation, probably by permanganate since Mn is high
Taste and odor	Oxidation may treat t&o, otherwise activated carbon or perhaps ozonation
Disinfection (always)	Ozonation - may help with taste and odor. Also need combined chlorine for residual
Fluoridation (always)	Flouride addition

2. A ground water with the water-quality characteristics listed below is being considered for a municipal water supply.

a. Which water-quality constituents are problematic and why (short answer)? (10 points)

b. Identify a set of treatment technologies (unit processes) to make this water suitable for drinking water. (10 points)

Turbidity	0.1 NTU
Iron	0.2 mg/L
Calcium	121 mg/L
Magnesium	57 mg/L
Sodium	117 mg/L
Potassium	3 mg/L

Manganese	0.04 mg/L
Carbonate	0 mg/L
Bicarbonate	298 mg/L
Sulfate	240 mg/L
Chloride	210 mg/L
Nitrate	7.4 mg/L as NO_3

See attached spreadsheet. Note that treatment for hardness requires lime and soda ash for both carbonate and non-carbonate hardness.

Scoring:

Part a:

-1 point for not recognizing sulfate, chloride, sodium are marginal

Part b:

+1 point for explicitly recognizing implications of different kinds of hardness

but -2 points for not including soda ash

-2 points for leaving out disinfection

Problem 2

	Reported conc.	MCL	
Turbidity	0.1 NTU	~0	**OK**
Iron	0.2 mg/L	0.3	**OK**
Manganese	0.04 mg/L	0.05	**OK**
Chloride	210 mg/L	250	**Marginal**
Sulfate	240 mg/L	250	**Marginal**
Sodium	117 mg/L	20	**Guidance level only, but potentially a problem**

		Conc mg/L	MW	Equiv	Eq Wt	Equiv conc meq/L	Conc mg/L as $CaCO_3$	Sum Eq meq/L
Calcium	121 mg/L	121	40	2	20	6.1	302.5	
Magnesium	57 mg/L	57	24.4	2	12.2	4.7	233.6	
Sodium	117 mg/L	117	23	1	23	5.1	254.3	
Potassium	3 mg/L	3	39.1	1	39.1	0.1	3.8	15.9
Carbonate	0 mg/L	0	60	2	30	0.0	0.0	
Bicarbonate	298 mg/L	298	61	1	61	4.9	244.3	
Sulfate	240 mg/L	240	96	2	48	5.0	250.0	
Chloride	210 mg/L	210	35.5	1	35.5	5.9	295.8	
Nitrate	7.4 mg/L as NO_3	7.4	62	1	62	0.1	6.0	15.9

Hardness 536.1 **Too high**
Alkalinity 244.3

Treatment technologies:

Hardness	Lime and soda ash needed to remove carbonate and non-carbonate hardness
Disinfection (always)	Ozonation or chlorination. Also need combined chlorine for residual
Fluoridation (always)	Flouride addition

3. You are the environmental manager for the Big Dig. The Massachusetts Department of Environmental Protection is requiring that 85% of all suspended solids be removed from any water pumped on the project. You have to come up with an inexpensive, on-site treatment system to achieve this.

See attached calculations

a. Assume that the suspended solids in the pumped water are a typical silt particle with an equivalent diameter of 62 microns and density of 2.6 g/cm^3. Assume a kinematic viscosity of 0.01 cm^2/sec. What is the settling velocity of a particle assuming discrete particle settling and creeping flow? Is the creeping flow assumption valid? (10 points)

   Points: 2 points off for arithmetic errors.

b. You would like to adapt a “roll-off box” as a sediment settling tank. A typical “roll-off” box is rectangular, 2.5 m wide by 4 m long by 1.5 m high. You plan to pump the water into one end of the tank such that it is uniformly distributed across the width and depth of the tank. Similarly, at the other end of the tank, water will be drawn uniformly from the full width and depth of the tank (see sketch). Assume the sediment settles at a constant velocity and that any sediment that settles to the bottom of the tank sticks to the bottom and is removed. You can ignore diffusion as a transport process. How much flow can you pass through the box and still achieve 85% removal? (10 points)

   Credit: 0 points for incorrect theory/equations

c. You implement your roll-off-box treatment unit and it works pretty well, except you are encountering more clay particles than anticipated. Because the clay particles are smaller, they do not settle as well as the silt particles you assumed in your design. You already have the roll-off boxes bought and on-site and are stuck with them. Describe briefly how you could improve settling in the roll-off boxes. (5 points)

