CE 474/574 - Unit Operations in Environmental Engineering

Design Assignment 1.
Chlorination of the Drain, OR Public Water Supply

The town of Drain, Oregon (pop. 1,011; see attached map) takes its public water supply from nearby Elk Creek.   Because the town has a population fewer than 10,000, the system was not previously required to disinfect its water.   Now, however, the Federal Long Term 1 Enhanced Surface Water Treatment Rule ("LT-2"), effective December 15, 2005, strengthens microbial controls for small systems, i.e., those systems serving fewer than 10,000 people.

The new rules require Drain to disinfect its water, and include provisions specifically to address *Giardia* cysts.   (With a name like "Elk Creek" the EPA knew the supply could like be contaminated by the wastes of large mammals!   Beaver are also very common in the watershed and are particularly likely to harbor this pathogen.)   As to the new rule, the EPA summary states:

> *Among its provisions, the rule requires that a surface water system have sufficient*
> *treatment to reduce the source water concentration of Giardia lamblia and viruses*
> *by at least 99.9 percent (3-log) and 99.99 percent (4-log), respectively.*

The town system will serve no industries and only a few shops and restaurants, so the total water use can be estimated from the U.S. national average for domestic water use which is 105 gpcd.   At this level of supply it may be cost effective to chlorinate with either HTH or Cl gas.

Prepare a report to be submitted to Mr. Sal Monella, the Chief Health Officer for Drain.   Your report should summarize issues raised in the questions below.

     <u>Elk Creek River Data:</u>

     Average minimum temperature = 5°C
     Average maximum temperature = 23°C
     pH = 6.0

 A chlorine demand test on the raw river water gives results as follows:

Cl Dose, mg/L	Residual Cl after 10 min, mg/L
0.40	0.38
0.80	0.72
1.20	1.00
1.60	0.96
2.00	0.40
2.40	0.80
2.80	1.20
3.20	1.60
3.60	2.00
4.20	2.40
4.60	2.80
5.00	3.20

The water system will pump the water to a contact tank that allows enough detention time to meet

the C.t standard.   The water will be chlorinated immediately after the pump.   A pipe connecting the chlorinator to the detention tank will have a residence time at average flow of about 10 minutes.   This is enough time for all the chlorine demand reactions to go to completion by the time the water enters the detention tank, so you can used the demand curve data provided.

It is recommended that the contact concentration be maintained at least 2.0 mg/L because *Giardia* is common in surface waters in this area. Preliminary tests indicate that the residual Cl concentration is fairly stable after the 10 minutes spent in the supply pipes, but to be on the safe side, is proposed that there be residual chlorine concentration of **2.4 mg/L** in the water when it enters the tank (i.e., after 10 min of contact in the pipe).

1.   Sketch the chlorine demand curve as shown in the text and in the lecture. What is the *breakpoint* dosage?

2.   What is the dose of chlorine (mg/L) that must be used to achieve a (post-breakpoint) residual chlorine of 2.4 mg/L?

3.   How many pounds of liquified chlorine gas per day must be used to treat the average daily flow in the system?

4.   How many pounds of HTH per day must be used to treat the average flow of water through the system?   Note that the HTH is described as having "70% chlorine content as Cl_2". This just means that 1.0 lb of HTH produces the same amount of hypochlorite as would 0.70 lb of Cl_2 gas.   This system makes it easy to compare HTH and chlorine consumption.

5.   At pH 6.0, most of the chlorine in the water should be in the form of HOCl.   Verify this by consulting Table 16.1 and report the expected %HOCl.

        Note to those who took Water Quality Chemistry: You can obviously calculate this directly by calculating the ratio of [OCl-]/ [HOCl] using the K_a.   If you are not too up on your chemistry, you can solve this by just rearranging Eq. 16.8 in the text to solve for this ratio and plugging in [H+] = 10^{-6} (which comes from the definition of pH 6.0).   For K_a do NOT use the K value from Eq.16.7 (different reaction) but use K_a given inside Fig. 16.1.

6.   We noted in class that using Cl_2 gas generates one H^+ for each HOCl formed. In the previous section you verified that essentially all of the chlorine remains in the form of HOCl, so you don't have to worry about acidity contributed by the ionization of HOCl to OCl-.   We wish to maintain the pH of the water at 6.0 so we must neutralize the H^+ ions contributed by the formation reaction.   Soda ash (sodium carbonate, Na_2CO_3) is a convenient and fairly cheap base we add to achieve this neutralization.

