Everything You Ever Wanted to Know About CT (and then some)

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Background

- All surface water contains bacteria and may contain protozoa and viruses.
- Many waterborne pathogens, i.e. organisms harmful to human health, are a result of contamination of surface water bodies.
- Pathogens can also contaminate a groundwater supply or enter into a distribution system.
- Prior to water disinfection and filtration, waterborne pathogens killed thousands/yr in the U.S.

Background

Waterborne outbreaks in U.S. public water systems between 1991 and 2000

Pathogen	# Outbreaks	# Cases
E. coli O157:H7/C. jejuni	1	781
Giardia	16	2,240
Hepatitis A virus	1	46
Norwalk-like viruses	3	2,400
Cryptosporidium	9	408,220
Salmonellae (nontyphoid)	2	749

Reg Requirements

- SWTR: all surface water & GWUDI systems required to achieve 99.9% (3-log) removal and/or inactivation of Giardia and 99.99% (4-log) inactivation of viruses through treatment and disinfection.

- Groundwater Rule: Groundwater systems with a source water sample that is fecal-positive or with other significant deficiencies may be required to disinfect or otherwise treat to achieve 99.99% (4-log) inactivation of viruses.

Disinfection

Different disinfectants have advantages and disadvantages. Chlorine (Cl_2, calcium hypochlorite or sodium hypochlorite) are most common in NM.

Disinfection	Advantages	Disadvantages
Chlorine	• Leaves residual • Effective w/bacteria, viruses and Giardia	•Creates DBPs •Not effective against Crypto
Chloramines	•Lower DBP production	•Relatively weak disinfectant •Requires using Ammonia
Chlorine dioxide	•Effective against Crypto •Will not form THMs or HAAs	•Highly volatile residuals •High chemical cost
UV	•No chemicals •Effective against Crypto •No DBPs	•Doesn’t leave residual •High energy consumption

Chlorine Disinfection

Chlorine does not kill pathogens instantaneously on contact. The rate of inactivation depends on 5 factors:

- The Pathogen
- Chlorine Concentration, C (mg/l)
- Contact Time, T (minutes)
- Temperature of water
- pH of water

Pathogens

Some pathogens are harder to inactivate with chlorine than others

- Bacteria are easily inactivated
- Viruses are easily inactivated
- Giardia is tougher to inactivate and requires more contact time or higher residual Chlorine
- Chlorine is not very effective at inactivating Cryptosporidium

Chlorine Concentration & Time

- For bacteria, viruses and Giardia, the inactivation rate increases with contact time, T, or with increasing chlorine concentration, C
- In order to determine if C and T are adequate to get a certain % inactivation for a given pathogen, one can consider C x T, usually written CT, and compare the measured value with minimum requirements for CT

Calculating CT

- Use conservative estimates:
  - For T, use time estimated between disinfectant injection and first customer based on peak flow rates
  - For C, use lowest measured daily residual at injection point
- T is measured in minutes, C is measured in mg/l, Temperature is measured in ºCelsius
- If you have adequate CT for Giardia, then you have adequate CT for viruses.

Calculating CT

To Calculate T, you must find the volume of each section of distribution and storage between the disinfection injection points and the first customer:

- For storage, use the lowest water level
- volume of a cylinder (pipe, tank): $v = H \times \pi \times r^2$
  where H = pipe length or minimum water level
  r = radius
- Convert cubic feet (ft^3) into gallons by multiplying by 7.48 gallons/ ft^3
- For a given unit, T = v/(maximum flow rate)

CT Example 1

Problem: Groundwater system injects chlorine 1000 feet before the first customer. No storage tank. Distribution line is 6 inch diameter. Maximum pumping rate is 150 gpm. Lowest chlorine residual (C) measured is 1.2 mg/l. Temperature of the water is 11 ºC and the pH was 7.1

Solution:

1. Cross-sectional are of pipe:

   $\pi\ (.25\ ft)^2 = .196\ ft^2$

2. Volume of length of pipe:

   $1000\ ft \times .196\ ft^2 = 196\ ft^3$

3. Convert pipe volume to gallons:

   $196\ ft^3 \times 7.48\ gal/\ ft^3 = 1{,}469\ gal$

CT Example 1

Solution (continued):

4. Calculate time between injection point and first customer:

   T = 1,469 gal / 150 gallons per minute = 9.79 minutes

5. CT = 1.2 mg/l x 9.79 min = **11.7 mg-min/l**

Note: Units of CT are meaningless

Bonus Question

What pathogen is very resistant to inactivation by Chlorine?