   Credit: 5 points for adding coagulant

   4 points for other alternatives that were in the right direction but not actually workable

   4.5 for including unworkable alternatives

Problem 3

a. $d_e = 62\ \mu m$

$\rho_1 = 2.6\ g/cm^3$ $\qquad \rho = 1.0\ g/cm^3$

$\nu = 0.01\ cm^2/s$

From lecture 05-06 Notes, pg 5

$$V_s = \frac{g d^2 (\rho_1 - \rho)}{18\ \nu \rho}$$

$$= \frac{9.8\ m/s^2 \cdot (62 \times 10^{-6}\ m)^2\ (2.6 - 1.0)\ g/cm^3}{18\ \ 0.01\ cm^2/s\ \ 1.0\ g/cm^3\ \cdot\ 10^{-4}\ m^2/cm^2}$$

$$= 0.0033\ m/s = 0.33\ cm/s$$

Check Reynolds Number (Lecture Notes, pg 3)

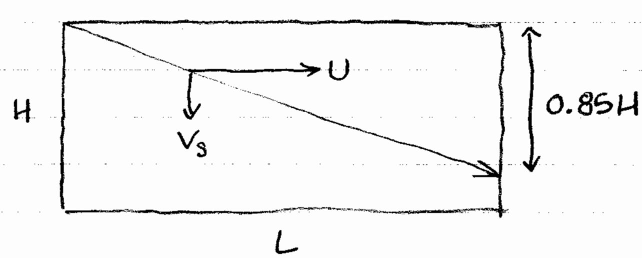
$$\mathbb{R} = \frac{V_s d}{\nu}$$

$$= \frac{0.0033\ m/s\ \ 62 \times 10^{-6}\ m}{0.01 \times 10^{-4}\ m^2/s}$$

$$= 0.205 < 1$$ – barely in laminar region

b.

To get 85% removal U must be such that:



$$\frac{V_s}{U} = \frac{0.85H}{L}$$

$$U = \frac{V_s L}{0.85H} \qquad Q = U \cdot H \cdot W$$

$H = 1.5\ m \qquad W = 2.5\ m \qquad L = 4\ m$

$$U = \frac{0.0033\ m/s \cdot 4\ m}{0.85 \quad 1.5\ m} = 0.01\ m/s$$

$$Q = 0.01\ m/s \cdot 1.5\ m \cdot 2.5\ m$$

$$= 0.039\ m^3/s \cong 0.04\ m^3/s$$

Alternative approach

$$\frac{V_s}{V_o} = 0.85$$

$$V_o = Q/A_p = Q/(W \cdot L)$$

$$\therefore \quad Q = V_o \cdot W \cdot L / 0.85$$

$$= 0.0033\ m/s \cdot 2.5\ m \cdot 4\ m / 0.85$$

$$= 0.04\ m^3/s$$

c. Alternatives for treatment

Only practical alternative is to add a coagulant

Sedimentation would be increased by putting boxes in series, reducing depth, reducing flow, or adding mid-depth trays, but consider how much would be needed

clay particle size is < 2 μm

$$V_s \sim d^2$$

$$\therefore \quad V_s \text{ for clay will be } \left(\frac{2}{62}\right)^2 = 0.001$$

You would need 1000 boxes in series, 1/1000 of depth, 1/1000 of flow.

Adding mid-depth tray has other practical problems: how do you clean settled sediment from below tray?

4. A shallow pond receives organic wastes from a fruit juice processing factory. The pond has operated successfully under the following conditions. The pond volume is 3.5×10^5 m^3; the wastewater flow rate into the pond is 0.2 m^3/s; and the average concentration of organic matter in the waste measured as COD is 300 mg/L. The long-term average pond effluent into an adjacent river has a concentration of 50 mg/L of COD. The pond may be assumed to be fully mixed and the COD removal may be assumed to be first-order.

See attached calculations

a. Calculate the rate constant for COD removal in the pond. (5 points)
Credit: 0 points for using wrong formula (plug flow vs. FMT)

b. The EPA has set new discharge permit conditions that will require the pond effluent COD to be 35 mg/L. Two options are being considered:

i. Modify internal operations to produce a plant waste stream having the same flow rate as before but with a COD concentration of 200 mg/L.

ii. Retain the original waste stream concentration and flow rate but mix the plant discharge with fresh water to reduce the waste concentration to 200 mg/L as it enters the pond. (Ignore for purposes of this problem that this approach is not allowed by EPA rules.)

