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Syracuse University College of Engineering & Computer Science
Environmental Finance Center

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

Chlorine Disinfection

June, 2026 (9:00 am to 3:00 pm EST)

Instructor: Daryl Gotham, PE, Senior Research Engineer

Great Lakes Environmental Infrastructure Center, MTU

This program is made possible under a cooperative agreement with US EPA.

Certificate of Completion

This session has been submitted and received approval for 0.475 Continuing Education Units or 4.75 Contact Hours from the New York State Department of Health, Bureau of Water Supply Protection. Eligible attendees will receive a certificate of attendance for their personal record.

To receive a certificate:

- You must attend the entire session
- You must sign in at the beginning and sign out at the end of the training
- Certificates will be sent via email within 30 days

If you have questions or need assistance, please contact smallsystems@syr.edu.

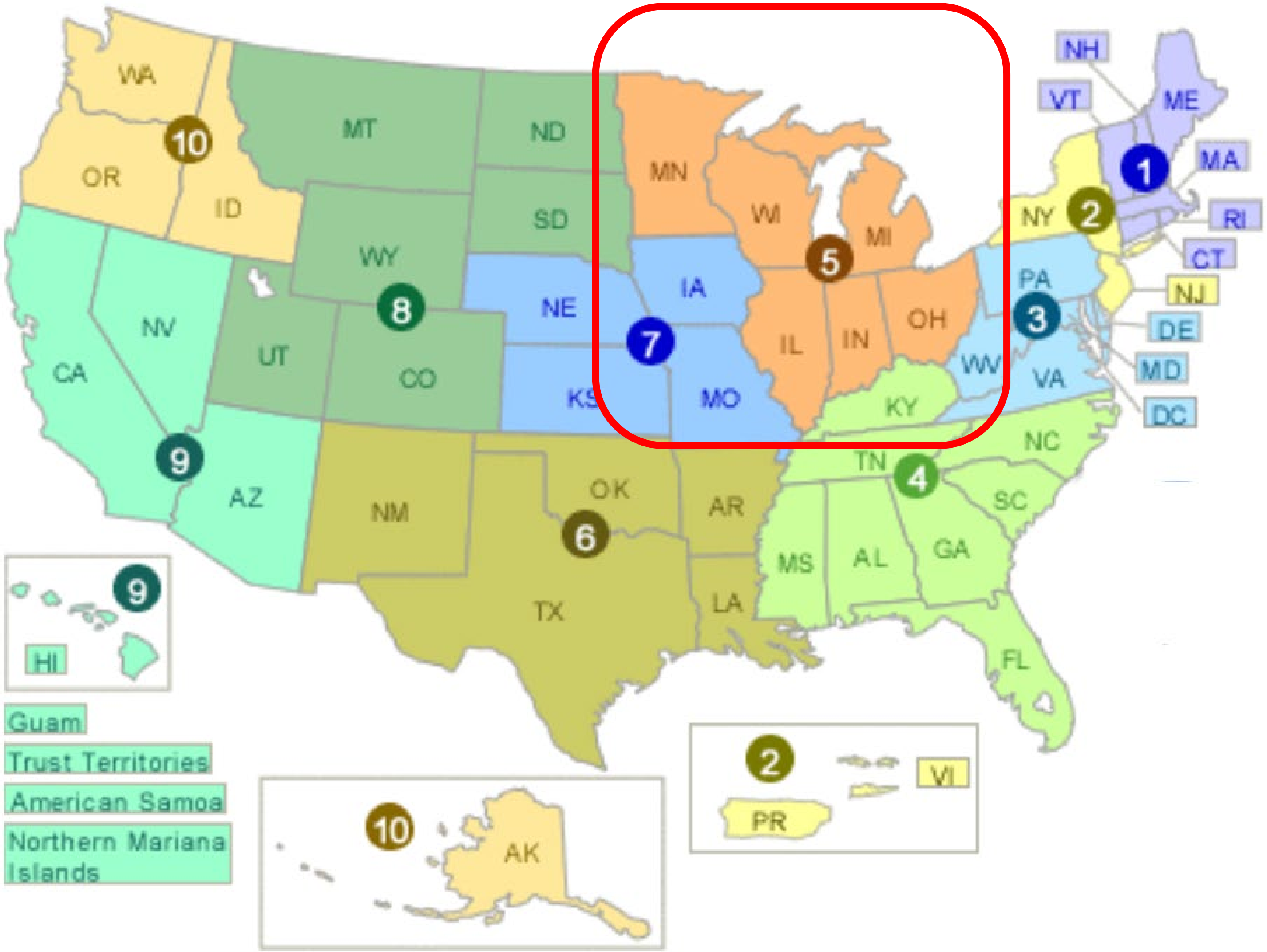
EFCN
environmental finance center network

About Us

The **Environmental Finance Center Network (EFCN)** is a university- and non-profit-based organization creating innovative solutions to the difficult how-to-pay issues of environmental protection and water infrastructure.