CT Tables

How do we know if the calculated CT value is good enough?

- EPA has published CT tables for different pathogens and disinfectants

- The tabulated values in the CT tables are also dependent on temperature and pH.

CT Tables

Below is a CT table for viruses. Note how temperature and pH impacts CT:

	Log Inactivation					
	2.0		3.0		4.0	
pH	6 - 9	10	6 - 9	10	6 - 9	10
Temperature (ºC)						
0.5	6	45	9	66	12	90
5	4	30	6	44	8	60
10	3	22	4	33	6	45
15	2	15	3	22	4	30
20	1	11	2	16	3	22
25	1	7	1	11	2	15

Rules of Thumb

Note from CT tables that:

- Chlorine is more effective with decreasing pH
- Chlorine is more effective with increasing Temperature
  - May be easier to meet CT in summer than winter
  - DBP production increases with higher temp
- Use most conservative value from table for temperature and pH values in between tabulated values

Example 1 (continued)

Problem: Does the system in Example 1 meet the 4-log reduction requirement for Viruses through chlorine disinfection?

Solution:

6. Find required CT:

   Using the CT table for viruses, at temp = 11 ºC, pH = 7.1 and % reduction = 99.99% (4 log), we find the CT value in the table is 6

7. The value calculated for the system was 11.7. Because 11.7 > 6, the CT at the system was adequate to meet the CT requirement of 4-log reduction of viruses.

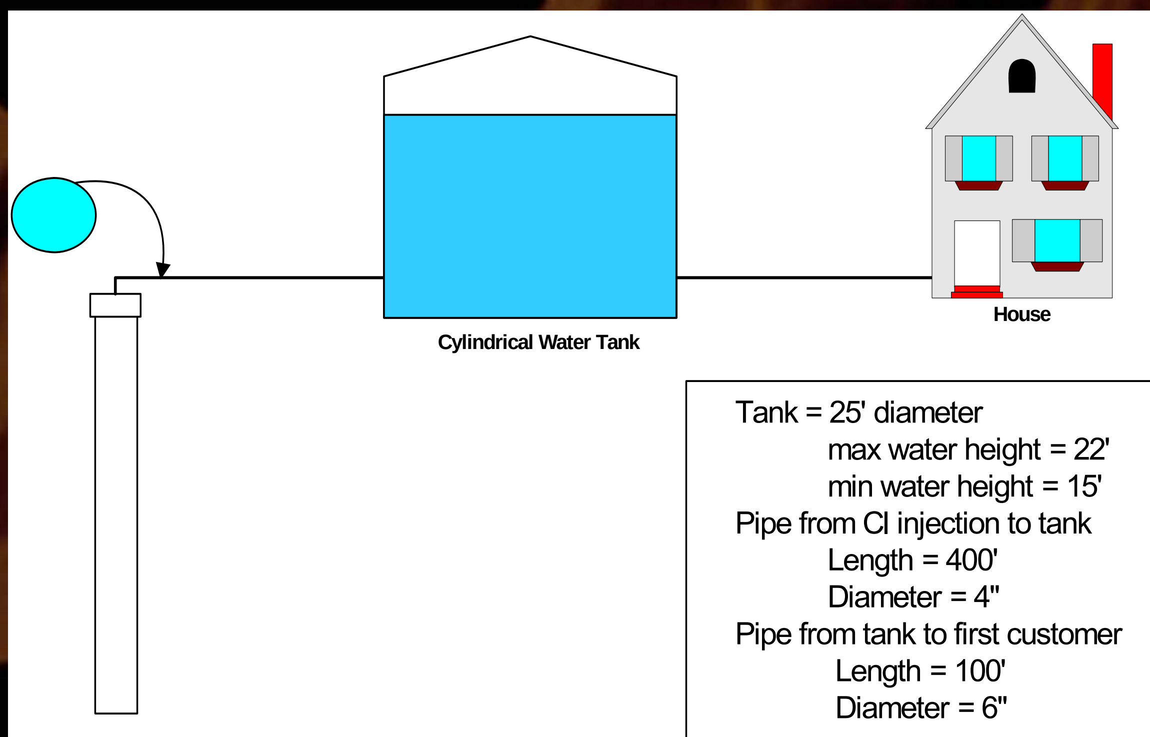
Residual Monitoring

- Surface Water systems that filter must monitor chlorine residual of water entering distribution continuously and the lowest daily value recorded. Daily pH and temp must also be recorded.