Which option to do you recommend? Demonstrate through calculations why it is preferred. (10 points)
Credit: -2 points for not getting to the bottom line and computing concentrations
-2 points for computing incorrect flow for option 2
-5 points for analyzing with plug-flow equations

c. Describe an alternative option for reducing the pond effluent concentration and demonstrate with calculations why it would work. (10 points)
Credit: 10 points for installing baffles and creating plug flow (most practical alternative)
8 points for less practical but theoretically possible solutions: decrease Q or increase V
A couple of other alternatives were graded based on practicality, theoretical appropriateness

Problem 4

a. For fully-mixed tank under steady-state conditions

$$\frac{C_{out}}{C_{in}} = \frac{1}{1 + Kt_R} = \frac{50}{300}$$

$$t_R = \frac{\forall}{Q} = \frac{3.5 \times 10^5 \ m^3}{0.2 \ m^3/s}$$

$$= 1{,}750{,}000 \text{ sec}$$

$$= 20.26 \text{ days} \approx 20 \text{ day}$$

$$\frac{1}{1 + Kt_R} = \frac{C_{out}}{C_{in}}$$

$$1 + Kt_R = \frac{C_{out}}{C_{in}}$$

$$K = \frac{1}{t_R}\left(\frac{C_{out}}{C_{in}} - 1\right) = \frac{5}{20.26}$$

$$= 0.247 \text{ day}^{-1}$$

$$= 0.010 \text{ hr}^{-1}$$

$$= 2.86 \times 10^{-6} \text{ sec}^{-1}$$

b. i. $C_{in} = 200$ mg/L, everything else the same

$$C_{out} = \frac{C_{in}}{1 + Kt_R} = \frac{200}{1 + 0.247 \text{ day}^{-1} \ 20.26 \text{ day}}$$

$$= 33.3 \text{ mg/L}$$

b. (continued)

ii Changing c_{in} by dilution requires an increase in Q

$$Q_{old} \, C_{in_{old}} = Q_{new} \, C_{in_{new}}$$

$$0.2 \frac{m^3}{s} \; 300 \frac{mg}{L} = Q_{new} \; 200 \frac{mg}{L}$$

$$Q_{new} = 0.3 \frac{m^3}{s}$$

$$t_{R_{new}} = \frac{\forall}{Q_{new}} = \frac{3.5 \times 10^5 \; m^3}{0.3 \; m^3/s}$$

$$= 1.17 \times 10^6 \; sec$$

$$= 13.5 \; days$$

$$C_{out_{new}} = \frac{C_{in_{new}}}{1 + k t_{R_{new}}} = \frac{200}{1 + 0.247 \cdot 13.5}$$

$$= 46.1 \; mg/L \; COD$$

Option ii fails to meet the 35 mg/L limit
Option i meets the limit and is preferred.
(Dilution is not the solution to pollution)

c. Fully-mixed tank is least efficient. If baffles could be placed in the pond to create plug flow with same residence time, the outflow concentration would be:

$$c_{out} = c_{in} \, e^{-kt_R}$$

$$= 300 \frac{mg}{L} \exp - (0.247 \cdot 20.26)$$

$$= 2 \; mg/L$$

c. (continued)

Therefore, even imperfect plug flow ought to greatly improve effluent quality

Increasing t_R by increasing $\forall$ or decreasing Q would improve treatment but are less practical.

5. WATER QUALITY MIX AND MATCH

Match the water-quality constituents in Column 1 with the corresponding effect in Column 2 by filling in the corresponding letter as shown by the example. Be careful!—some of the effects in Column 2 could be used for multiple constituents in Column 1. You should pick the effect that best fits each constituent. There is a one-to-one correspondence between the columns (i.e., you should use each effect from Column 2 for only one constituent in Column 1). (1 points each, 10 points total)

	Column 1 Water-quality constituent	Fill in
Ex.	**Selenium**	**c.**
1.	Nitrate	**e.**
2.	Trihalomethanes	**a.**
3.	Fluoride	**j.**
4.	Giardia	**k.**
5.	Un-ionized ammonia	**h.**
6.	*Pseudomonas aeruginosa*	**b.**
7.	Phenols	**g.**
8.	Hardness	**f.**
9.	*Schistosoma*	**d.**
10.	Manganese	**i.**

	Column 2 Effect
a.	Suspected to cause cancer
b.	Dermatitis
c.	Hair loss
d.	Snail fever
e.	Blue-baby syndrome
f.	Scaling of pipes and boilers
g.	Taste and odor
h.	Toxicity to fish
i.	Staining of laundry and bathroom fixtures
j.	Staining of teeth
k.	Gastrointestinal illness