The EFCN works collectively and as individual centers to address these issues across the entire U.S, including the 5 territories and the Navajo Nation. The EFCN aims to assist public and private sectors through training, direct professional assistance, production of durable resources, and innovative policy ideas.

Nationwide Reach of EFC Network



EFCN
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Great Lakes Environmental Infrastructure Center

Environmental Finance Center for EPA Region 5

Serve small communities (population of less than 10,000) throughout EPA Region 5: Indiana, Illinois, Michigan, Minnesota, Ohio, Wisconsin, and 35 federally recognized American Indian governments.

Training, Research, and Technical Assistance, with a mission to help water and wastewater utilities increase technical, managerial, and financial capacity (TMF).

Agenda

• 9:00 – 9:40	Introductions & Chlorine Disinfection Overview
• 9:40 – 10:20	Chlorine Types, Chlorine Feed Equipment O & M
• 10:20 – 10:30	**Break**
• 10:30 – 11:00	Chlorine Dosage & Demand
• 11:00 – 12:00	Feed Rate Calculations
• 12:00 – 1:00	**Break**
• 1:00 – 2:00	Disinfection, Contact Time and CT Values
• 2:00 – 2:40	Chlorine Safety & Chlorine Residual Testing
• 2:40 – 2:55	Disinfection Byproducts
• 2:55 – 3:00	Q & A

Disinfection Overview

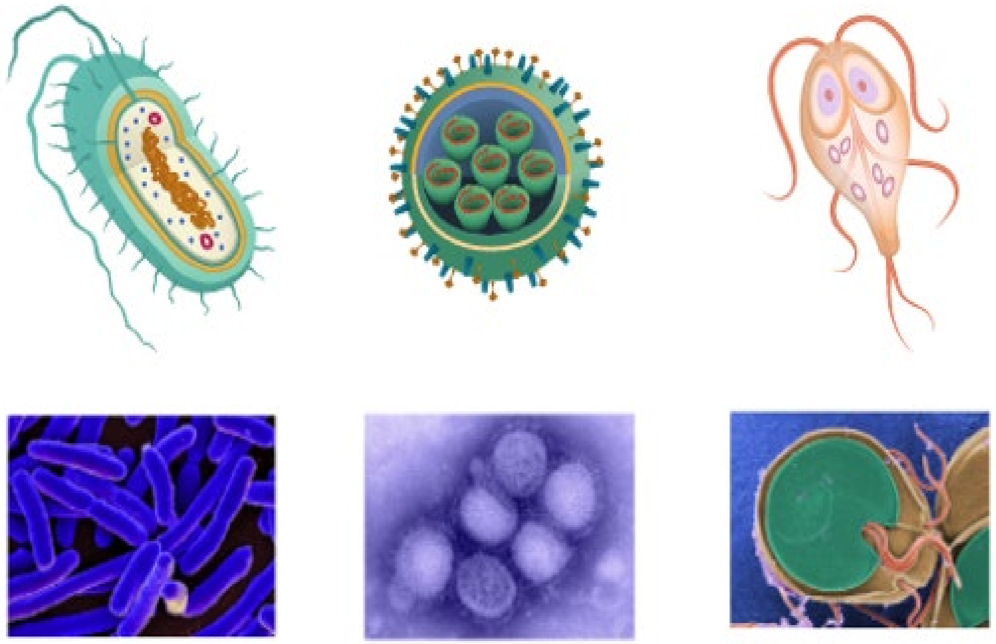
Disinfection: The inactivation and/or destruction of pathogenic organisms in drinking water to protect public health.

The effectiveness of chlorine disinfection depends primarily on:

1. Residual concentration
2. Contact time

(Other factors that can affect Cl disinfection include pH, turbidity, temperature, & reducing compounds)