- Groundwater systems required to disinfect under the GWR must monitor residual as follows:
  - If system serves > 3,300 customers, monitor continuously and record lowest daily value.
  - If system serves ≤ 3,300 customers, system takes daily grab sample at time of peak flow.
  - No explicit requirement for pH and temp, but this is necessary to demonstrate 4-log removal.

Example 2

Problem: System shown below has peak flow rate of 250 gpm. Low residual measured at .8 mg/l. pH measured at 7.5, water temp measured at 5 °C. What is CT?



Example 2

Solution:

1. Find T for pipe 1:

   volume = 400ft x π x (.167 ft)^2 x 7.48 gal/ft^3 = 261 gal

   T = 261 gal/250gpm = 1.04 minutes

2. Find T for pipe 2:

   volume = 100ft x π x (.25 ft)^2 x 7.48 gal/ft^3 = 146 gal

   T = 146 gal/250gpm = .584 minutes

Question : Is 250 gpm the correct flow for pipe 2?

Example 2

3. What about the tank?

If you assume no short-circuiting (plug flow):

volume = 15ft x π x $(12.5\text{ft})^2$ x 7.48 gal/ft^3 = 55, 076 gal

T = 55,076 gal/250 gpm = 220 minutes

Generally assume there is short circuiting in which case you use a short-circuiting factor, F_{sc}, as follows:

T = Fsc x (minimum volume)/(maximum flow)

Example 2

The following is a table of F_{sc} values from EPA:

Baffling Condition	Baffling Description	F_{sc}
Unbaffled	None; high inlet ad outlet flow velocities, variable water level	0.1
Poor	Single or multiple unbaffled inlets and outlets, no intra-basin baffles	0.3
Average	Baffled inlet or outlet with some intra-basin baffling	0.5
Superior	Perforated inlet baffle, serpentine or perforated intra-basin baffles, outlet weir or perforated weir	0.7
Perfect (plug flow)	Very high length to width ratio (pipeline flow), perforated inlet, outlet, and intra-basin baffles.	1.0

Example 2

Assuming this tank was unbaffled, we get:

T = 0.1 x 55,076 gal/250 gpm = 22 minutes

4. Total CT (with unbaffled tank):

   CT = .8 mg/l x (22 min + 1.04 min + .584 min)

   = 18.9 mg-min/l

5. Do we have 4-log inactivation for viruses?

   Required CT from table is 8 mg-min/l

Surface Water CT

- Surface water systems need to have 3-log inactivation/removal of Giardia.
- Systems that pre-chlorinate can count the time through treatment system up to the point of post-chlorine injection.
- EPA has published CT tables for Giardia. These tables are much more detailed with pH in increments of .5 and CT values depending on the free chlorine residual.

More Rules of Thumb

- Time and volume estimates must be conservative

- Floating tanks get no contact time credit

Bonus Questions

Chlorine is more effective at inactivating Giardia with increasing ___________

*Describe groundwater system requirements for reduction of Cryptosporidium, viruses and Giardia

Example 3

Problem: peak flow rate of 250 gpm. Low residual measured at .8 mg/l. pH measured at 7.5, water temp measured at 5 °C. What is CT?

Solution: Calculated CT is the same as in Example 2. However, we must now use CT tables for Giardia. The following is an excerpt:

Chlorine (mg/l)	pH = 7.5 Log Inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0
<= .4	28	55	83	111	138	166
0.6	29	57	86	114	143	171
0.8	29	58	88	117	146	175
1	30	60	90	119	149	179
1.2	31	61	92	122	153	183
1.4	32	62	94	125	156	187

