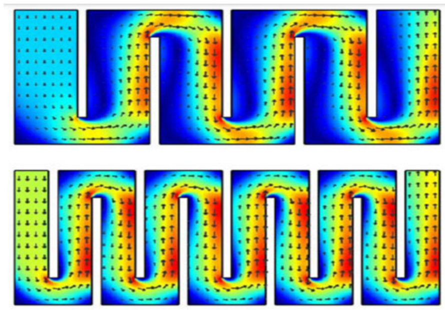
Chlorine Disinfection and CT Calculations



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Environmental Finance Center for EPA Region 5

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Great Lakes Environmental Infrastructure Center
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Training and Technical Assistance to increase technical, managerial, and financial capacity of utilities.

Located: Michigan Technological University (Michigan Tech) within the Center for Technology & Training.

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Tim Colling P.E., Director
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Outline for this class

Overview: **Disinfection purpose and challenges**

Part 1: **Dose and residual concepts**

- Understand key concepts and mathematical relationships in chlorine disinfection.

Part 2: **Feed rate calculations**

- Calculate chlorine dosages and feed rates when using different forms of chlorine.

Part 3: **CT Calculations**

- Calculate CT values necessary to inactivate pathogens and comply with regulations.

Part 4: **Challenge problems**

- Apply your knowledge

Poll #1

If you could only choose one, which of the following activities do you think provides (or would provide) the most benefit for drinking water quality improvement in your community?

a) Implementation of source water protection plans.

b) Flushing programs to manage water age.

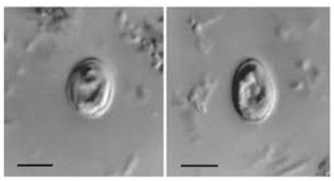
c) Ice pigging to remove biofilms.

d) Changing the type of disinfectant

e) Something else (please share in the chat)

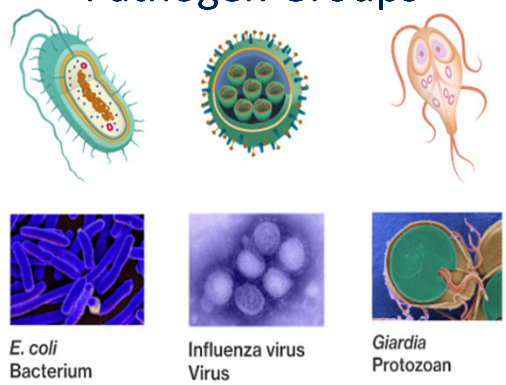
The effectiveness of chlorine disinfection depends on:

1. Residual concentration
2. Contact time
3. pH and Temperature



Chlorine disinfection does not inactivate Cryptosporidium oocysts

Pathogen Groups

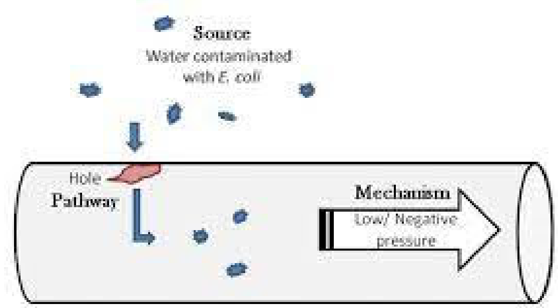


Bacteria are destroyed while viruses and most protozoa are inactivated when rendered incapable of replicating or reproducing

Distribution protection

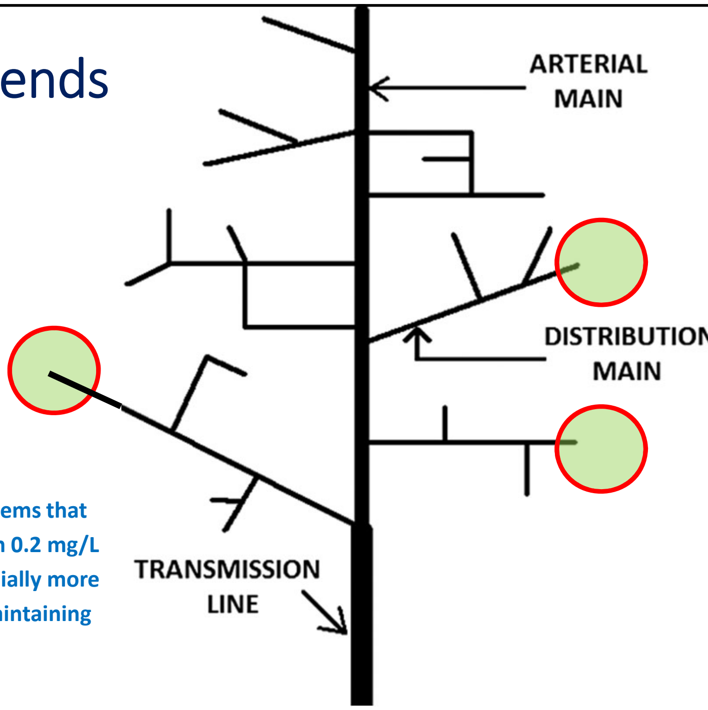
Two most important distribution control measures

1. Continuous positive water pressure
2. Physical integrity of the distribution system



- Contamination events require a source (contaminated groundwater), a pathway (pipe crack), and a mechanism (low pressure event).
- After initial disinfection, maintaining a free chlorine residual in the distribution system is a final barrier to protect against contamination, but once the residual is used up, there is no more disinfecting power.
- Multiple studies correlate water borne disease occurrences with main breaks, main repairs, and low pressure events.

Dead-ends



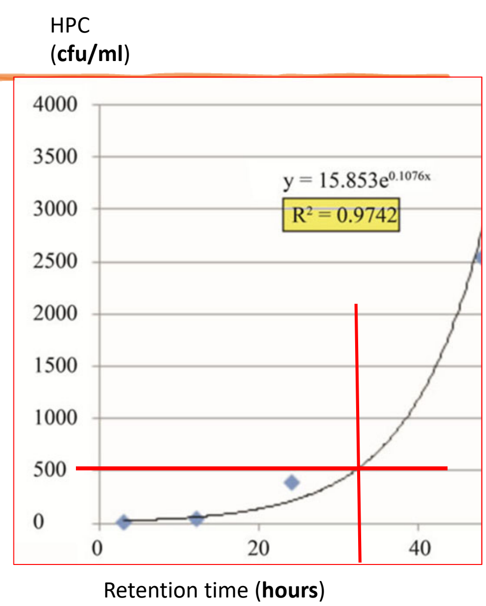
- Higher water age
- Loss of chorine residual
- Increased biofilm growth
- Increased disinfection byproduct formation (DBP)

LeChevallier et al. (1996) found that distribution systems that have dead-ends with free chlorine residuals less than 0.2 mg/L or chloramine levels less than 0.5 mg/L had substantially more coliform occurrences (system-wide) than systems maintaining higher residuals.