Pathogen Groups



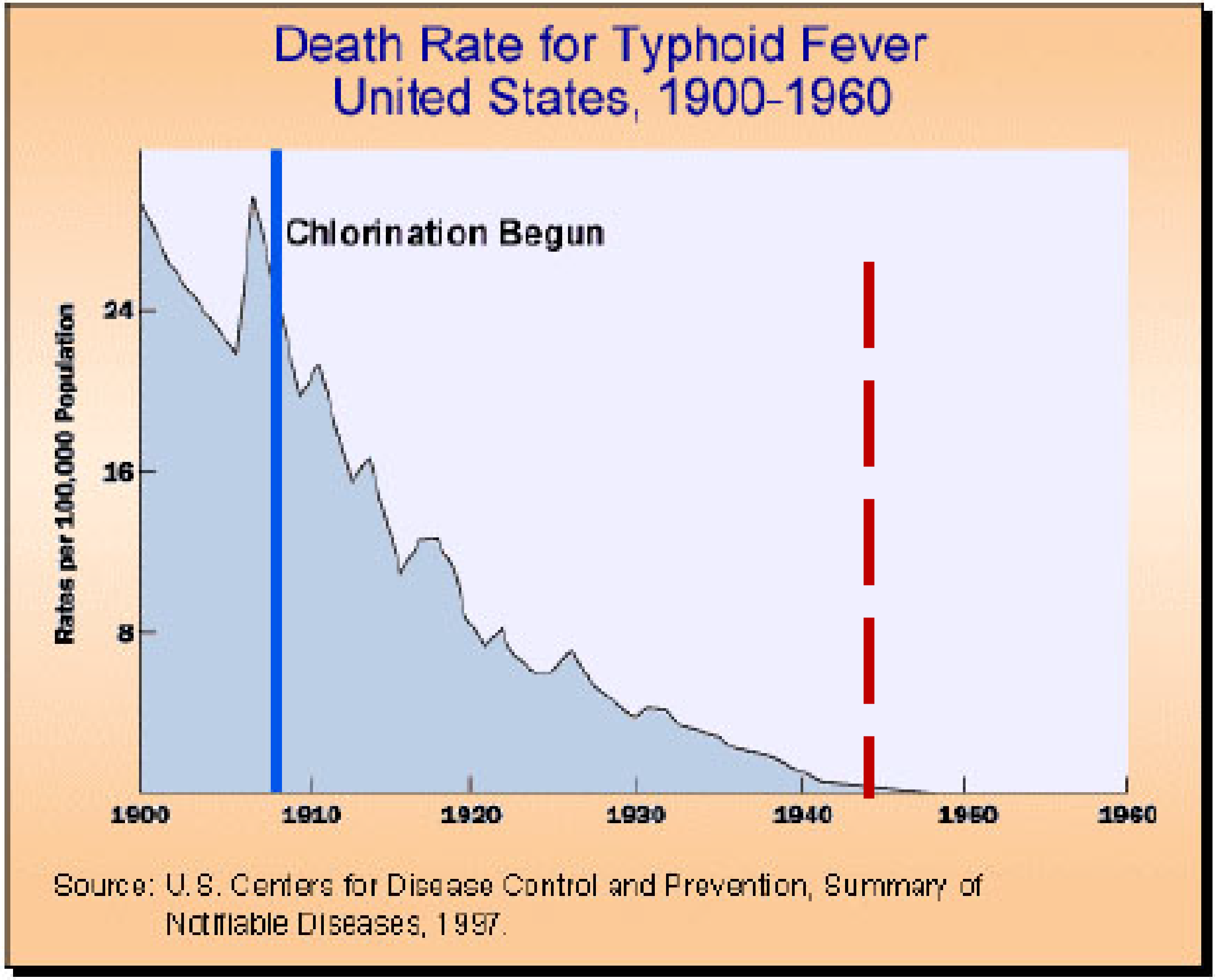
E. coli
Bacterium

Influenza virus
Virus

Giardia
Protozoan

Health Impact of Chlorine Disinfection

- 1,000s of deaths due to water borne diseases - but no one understood the cause
- 1670s Antonie van Leeuwenhoek first observes microbes using a microscope
- 1854 John Snow figured out that cholera was a cause of a waterborne disease epidemic
- 1860s Germ Theory developed by Louis Pasteur (microbial infection)
- 1908 New Jersey- first system in US to chlorinate drinking water
- The US water industry achieves less than 1 death per 100,000 around 1945



