Homework #5 Disinfection

4 points total for entire homework

1. Briefly describe the main factors that affect the effectiveness of disinfection using free chlorine for inactivating pathogens.

Answer:

1 point for #1

A. Type of microorganism
   - Hardest to easiest to disinfect: Protozoans > viruses > bacteria

B. Dose of chlorine
   - More effective as dose goes up

C. Contact time
   - More effect as contact time increases

D. Water Quality
   a. Temperature
      - More effective as temp goes up
   b. pH of water
      - chlorine is more effective at lower pH
   c. chlorine-reactive substances (Fe, Mn, Sulfur)
      - less effective if chlorine dissipates quickly due to reaction with these substances, resulting in high chlorine demand

1 point for #2

2. Consider the effect of pH on the distribution of the free chlorine species:
   a) Construct a figure showing the percent distribution of HOCl and OCl^{-1} as a function of pH (3 to 11) using an equilibrium acidity constant (K_a) of $3.16x10^{-8}$.
   b) Calculate directly (do not read from the figure) the % HOCl existing at pHs of 5.5, 6.5, 7.5, and 8.5.
   c) For a constant dosage of chlorine, is it better to disinfect at pH below 7.5 or at pH above 7.5? why?

Answer:

a) To construct the figure, you'll need to modify the equilibrium equation. The %HOCl is just the ratio of the [HOC] to the total free residual chlorine (i.e., the sum of [HOCl] and $[OCl^-]$). This can be determined from the following:

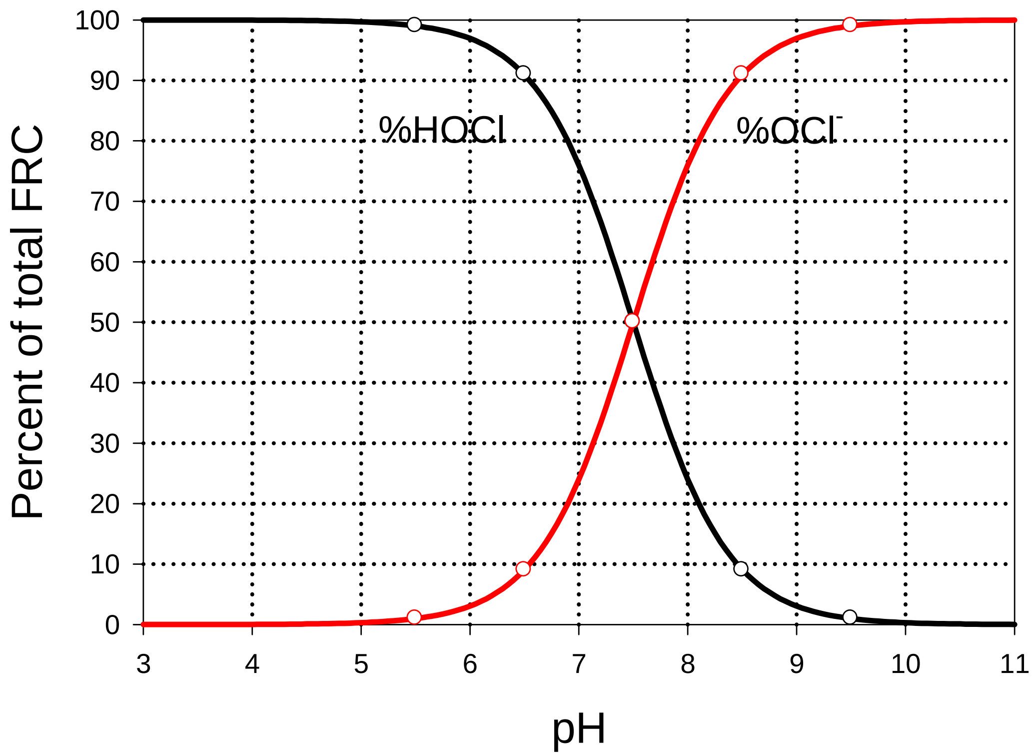
$$K_a = 3.16x10^{-8} = 10^{-7.5} = \frac{[H^+][OCl^-]}{[HOCl]}$$

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

$$1 + \frac{10^{-7.5}}{[H^+]} = \frac{[HOCl] + [OCl^-]}{[HOCl]}$$

And finally:

$$\left(1+\frac{10^{-7.5}}{[H^+]}\right)^{-1} = \frac{[HOCl]}{[HOCl]+[OCl^-]}$$



b) Now calculate the %HOCl values for each of the requested pHs.

pH	[H+]	%HOCl
5.5	3.16E-06	99.01%
6.5	3.16E-07	90.91%
7.5	3.16E-08	50.00%
8.5	3.16E-09	9.09%

3. The hydraulics of a disinfection contact chamber were characterized at design flow using a tracer study based on a step or continuous feed of fluoride at 2.0 mg/L. Initially, there was no fluoride in the water. Results of measurements of fluoride concentration in the reactor effluent are shown in the table below.