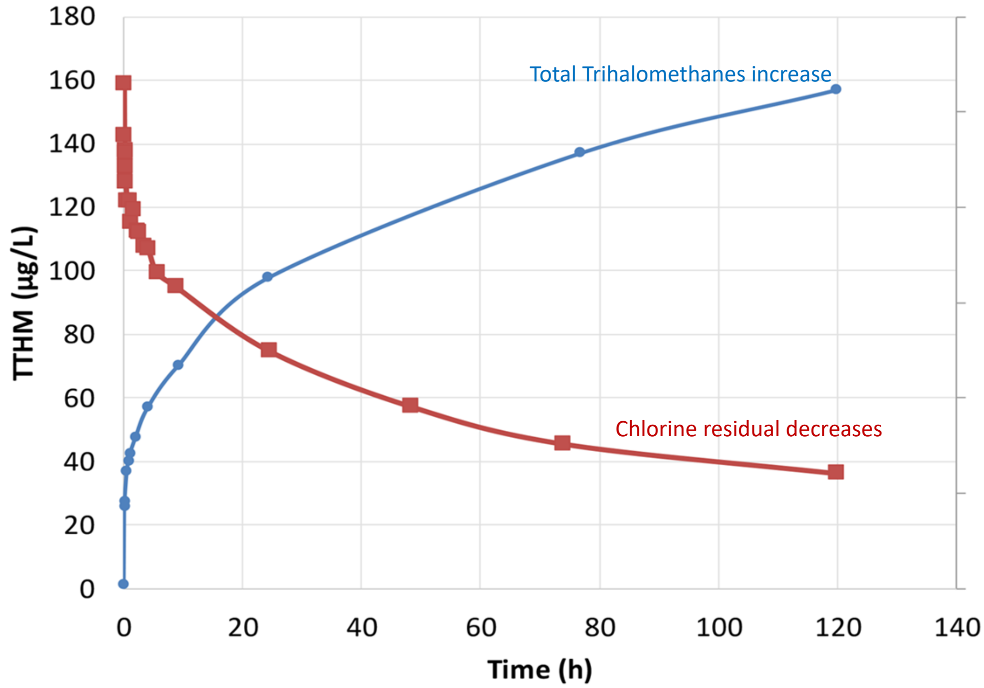
Effects of increased water age

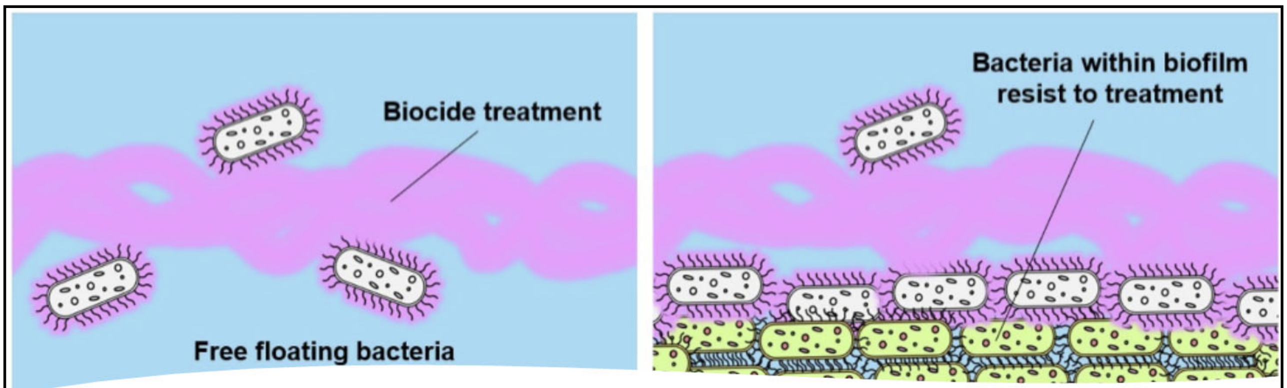
In a civil engineering research study "Effects of Residence Time to Water Quality in Large Water Distribution Systems" (Hossein Shamsaei et al., 2013)

- Areas of low velocities in water systems, both **heterotrophic plate bacteria** (HPC) growth and levels of **TTHMs** continued to increase with water age regardless of normal chlorine residuals.
- Chlorine residuals decreased with water age



***cfu/ml = colony-forming units observed per ml**





Biofilms protect pathogenic microbes from harsh environmental factors, including **chlorine**, shear stress, heat, inhibitors, and detergents, allowing them to survive (Hemdan et al., 2021).

EPS – Extracellular polymeric substances – gel like substances secreted by bacteria

Conclusions

Disinfection is one component of a multiple barrier approach: other components include:

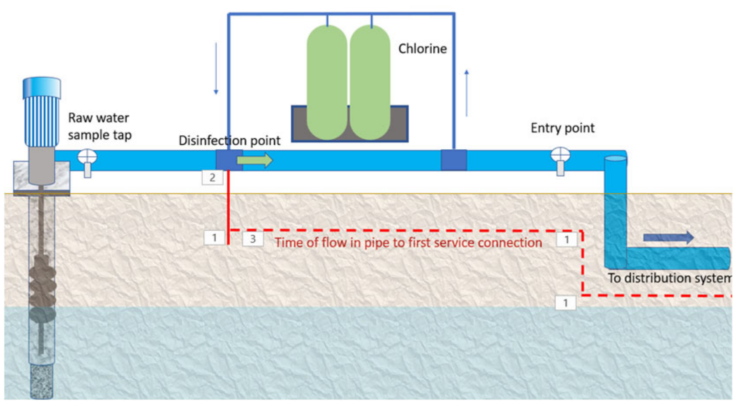
- Flushing
- Source and distribution system protection
- Elimination of sanitary defects
- Treatment

Disinfection challenges include biofilms, and changes corresponding to water age:

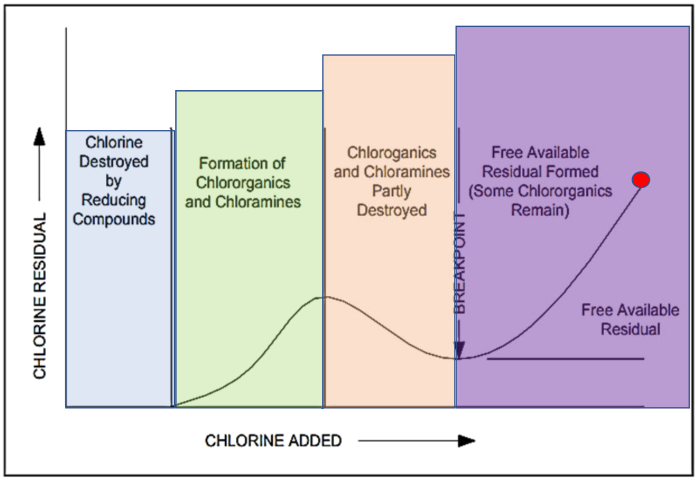
- increase in disinfection byproducts,
- increased bacterial growth, and
- decay of disinfection residual

Part 1

Dose and residual concepts



Total residual as chlorine concentration increases



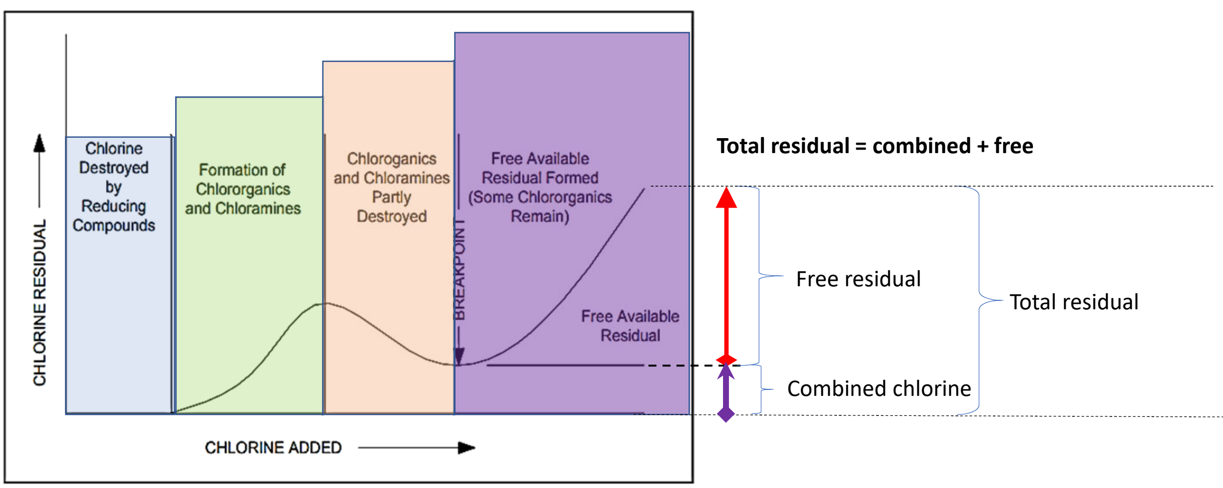
A: Reducing compounds use up a portion of the chlorine dose.

B: Chloramines produced from reactions with organics and nitrogen compounds.

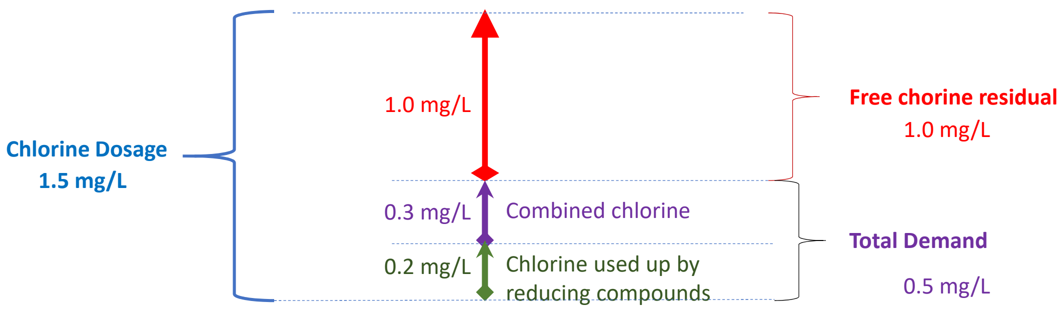
C: Chloramines destroyed by increased chlorine concentration

D: After the "breakpoint" all demand is satisfied and free residual begins to build