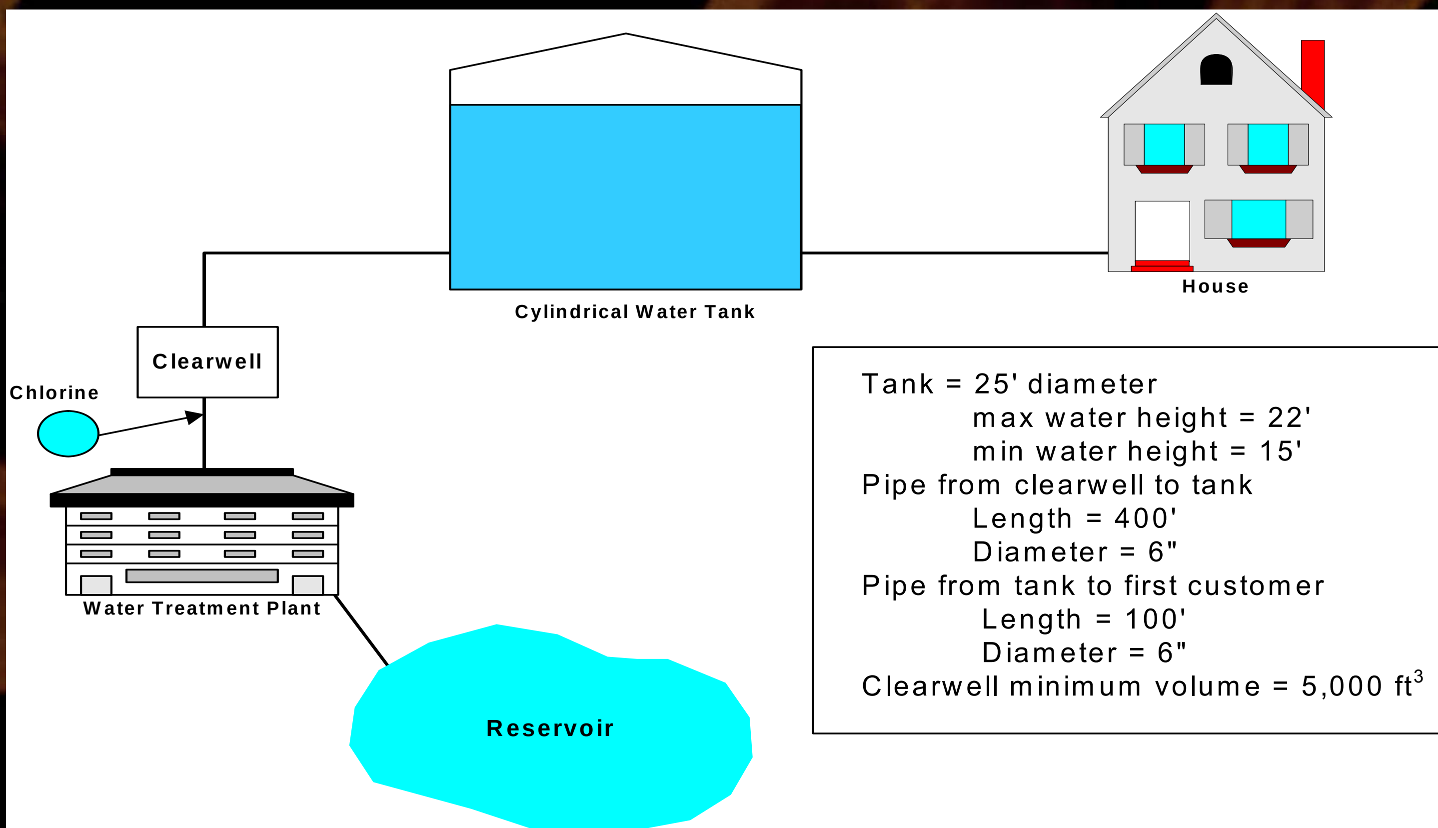
Example 3

The system doesn’t meet required CT for giardia through disinfection alone. What are some things the system could do to meet CT requirement?

- Removal credits through treatment
- Increase disinfectant residual
- Add baffling to tank
- Increase minimum water level in tank
- Add storage capacity

Example 4

Problem: System shown below has peak flow rate of 250 gpm. Low residual measured at .8 mg/l, pH measured at 7.5, water temp measured at 5 °C. What is CT? If the system gets 2 log removal credit from treatment, does it have adequate CT?



For More Information

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- Look at EPA's LT1ESWTR Disinfection Profiling and Benchmarking guidance document at
  http://www.epa.gov/safewater/mdbp/pdf/profile/lt1profiling.pdf