Chlorine Types

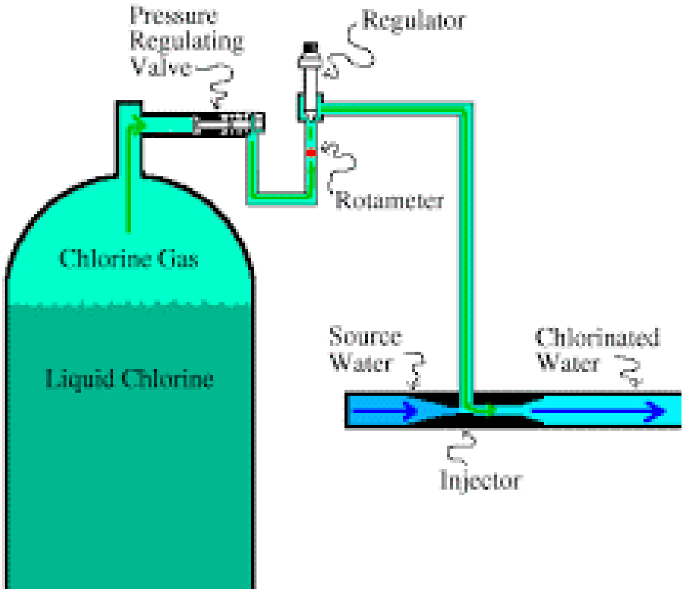
GAS CHLORINE

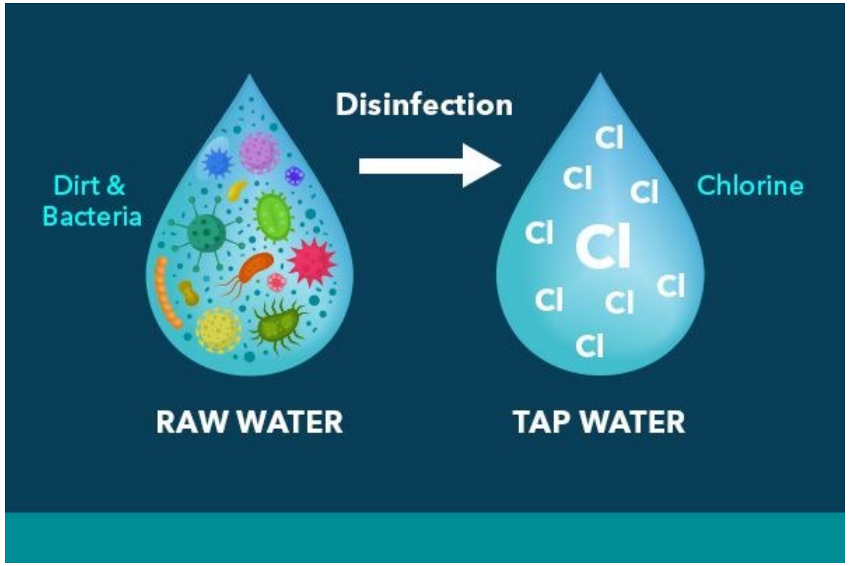
CALCIUM HYPOCHLORITE

SODIUM HYPOCHLORITE

Gas Chlorine

- 100% Strength chlorine Cl2
- Greenish-yellow gas, toxic and dangerous
- Fed with chlorination equipment





Sodium Hypochlorite

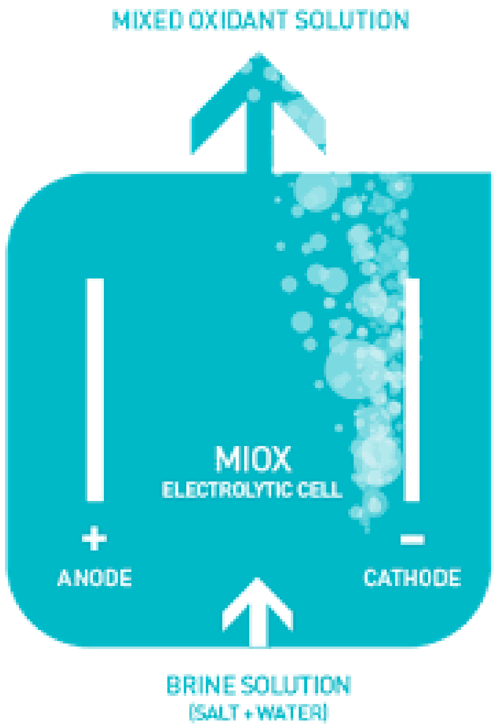
- Liquid form
- Strength varies typically from 5.25% to 12.5%
- Feeding 12.5% is approximately 1 pound per gallon
- Fed with a chemical feed injection pump

Calcium Hypochlorite

Solid form of chlorine

- Also called high-test hypochlorite (HTH)
- Typically, 65% to 70% strength
- Typically used in tablet form to disinfect water mains
- Can be dissolved in water and fed with a chemical feed pump

Other Forms of Chlorine



Mixed Oxidants

- Created onsite using a MiOx unit that creates chlorine products from salt, water, and electricity.