Residual components after breakpoint

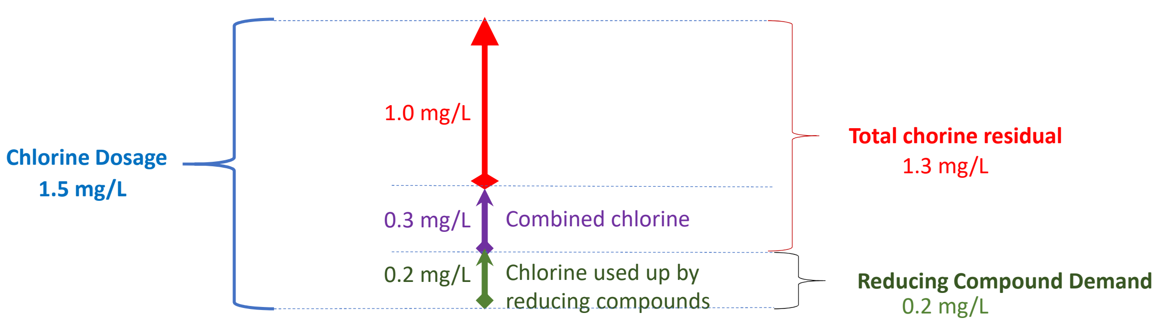


Dose = total demand + free Residual



1.5 mg/L = 1.0 mg/L free residual + 0.5 mg/L demand

Dose = reducing compound demand + total Residual



1.5 mg/L = 1.3 mg/L total residual + 0.2 mg/L reducing compound demand

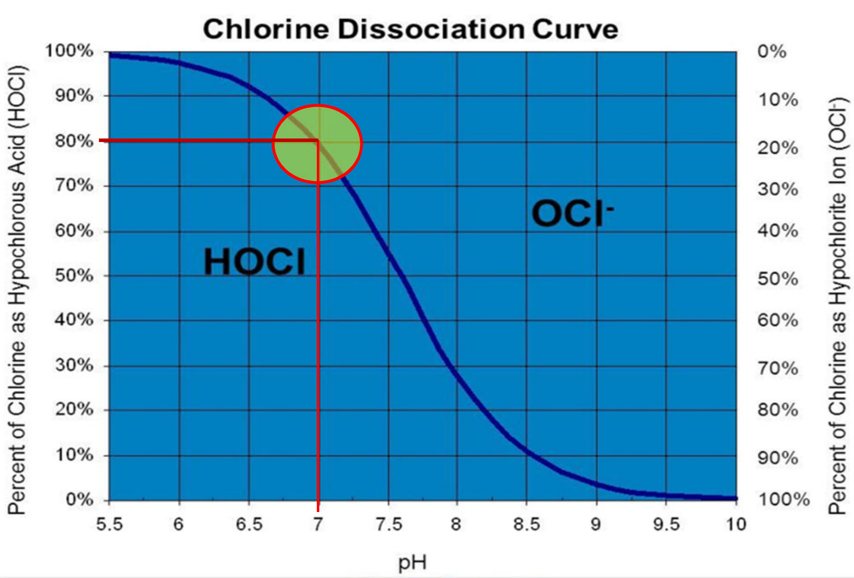
Dose = Demand + Residual

What dosage should be applied to a drinking water with a total demand of 0.4mg/L if the intended free residual is 1.2mg/L?

Solution: Add demand and intended residual

Dose = **0.4mg/L** demand + **1.2mg/L** residual = **1.6mg/L**

The effect of water pH on free chlorine residual



Notes:

Free chlorine residual consists of unreacted

- hypochlorous acid (HOCL) and
- hypochlorite ion (OCL-)

Hypochlorous acid is more effective because it has a greater ability to oxidize pathogens.

From the graph we see that at a pH of 7.0, free residual is

- 80% HOCL and
- 20% is OCL-

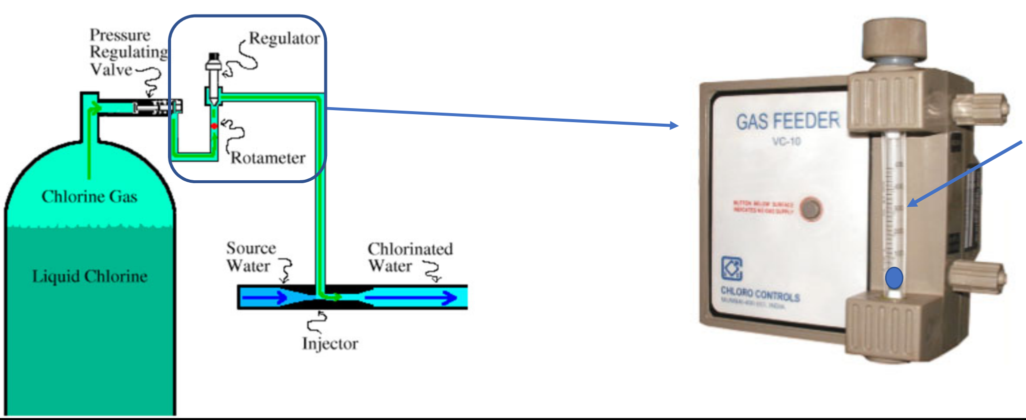
Part 2 Feed rate calculations

Two points to keep in mind:

1. The goal in all chlorine feed rate equations is to provide the correct amount of **elemental or pure chlorine** necessary to obtain the intended dosage, regardless of the chlorine product type.
2. Feed rates are calculated to be **proportional** to water flow.

Pounds Formula for gas chlorine

Pounds per Day = MGD(flow) x mg/L(dose) x 8.34 lbs/gallon



Rotameter will provide units in lbs/day

Pounds Formula Example

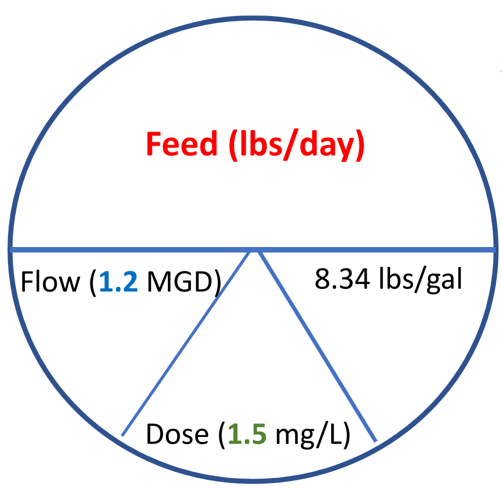
What is the feed rate setting for chlorine gas in lbs/day if the plant flow 1.2 MGD and the required dosage concentration 1.5 mg/L?

Solution: Using the pounds formula equation, plug in 1.2 MGD for flow, and 1.5 mg/L for dosage into the formula.

Chlorine Feed in lbs/day

1.2 MGD x 1.5 mg/L x 8.34 lbs./gal = 15 lbs./day

Solving the same problem with a pie formula



The unknown value is placed on the left of the equal sign, and all the other values on the right.

Feed (lbs./day) = 1.2 MGD x 1.5 mg/L x 8.34lb/gal

= 15 lbs/day

Multiply across bottom to solve top of chart.

Solving for dosage with the pounds formula

An operator checks the settings at a treatment plant and notes that the chlorine feed rate is set at 30 pounds per day and that the plant flow is 2.1 MGD. What is the dose of chlorine in mg/L that is being administered to this water source?

Step 1: Plug the known values into the Pounds Formula.

$$\text{30 pounds per day} = \boxed{\text{2.1 MGD}} \times \textbf{dose(mg/L)} \times \boxed{\text{8.34 lb/gal}}$$

Step 2: Divide both sides of the equation by (2.1 MGD x 8.34lb/gal)

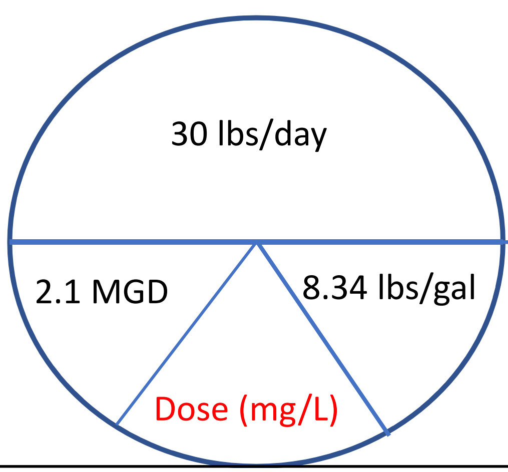
$$\frac{\text{30 pounds per day feed}}{\text{2.1MGD x 8.34lb/gal}} = \frac{\cancel{\text{2.1 MGD}} \times \textbf{dose(mg/L)} \times \cancel{\text{8.34 lb/gal}}}{\cancel{\text{2.1MGD}} \times \cancel{\text{8.34lb/gal}}}$$

Step 3: Cancel like terms. Write and solve the simplified equation.

$$\frac{\text{30 pounds per day feed}}{\text{2.1 MGD x 8.34 lbs./gal}} = \text{dose (mg/L)} \quad = \textbf{1.71 mg/L}$$

Solving the same problem with a pie formula

An operator checks the settings at a treatment plant and notes that the chlorine feed rate is set at 30 pounds per day and that the plant flow is 2.1 MGD. What is the dose of chlorine in mg/L that is being administered to this water source.



$$\text{Dose} = \frac{\textbf{30 Pounds per day feed}}{\textbf{2.1 MGD x 8.34 lb/gal}} = \textbf{1.71 mg/L}$$

Calculating Feed Rates for Sodium Hypochlorite

$$\text{Gallons per day} = \frac{\boxed{\text{MGD x mg/L x 8.34 lbs./day}}}{\boxed{\text{\%strength}} \text{ x } \boxed{\text{weight per gallon}}}$$

Top part of equation calculates lbs of pure Cl

Dividing by % strength gives weight of sodium hypochlorite liquid actually needed.

Dividing by weight per gallon will give you the number of gallons needed per day.

$$\textbf{Gallons per day} = \frac{\textbf{MGD x mg/L x 8.34 lbs/day}}{\textbf{\%strength x } \boxed{\textbf{s.g. x 8.34 lb/gal}}}$$

Weight per gallon

Liquid chemical weight.

Calculate the weight of 1 gallon of 12.5% sodium hypochlorite, assuming it has a specific weight of 1.2.

Solution: Multiple the weight of water by the specific weight of 1.2.

1.2 x 8.34 lbs./gal = 10 lbs./gal

Percent Strength is based on the weight of chlorine compared to total weight.