2 points for #3

Time (min)	Effluent Fluoride Conc (mg/L)
0	0
5	0
10	0
15	0.05

20	0.10
25	0.45
30	0.72
35	0.95
40	1.20
50	1.46
60	1.65
70	1.88
80	1.92
90	2.0
100	2.0

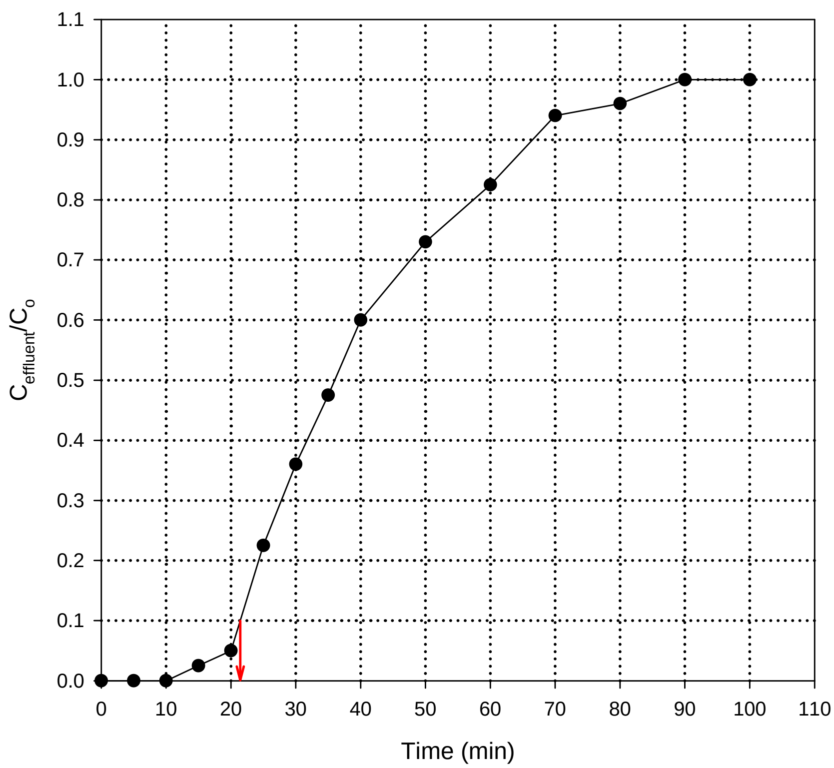
a) Plot the effluent fluoride concentration data and determine the t_{10} time in minutes.

b) The water utility would like to exceed the *Giardia* removal required by US EPA and obtain 1 log inactivation by disinfection. Determine the disinfectant residual needed if free chlorine disinfection is used and compare to that needed if chloramine disinfection is used. The disinfection contact chamber characterized in part a) will be used for conditions of: water temperature of 5°C, pH of 7.0.

c) The tracer data in the table above show that the mean hydraulic detention time (t_R) of the contact chamber is 40.3 minutes. Calculate the ratio of t_{10} to t_R. How much smaller in volume could the contact chamber be if it exhibited ideal plug flow behavior?

Answer:

a. plot of effluent fluoride concentration for the purposes of determining t_{10}, is best done by converting the data to the ratio to the feed concentration:



From this graphical representation, we can see that:

t_{10} = 22 minutes

b. Using table 7-4 (pg 245) in the text, we have the following Ct values

Disinfectant	$Ct_{required}$ (mg/L min)	$C_{required}$ (mg/L)
Chlorine	50	2.3
Chloramines	740	33.6

Then the required concentration can be determined for each from:

$$Ct_{required} = C_{required} \times t_{10}$$
$$C_{required} = Ct_{required}/22 \text{ min}$$

Additional note: the MRDL for chloramines is 4 mg/L, so that chloramines are not feasible for achieving 1 log *Giardia* inactivation with the current contact chamber.

c. The contactor efficiency is calculated by:

$$t_{10}/t_R = 22 \text{ min}/ 40.3 \text{ min} = 0.55$$

since a PFR has an efficiency of 1, it would only need to have:

$$t_R = 22 \text{ min}$$

which is:

$$(40.3-22)/40.3 \times 100\% = 45\% \text{ smaller}$$