        Note that at pH 6.0 we can roughly assume that the carbonate neutralization reaction is

        $CO_3^{2-} + H^+ \; \text{-->} \; HCO_3^-$ (I.e., each carbonate added picks up one proton and becomes a bicarbonate)

        Calculate how many moles/L of Na_2CO_3 must be added to neutralize the acidity contributed by the formation of HOCl and then calculate how many pounds of commercially available soda ash per day must be used to treat the average flow of water through the system?

Note: For the chemistry-phobic, this is not really a chemistry problem. It's really just a simple calculation: For each mole of Cl_2 added, add one *equivalent* of soda ash. Since the carbonate in soda ash has a valence (neutralizing power) of 2 per mole, divide the moles by 2. (Equivalents of soda ash = 0.5 moles of soda ash). Take the total molarity of soda ash added and use the molecular weight of Na2CO3 to convert to grams, then pounds of soda

ash. Remember to correct the final number for the purity of the commercial soda ash. [Find data for soda ash and other chemicals at the end of the assignment.]

7. Adding HTH cause protons (H+, acidity) to be consumed because of the reaction OCl- + H+ = HOCl..   If we wish to maintain the water at pH 6.0, where most of the chlorine is HOCl, then each OCl- ion added as HTH will consume one hydrogen ion.   To maintain the pH we will add muriatic (hydrochloric) acid (HCl). Since HCl is a strong acid, one mole of HCl will satisfy one mole of added OCl-.
Calculate how many moles/L of HCl must be added to neutralize the alkalinity contributed by the formation of HOCl from HTH and then calculate how many gallons of commercially available muriatic acid per day must be used to treat the average flow of water through the system? [Find data for muriatic acid at the end of the assignment.]

8. From the text reading you can find values of C t for 99.9% (3-log) reduction in *Giardia* cysts for a free Cl concentration of 2.0 mg/L.   (Assume conservatively that the residual chlorine is 2.0 rather than the 2.4 we are designing the dosage for.)   Interpolate as necessary to find C.t for your chosen design temperature. Use this estimate to calculate the required retention time in minutes for the proposed contact tank.

    What is the volume of the detention tank to achieve this retention time for the average daily flow through the system?   (Do *not* include the 10 min retention in the supply pipe in your calculations here.)

9. Using the C.t tables in the Course Readings webpage link, verify that the system designed to meet the log-3 reduction in *Giardia* will also satisfy the log-4 reduction requirement for viruses.   (In other words, if we design for *Giardia* we more than satisfy the virus requirement.)

10. Use the dosage information you calculated above to compute the **total cost per day** of **all** chemicals need to treat the water supply for the town of Drain.   Compare the cost of using Cl gas to that of using HTH when all chemical costs are considered.   What other factors must be balanced against the chemical costs?

Data on Chemical Supplies

All prices are as delivered to Drain, Oregon.

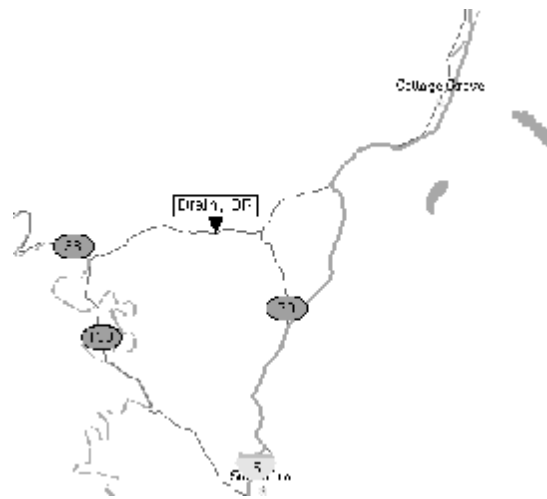**Chlorine gas:** Supplied as a pure liquid under pressure in 100 lb tanks at $175/tank

HTH (High-Test Hypochlorite): $Ca(OCl)_2$ supplied with purity guaranteed at 70% chlorine (as Cl_2) by weight. Price is $195 per 50 lb drum of powder.

Soda Ash: Supplied a dry powder in 50-lb sacks that are approximately 95% Na_2CO_3. The price is $14 per sack. [Note: Because this chemical is less than 100% pure, divide the desired amount of Na_2CO_3 to get the actual product needed.]

Muriatic Acid (HCl): Concentrated HCl is a 37% solution by weight. The specific gravity is 1.18.   A 55-gal drum is $78. [Use same correction here for the 37% factor.]

Map of Drain, Oregon

Regional Locator Map