1 gallon of 12.5% strength sodium hypochlorite weighs 10 lbs and contains1.25 lbs. of pure chlorine. (0.125 x 10 lbs. = 1.25 lbs).

Sodium Hypochlorite Feed Rate example

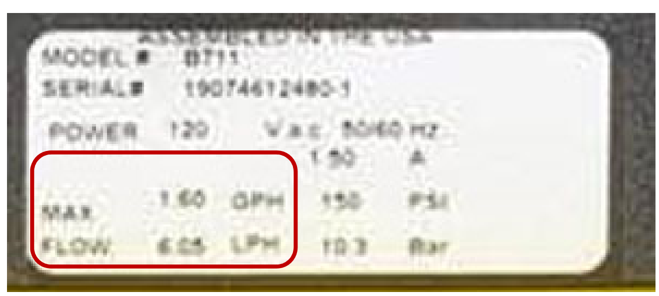
What is the feed rate in gallons per day for 12.5% sodium hypochlorite with a s.g. of 1.2 when the plant flow is 0.5 MGD and the intended dosage is 0.9 mg/L?

Solution: Use the following formula, and plug in values for flow, dosage, specific gravity, and solution strength.

$$\text{Gallons per day} = \frac{\text{Flow (MGD)} \times \text{Conc. (mg/L)} \times 8.34 \text{ lbs/day}}{\text{\%strength} \times \text{s.g.} \times 8.34 \text{ lb/gal}}$$

$$\frac{0.5 \text{ MGD} \times 0.9 \text{ mg/L} \times 8.34 \text{ lb/gal}}{0.125 \times 1.2 \times 8.34 \text{ lb/gal}} = 3 \text{ gallons per day}$$

Chemical pump feed setting and sizing



Max Flow given as **1.6 GPH**

When speed and stroke are both set to 100%

Chemical Feed Pump Output Calculation

A chemical feed pump is rated for a maximum flow of 1.0 gallons per hour (gph). What is the actual output of the pump if both the stroke and speed are set at 70%.

Actual Output = **Max Output x [%Stroke x % Speed]**

We will use the decimal equivalent of 70% which is 0.7 for the stroke and speed.

Actual output = 1.0 gph x (0.7 speed x 0.7 stroke) = 0.49 gph

Notice that this setting produces about 0.5 gph which is half the pump's maximum capacity of 1.0 gph.

Also, ***0.49 gph*** *x 24 hrs./day =* ***11. 76*** *Gallons per day*

Calcium Hypochlorite (high test hypochlorite or HTH)

Top part of equation calculates lbs of pure Cl

$$\textbf{Lbs/day} = \frac{\textbf{Flow in MGD x Dose in mg/L x 8.34 lbs./gal}}{\textbf{\% strength of HTH}}$$

Dividing by % strength gives weight of material needed.

Calcium hypochlorite can be in the form of tablets, pellets, or powder. It is generally 65% to 70% strength.

Calcium Hypochlorite feed rate calculation

Calculate the feed rate for 68% strength calcium hypochlorite when the plant flow is 0.5 MDG and the desired dose is 1.2 mg/L.

Solution: Use formula for HTH feed rate; plug in flow, dose, and chemical strength.

$$\text{Lbs/day} = \frac{\text{Flow in MGD} \times \text{Dose in mg/L} \times 8.34 \text{ lbs./gal}}{\text{\% strength of HTH}}$$

$$\frac{0.5 \text{ MGD} \times 1.2 \text{ mg/L} \times 8.34 \text{ lbs./gal}}{0.68} = 7.36 \text{ lb/day}$$

Poll #2

What is the primary type of disinfectant used to inactivate pathogens in your water system?

a) Gas chlorine
b) Sodium or calcium hypochlorite
c) Ozone
d) UV
e) Something else (please share in the chat)

Part 3: CT Calculations

CT is the concentration of chlorine in mg/L multiplied by contact time in minutes used for disinfection compliance.

- 3-log inactivation of Giardia (99.9%)
- 4-log inactivation of viruses (99.99%)

Example: **Water is disinfected with a free chlorine residual of 2 mg/L and a contact time of 30 minutes. What CT value has been achieved?**

2 mg/L x 30 minutes = **60 mg-min/L**

Using a CT table for 4-log inactivation of viruses with chlorine

Temperature (°C)	Log Inactivation1	
	4.0	
	pH 6-9	pH 10
0.5	12	90
5	8	60
10	6	45
15	4	30
20	3	22
25	2	15

To use the table
Match the daily minimum temperature and daily maximum pH of your water source.

1. The temperature of your water is 15 degrees C
2. The pH of your water is 7.5
3. The table indicates we need to attain a CT value of 4 or greater to order to satisfy 4-log inactivation of viruses.
4. Example: A residual of 1 mg/L x 4 minutes of contact time would just satisfy the required level of inactivation.

CT table for 3-log inactivation of Giardia with chlorine (for 15C)

To use the table: Match the daily minimum temperature and daily maximum pH of your water source with the minimum daily free chlorine residual. Different Giardia CT tables are used for different temperature ranges, and chlorine residual also affects required CT.

Example: Temperature =15 C | pH = 7.0 | Residual = 0.8 mg/L ➔ **Required CT** = **73**

Table C-4. CT Values for Inactivation of Giardia Cysts by Free Chlorine at 15°C

CHLORINE CONCENTRATION (mg/L)	pH<=6 Log Inactivation						pH=6.5 Log Inactivation						pH=7.0 Log Inactivation						pH=7.5 Log Inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	8	16	25	33	41	49	10	20	30	39	49	59	12	23	35	47	58	70	14	28	42	55	69	83
0.6	8	17	25	33	42	50	10	20	30	40	50	60	12	24	36	48	60	72	14	29	43	57	72	86
0.8	9	17	26	35	43	52	10	20	31	41	51	61	12	24	37	49	61	73	15	29	44	59	73	88
1	9	18	27	35	44	53	11	21	32	42	53	63	13	25	38	50	63	75	15	30	45	60	75	90
1.2	9	18	27	36	45	54	11	21	32	43	53	64	13	25	38	51	63	76	15	31	46	61	77	92
1.4	9	18	28	37	46	55	11	22	33	43	54	65	13	26	39	52	65	78	16	31	47	63	78	94
1.6	9	19	28	37	47	56	11	22	33	44	55	66	13	26	40	53	66	79	16	32	48	64	80	96
1.8	10	19	29	38	48	57	11	23	34	45	57	68	14	27	41	54	68	81	16	33	49	65	82	98
2	10	19	29	39	48	58	12	23	35	46	58	69	14	28	42	55	69	83	17	33	50	67	83	100
2.2	10	20	30	39	49	59	12	23	35	47	58	70	14	28	43	57	71	85	17	34	51	68	85	102
2.4	10	20	30	40	50	60	12	24	36	48	60	72	14	29	43	57	72	86	18	35	53	70	88	105
2.6	10	20	31	41	51	61	12	24	37	49	61	73	15	29	44	59	73	88	18	36	54	71	89	107
2.8	10	21	31	41	52	62	12	25	37	49	62	74	15	30	45	59	74	89	18	36	55	73	91	109
3	11	21	32	42	53	63	13	25	38	51	63	76	15	30	46	61	76	91	19	37	56	74	93	111

Combined log removal and inactivation

FILTRATION TREATMENT TECHNOLOGY	COMBINED FILTER EFFLUENT (CFE) TURBIDITY (95% MNTHLY/MAX) ntu	MAXIMUM LOGS OF CREDIT FOR PHYSICAL REMOVAL			MINIMUM LOGS OF INACTIVATION NEEDED BY DISINFECTION	
		Cryptosporidium	*Giardia*	Viruses	*Giardia*	Viruses
Conventional	*** 0.3/1	>2	2.5	2.0	0.5	2.0
Direct	***0.3/1	>2	2.0	1.0	1.0	3.0
Slow Sand	1/5	>2	2.0	2.0	1.0	2.0
Diatomaceous Earth	1/5	>2	2.0	1.0	1.0	3.0
Reverse Osmosis	0.3/1	>2	>3.0	3.0	0	1.0

Understanding Log Treatment Levels

Given

- 3 log treatment means 99.9% removal or inactivation.
- 4 log treatment means 99.99% removal or inactivation
- The term log refers to an exponent of 10

Illustrative Example

A quantity of raw water contains 1,000,000 microbes and receives 4-log treatment to remove 99.99%.

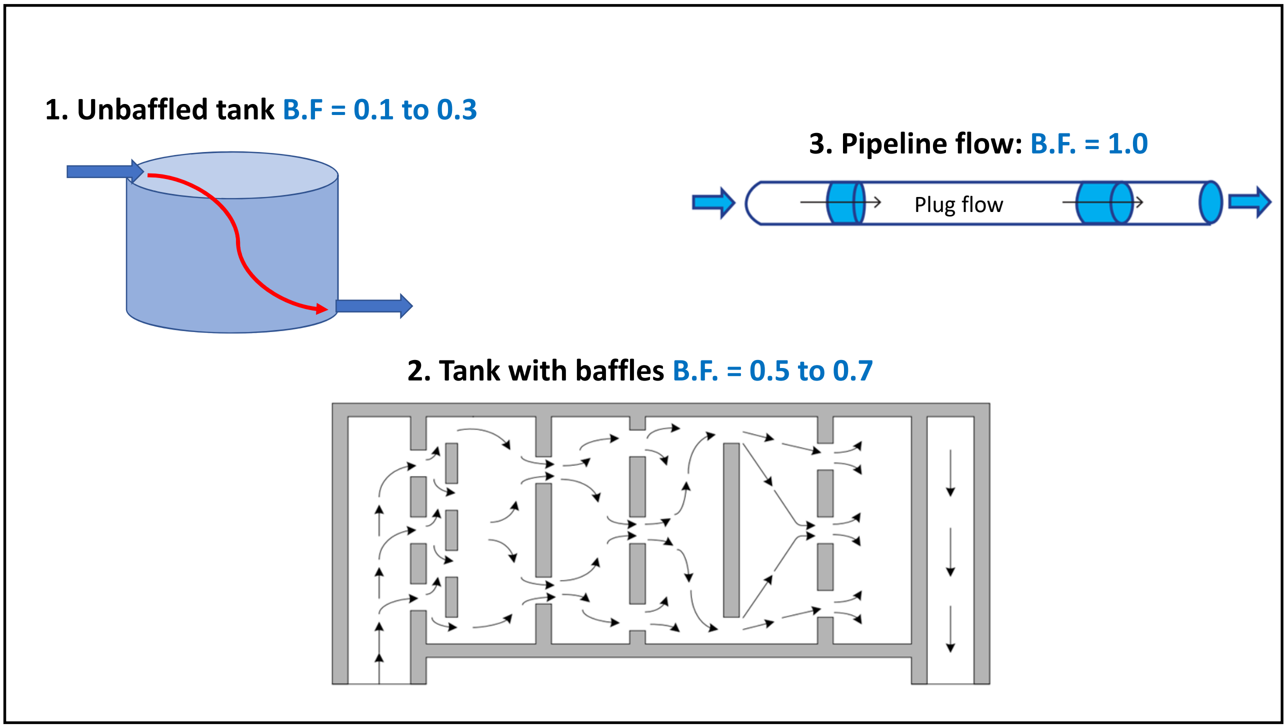
*1,000,000 microbes – [**1,000,000 x 0.9999**] = 100 microbes remaining*

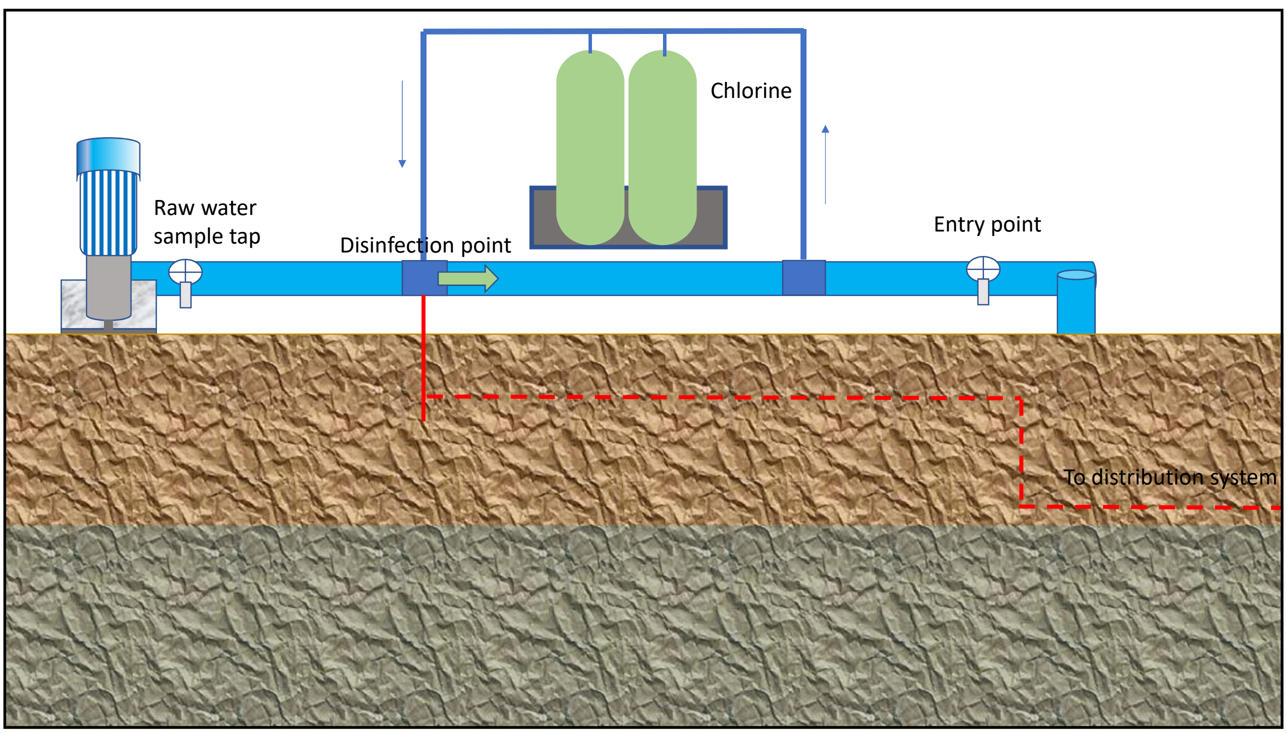
Take aways:

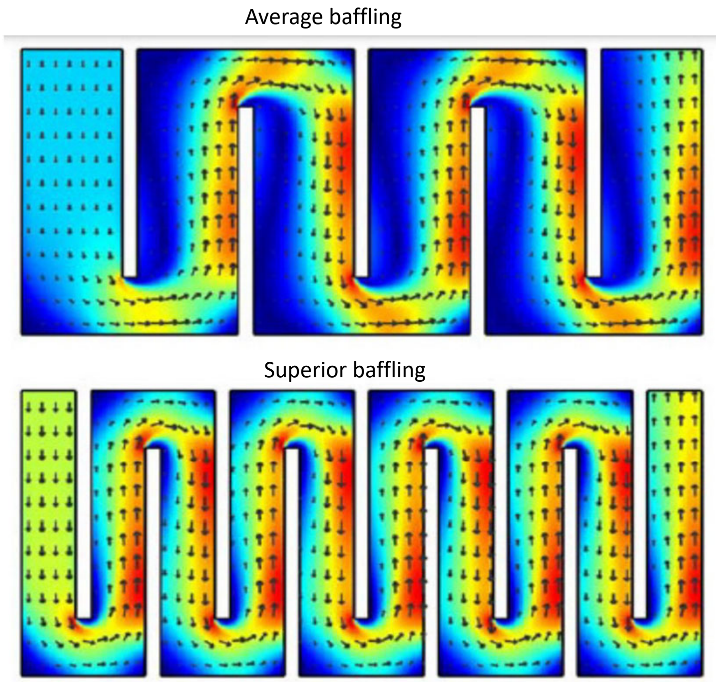
- The quantity of 10^6 microbes was reduced to 10^2.
- The reduction factor is 10,000 [*10,000 x 100 = 1,000,000*]
- This reduction factor can be expressed as 10^4, or 4-log:

Baffling factor indicates the degree to which a tank is protected against short circuiting.

Baffling Condition	Baffling Factor	Baffling Description
Unbaffled (mixed flow)	0.1	None, agitated basin, very low length to width ratio, high inlet and outlet flow velocities.
Poor	0.3	Single or multiple unbaffled inlets and outlets, no intra-basin baffles.
Average	0.5	Baffled inlet or outlet with some intra-basin baffles.
Superior	0.7	Perforated inlet baffle, serpentine or perforated intra-basin baffles, outlet weir, or perforated launders.
Perfect (plug flow)	1.0	Very high length to width ratio (pipeline flow), perforated inlet, outlet and intra-basin baffles.


1. Unbaffled tank B.F = 0.1 to 0.3
3. Pipeline flow: B.F. = 1.0
Plug flow
2. Tank with baffles B.F. = 0.5 to 0.7

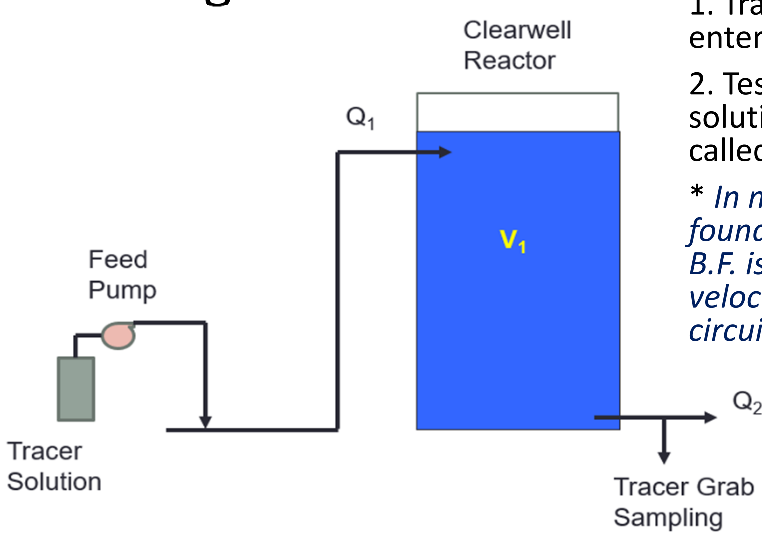

Chlorine
Raw water sample tap
Disinfection point
Entry point
To distribution system



Baffled flow models comparing average to superior baffling.

- Dark blue areas represent low velocity and inadequate mixing.
- Orange – red indicate higher velocities.
- Less dark blue for the superior baffled tank

Conducting a tracer test to determine actual baffling factor

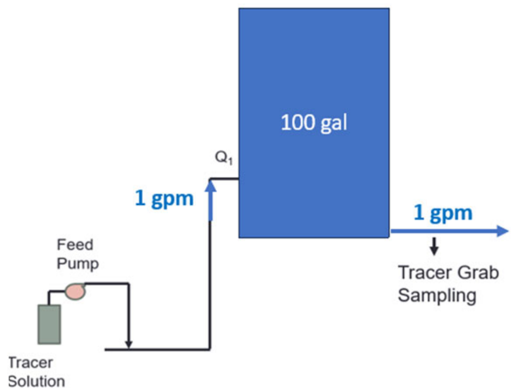


1. Tracer solution is added to water entering the basin.
2. Test is run until 10% of the tracer solution exits the tank (this time is called T10)

* *In multiple studies, B.F. has been found to change with flow, generally B.F. is lower with higher water velocities indicating greater short-circuiting.*

Simplified tracer test example

A 100-gallon tank has a flow through rate of 1 gpm. 10% of the tracer was found to exit the tank after 50 minutes.

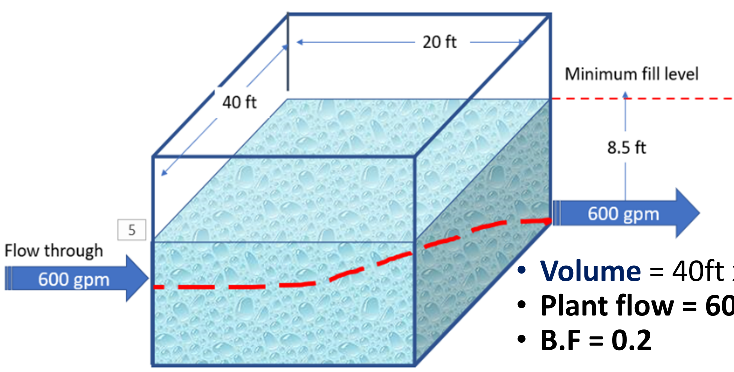


The baffling factor can be found using the ratio of T10 to theoretical contact time.

B.F. = 50 min/100 min = 0.5

Another way to think about this example is that it should take 100 minutes for the tracer to appear, however the tank functions like a tank half the size due to short-circuiting.

Contact Time and Short-circuiting



- **Volume** = 40ft x 20ft x 8.5 ft x 7.48gal/cf = **50,864 gal**
- **Plant flow = 600 gpm**
- **B.F = 0.2**

Theoretical Time = Volume (gallons) / Flow (gpm)

Time = 50,864 gal / 600 gpm = **84.77 minutes**

Chlorine Contact Time = Volume (gal) x **B.F.** / Flow (gpm)

Time = 50,864 gal x **0.2** / 600 gpm = **16.95 minutes**

Poll #3

How is chlorine contact time achieved in your drinking water system?

a) Water is disinfected as it flows through the pipeline between the wellhead and the first customer in the distribution system.
b) Water enters a baffled clear well after treatment to ensure adequate disinfection prior to entering the distribution system.
c) Water enters a storage tank where contact time is provided before entering the distribution system piping.
d) Something else (please share in the chat)

Log 4 Virus Inactivation Problem

A small ground water system maintains a minimum free chlorine residual of 0.8 mg/L. Contact time is provided by a 3,500-gallon pneumatic storage tank with a B.F. of 0.3. Maximum flow through the tank is 200 GPM. Determine if the system is attaining sufficient CT for 4-log virus inactivation when the water temp is 15 C and water pH is 8.5.

Step 1: Determine actual contact time.

$$\text{Time} = \frac{3{,}500 \text{ gallons} \times 0.3}{200 \text{ gpm}} = 5.25 \text{ minutes}$$

Step 2: Calculate actual CT being attained

0.8 mg/L x 5.25 minutes = 4.2 mg-min/L

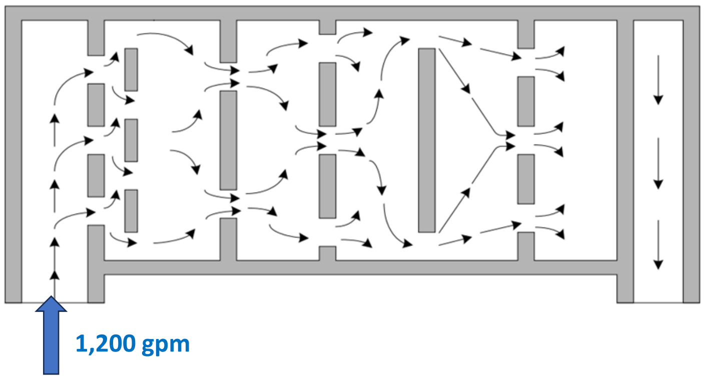
Step 3: Compare actual CT with required log 4 CT

Required CT for this pH and temp is 4.0. Actual CT is slightly greater; therefore, CT for log 4 virus is met.

Temperature (°C)	Log Inactivation1	
	4.0	
	pH 6-9	pH 10
0.5	12	90
5	8	60
10	6	45
15	4	30
20	3	22
25	2	15

Log 3 Giardia Inactivation Problem (1 of 2)

A water system treats a flow of 500 gpm. Immediately after filtration the water is dosed with a 1.5 mg/L dose of gas chlorine and enters a 50,000-gallon clear well that has a baffling factor of 0.6. Minimum water temperature is 15 C , maximum pH is 7.0, and the minimum free chlorine residual is 1.4 mg/L. Determine if the system has sufficient CT for achieve 3-log inactivation of Giardia



Step 1: Calculate contact time

Time = $\frac{50{,}000 \text{ gal} \times 0.6}{500 \text{ gpm}}$ = **60 min**

Step 2: Calculate CT achieved

CT = 60 min x 1.4 mg/L = **84 mg-min/L**

Next: ***Remember our calculated CT of 84 as we compare with the inactivation table in the next screen.***

Log 3 Giardia Inactivation Problem (2 of 2)

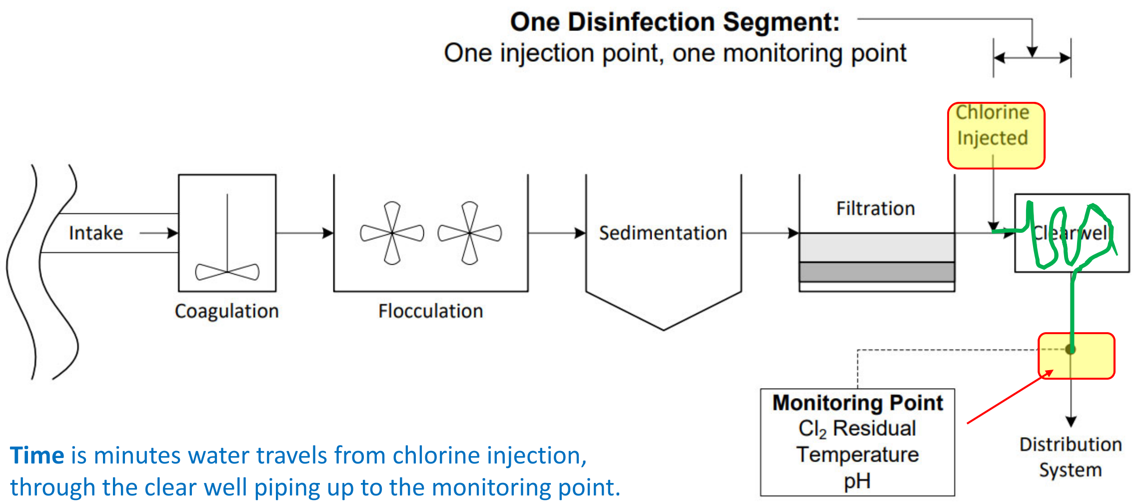
Find the required CT on the Giardia inactivation table using water temperature of 15 C , maximum pH of 7.0, and the minimum free chlorine residual of 1.4 mg/L.

We find the required CT is 78 mg-min/L and our actual **CT is 84 mg-min/L**. Therefore, our plant meets inactivation requirements.

Table C-4. CT Values for Inactivation of Giardia Cysts by Free Chlorine at 15°C

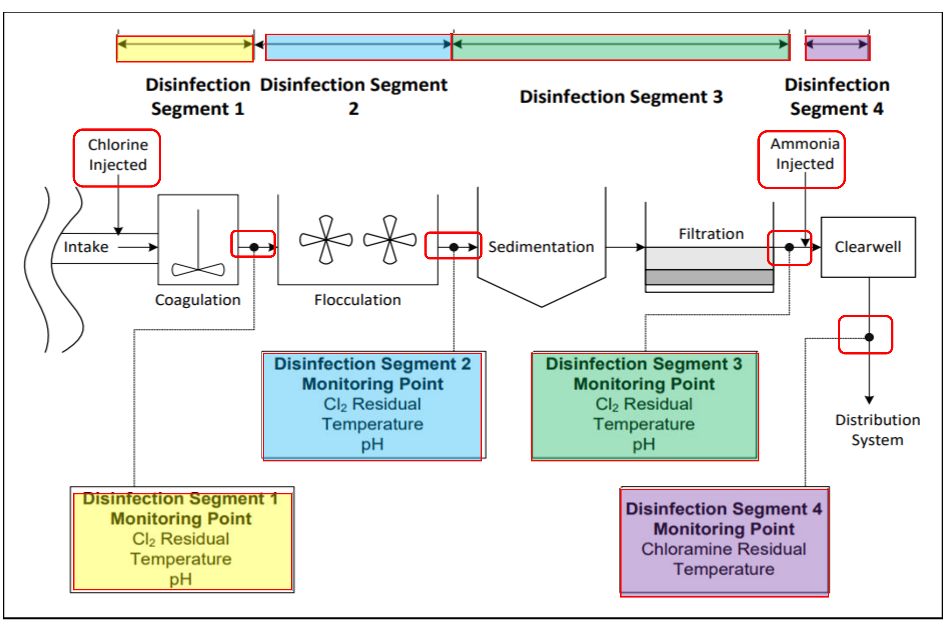
CHLORINE CONCENTRATION (mg/L)	pH<=6 Log Inactivation						pH=6.5 Log Inactivation						pH=7.0 Log Inactivation						pH=7.5 Log Inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	8	16	25	33	41	49	10	20	30	39	49	59	12	23	35	47	58	70	14	28	42	55	69	83
0.6	8	17	25	33	42	50	10	20	30	40	50	60	12	24	36	48	60	72	14	29	43	57	72	86
0.8	9	17	26	35	43	52	10	20	31	41	51	61	12	24	37	49	61	73	15	29	44	59	73	88
1	9	18	27	35	44	53	11	21	32	42	53	63	13	25	38	50	63	75	15	30	45	60	75	90
1.2	9	18	27	36	45	54	11	21	32	43	53	64	13	25	38	51	63	76	15	31	46	61	77	92
1.4	9	18	28	37	46	55	11	22	33	43	54	65	13	26	39	52	65	78	16	31	47	63	78	94
1.6	9	19	28	37	47	56	11	22	33	44	55	66	13	26	40	53	66	79	16	32	48	64	80	96
1.8	10	19	29	38	48	57	11	23	34	45	57	68	14	27	41	54	68	81	16	33	49	65	82	98
2	10	19	29	39	48	58	12	23	35	46	58	69	14	28	42	55	69	83	17	33	50	67	83	100
2.2	10	20	30	39	49	59	12	23	35	47	58	70	14	28	43	57	71	85	17	34	51	68	85	102
2.4	10	20	30	40	50	60	12	24	36	48	60	72	14	29	43	57	72	86	18	35	53	70	88	105
2.6	10	20	31	41	51	61	12	24	37	49	61	73	15	29	44	59	73	88	18	36	54	71	89	107
2.8	10	21	31	41	52	62	12	25	37	49	62	74	15	30	45	59	74	89	18	36	55	73	91	109
3	11	21	32	42	53	63	13	25	38	51	63	76	15	30	46	61	76	91	19	37	56	74	93	111

Disinfection Segments: Plant with 1 segment



1. **Time** is minutes water travels from chlorine injection, through the clear well piping up to the monitoring point.
2. **Concentration** is the chlorine residual in mg/L at the monitoring pt.

Disinfection Segments: Plant with multiple segments



Segment 1 = 0.5 log
Segment 2 = 0.5 log
Segment 3 = 1.0 log
Segment 4 = 2.0 log

Total Log = 4.0 log

Calculate log inactivation levels

Uses

1. Adding disinfection segments.
2. Summation of removal Log credits and calculated disinfection log inactivation
3. For creating a disinfection profile

Formulas for Log Inactivation of Giardia and Viruses

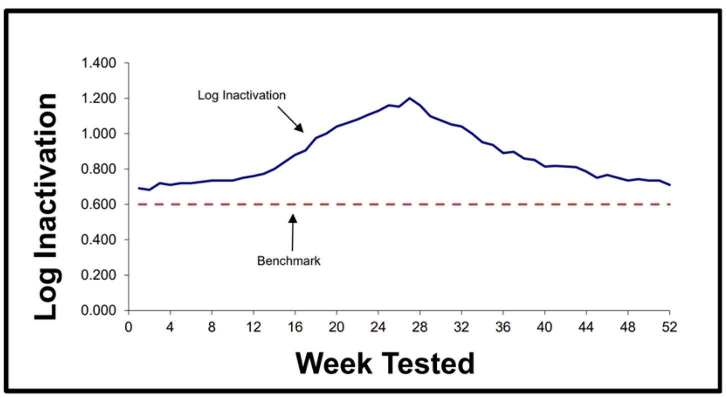
Giardia Log Inactivation = 3 x (CTcalc / CT99.9)

Virus Log Inactivation = 4 x (CTcalc / CT99.99)

Example: **The Giardia table shows that a CT of 137 is required for 3 log inactivation, however the calculated CT value is 71. How many logs have been achieved?**

Log inactivation = **3** x $\frac{71 \text{ min-mg/L}}{137 \text{ min-mg/L}}$ = **0.518 Log**

Creating a disinfection profile



1. Calculate the log inactivation level achieved each week for 1-year.
2. Average the data for each month
3. Benchmark is the month with the lowest average log inactivation (baseline).
4. Allows you to compare disinfection effectiveness over time and if there are changes made.

Disinfection Profiling and Benchmarking Technical Guidance Manual. USEPA (2020).

Poll #4

A water treatment plant has a clear well that provides 40 minutes of contact time with a free chlorine residual of 0.9 mg/L. The Giardia inactivation table shows that 3-log inactivation requires at CT of 74.

How many logs of inactivation treatment are being provided by the disinfection process? Select the closest answer.

a) 0.5 Log
b) 1.0 Log
c) 1.5 Log
d) 2.5 Log

Solution:

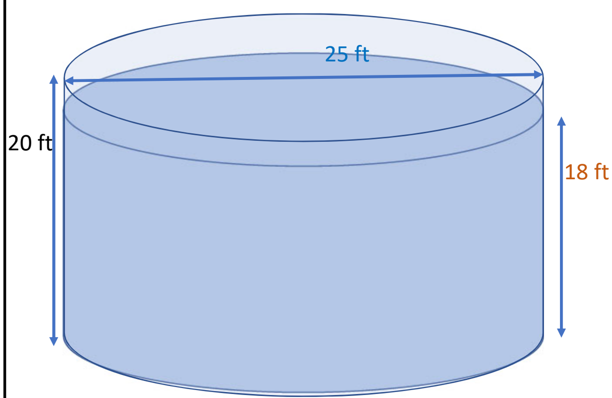
1. CT calc = 40 x 0.9 = **36 mg-min/L**
2. Log Inactivation (Giardia) = 3 x 36/74 = **1.495 Log**
3. Round to **1.5 Log**

Part 4

Challenge/Combination Problems

Challenge problem 1: Contact time and baffling factor

A cylindrical tank has a diameter of 25 feet and a height of 20 feet if the tank is filled to a height of 18-foot. Calculate the theoretical and actual detention time for this tank if the flow through the tank is 600 gallons per minute and the baffling factor is 0.1



Solution

Step 1: Find volume in gallons

V = D^2 x 0.785 x H x **7.48 gal/cf**

25ft x 25ft x 0.785 x 18ft x 7.48gal/cf = **66,057.75 gal**

Step 2: Calculate theoretical detention time

$\frac{66{,}058 \text{ gal}}{600 \text{ gpm}}$ = **110 minutes**

Step 3: Calculation chlorine contact time

$\frac{66{,}058 \text{ gal} \times 0.1}{600 \text{ gpm}}$ = **11 minutes**

Challenge problem 2: CT values and Log treatment (1 of 2)

A direct filtration plant receives 2-Log removal credit and needs to achieve 1 additional log through disinfection for 3 Log Giardia treatment. The required CT from the table below is 78 for 3 log Giardia treatment with a water temperature of 15 C, pH of 7.0, and chlorine concentration of 1.4 mg/L.

The chlorine contact basin is a 50,000-gallon tank with a baffling factor of 0.6.

Plant flow is 2 MGD. How many logs of inactivation are supplied by the disinfection process? Is the system in compliance?

Table C-4. CT Values for Inactivation of Giardia Cysts by Free Chlorine at 15°C

CHLORINE CONCENTRATION (mg/L)	pH<=6 Log Inactivation						pH=6.5 Log Inactivation						pH=7.0 Log Inactivation						pH=7.5 Log Inactivation					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	8	16	25	33	41	49	10	20	30	39	49	59	12	23	35	47	58	70	14	28	42	55	69	83
0.6	8	17	25	33	42	50	10	20	30	40	50	60	12	24	36	48	60	72	14	29	43	57	72	86
0.8	9	17	26	35	43	52	10	20	31	41	51	61	12	24	37	49	61	73	15	29	44	59	73	88
1	9	18	27	35	44	53	11	21	32	42	53	63	13	25	38	50	63	75	15	30	45	60	75	90
1.2	9	18	27	36	45	54	11	21	32	43	53	64	13	25	38	51	63	76	15	31	46	61	77	92
1.4	9	18	28	37	46	55	11	22	33	43	54	65	13	26	39	52	65	78	16	31	47	63	78	94
1.6	9	19	28	37	47	56	11	22	33	44	55	66	13	26	40	53	66	79	16	32	48	64	80	96
1.8	10	19	29	38	48	57	11	23	34	45	57	68	14	27	41	54	68	81	16	33	49	65	82	98
2	10	19	29	39	48	58	12	23	35	46	58	69	14	28	42	55	69	83	17	33	50	67	83	100
2.2	10	20	30	39	49	59	12	23	35	47	58	70	14	28	43	57	71	85	17	34	51	68	85	102
2.4	10	20	30	40	50	60	12	24	36	48	60	72	14	29	43	57	72	86	18	35	53	70	88	105
2.6	10	20	31	41	51	61	12	24	37	49	61	73	15	29	44	59	73	88	18	36	54	71	89	107
2.8	10	21	31	41	52	62	12	25	37	49	62	74	15	30	45	59	74	89	18	36	55	73	91	109
3	11	21	32	42	53	63	13	25	38	51	63	76	15	30	46	61	76	91	19	37	56	74	93	111

Challenge problem 2: CT values and Log treatment solution (2 of 2)

A direct filtration plant receives 2-Log removal credit and needs to achieve 1 additional log through disinfection for 3 Log Giardia treatment. The required CT is 78 for a water temperature of 15 C, pH of 7.0, and chlorine concentration of 1.4 mg/L.
The chlorine contact basin is a 50,000 gallon tank with a baffling factor of 0.6. Plant flow is 2 MGD. How many logs of inactivation are supplied by the disinfection process? Is the system in compliance?

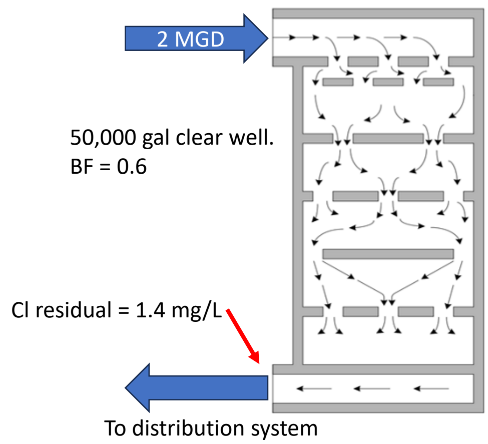
Step 1: Convert 2MGD to gallons per minute
*2,000,000 gpd ÷ 1,440 min/day = **1,389 GPM***

Step 2: Calculate contact time
$\dfrac{50{,}000 \text{ gal} \times 0.6}{1{,}389 \text{ gpm}} = \mathbf{21.6 \text{ minutes}}$

Step 3: Calculate CT
*1.4 mg/L x 21.6 min = **30.24 min-mg/L***

Step 4: Calculate Log inactivation:
$3 \times \dfrac{30.24}{78} = \mathbf{1.16 \text{ LOG}}$

System is in compliance: Total Log = 2 + 1.16 = 3.16 LOG



Challenge problem 3: Feed rate and dosage

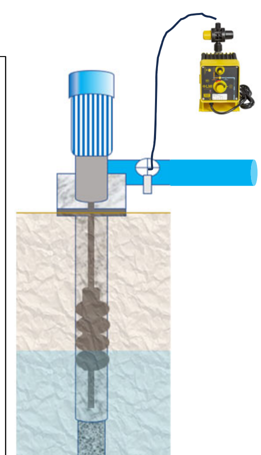
A groundwater well produces drinking water with a chlorine demand of 0.2 mg/L and has a flow of 600 GPM. Calculate the feed rate for 12.5% sodium hypochlorite with a specific weight of 1.2 if the desired residual is 1.1 mg/L.

Solution:

Step 1: Convert flow from GPM to MGD.
$\dfrac{600 \text{ GPM} \times 1{,}440 \text{ min/day}}{1{,}000{,}000 \text{ gal/MG}} = \mathbf{0.864 \text{ MGD}}$

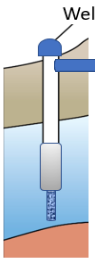
Step 2: Calculate dosage using Dose = demand + residual.
Dose = 0.2 mg/L + 1.1 mg/L = 1.3 mg/L

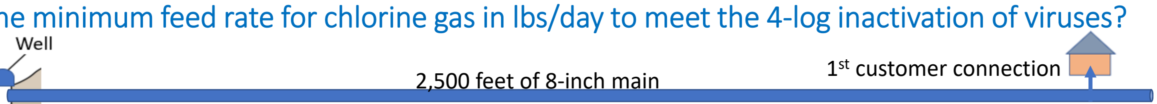
Step 3: Use the liquid sodium hypochlorite formula for feed in gallons per day.
$\dfrac{0.864 \text{ MGD} \times 1.3 \text{ mg/L} \times 8.34 \text{ lbs./gal}}{0.125 \times 1.2 \times 8.34 \text{ lbs./gal}} = \mathbf{7.49 \text{ gallons per day}}$



Challenge problem 4: CT for Virus inactivation

A groundwater system produces a flow of 2 cfs that travels from the injection point through 2,500 feet of 8-inch water main water before reaching the first customer connection. The water has a chlorine demand of 1.4 mg/L, a pH of 6.5, and an average temperature of 5 degrees Celsius. What is the minimum feed rate for chlorine gas in lbs/day to meet the 4-log inactivation of viruses?





Step 1: Convert flow from cfs to gpm and MGD.

2 cfs x 7.48gal/cf x 60sec/min = **897.6 gpm**

$$\frac{897.6 \text{ gpm} \times 1{,}440 \text{ min/day}}{1{,}000{,}000 \text{ gal/MG}} = \textbf{1.293 MGD}$$

Step 2: Calculate contact time

Volume of pipe = 0.67ft x 0.67ft x 0.785 x 2,500 ft x 7.48 gal/cf = 6,589.6 gal

Contact time = Vol/flow = 6,589.6 gal ÷ 897.6 gpm = 7.34 minutes

Step 3: Find minimum value for C, the free chlorine residual CT= 8

8 mg-min/L ÷ 7.34 min = **1.09 mg/L** (free residual needed)

Temperature °C	pH 6-9	10
0.5	12	90
5	8	60
10	6	45
15	4	30
20	3	22
25	2	15

Step 5: Determine Dose: Residual + Demand

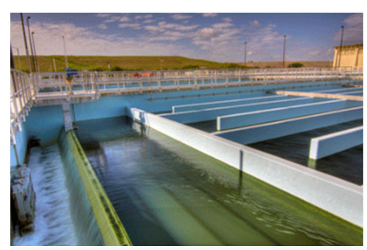
1.09 mg/L + 1.4 mg/L = **2.49 mg/L**

Step 6: Use pounds formula to determine minimum gas chlorine feed rate.

1.293 MGD x **2.49 mg/L** x 8.34 lb/gal = **26.85 lbs/day**

Challenge problem 5: Chlorine used up by demand

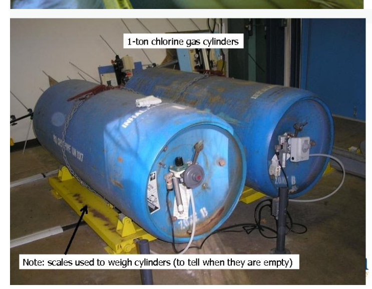
A water system that treats 50 MGD disinfects with gas chlorine and maintains a total residual of 1.75 mg/L. If the system is feeding 1,146 lbs per day of gas chlorine, how much chlorine is used up by reducing compound demand over the period of 1 year?



Step 1: Determine the dose

1,146.75 lbs/day = 50 mgd x **dose** x 8.34lb/gal

$$\frac{1{,}146 \text{ pounds per day}}{50\text{mgd} \times \textbf{8.34 lb/gal}} = 2.75 \text{ mg/L}$$



Step 2: Determine demand (Dose – residual)

Demand = 2.75 mg/L – 1.75 mg/L = **1.0 mg/L**

Step 3: Calculate pounds of Chlorine used up by demand in a year.

50MDG x **1.0 mg/L** x 8.34lb/gal x **365 days** = **152,205 lbs Chlorine**

Recommended Reference Materials

1. **Disinfection Profiling and Benchmarking - Technical Guidance Manual**. EPA 815-R-20-003. USEPA, 2020. https://www.epa.gov/system/files/documents/2022-02/disprof_bench_3rules_final_508.pdf
2. Lanchbery, A. (2019). WIOA. **Guide to the measurement and use of Ct.** https://wioa.org.au/wp-content/uploads/2019/10/Guide-to-the-measurement-and-use-of-Ct.pdf

Poll #5

Which topic area presented in this class do you think is most useful for current or future water quality efforts in your water system? (Select one).

a) Treatment Log calculations
b) Chlorine feed rate calculations
c) CT calculations for inactivation compliance
d) Baffling factors and contact time calculations
e) Something else (place your answer in the comments)

Contact information

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Technical assistance request form: https://gleic.org/form/technical-assistance-request-for

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Great Lakes Environmental Infrastructure Center
Environmental Finance Center for EPA Region 5

Technical assistance services

- Infrastructure funding assistance
- Rates and affordability
- Asset management plans
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- Compliance with regulations
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