Chlorine Dioxide

Typically used in paper manufacturing

Chloramines

Free chlorine residual is combined with ammonia to create a long-lasting residual and prevent disinfection byproducts

Chlorine Equipment

Chlorine Cylinders

Ton cylinders hold 2,000 lbs of gas chlorine and can deliver up to 450 lbs/day of gas (depending on temperature)

Higher amounts can be drawn from the liquid using a lower outlet valve

150 lb cylinders hold 150 lbs of chlorine gas and can deliver up to 42 lbs/day of gas

Emergency Kits: If a leak occurs, a Kit A is used for 150 lb cylinders, whereas a Kit B is required for ton containers

Gas Chlorine Room

Two sets of 150 lbs cylinders on scales and chained to prevent falling over

Feed rate gauges are mounted on the wall below the notice sign.

Chlorine gas injection points on yellow piping

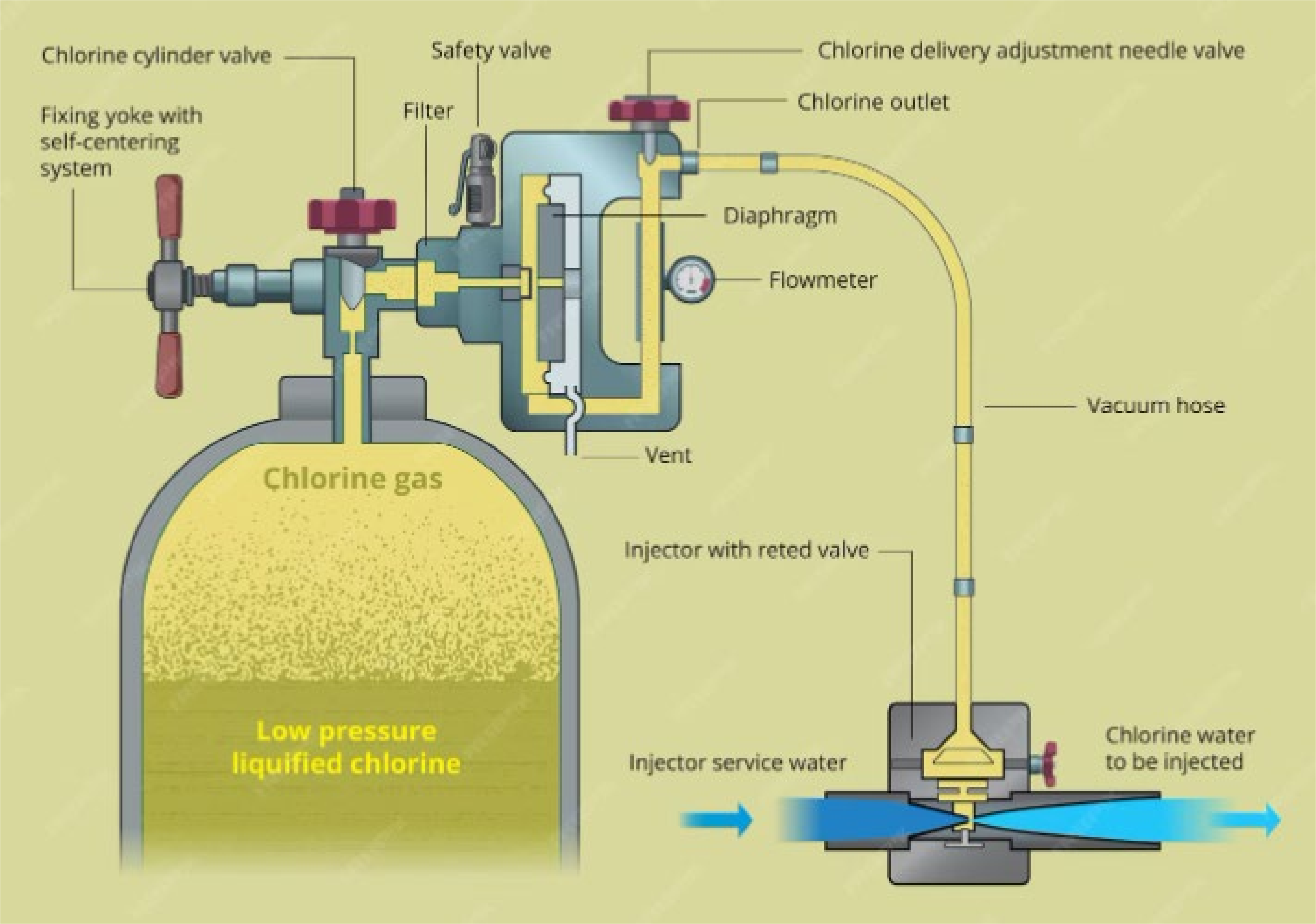
Chlorine residual analyzers on the wall to the right

Chlorine Cylinder Scales

Chlorine cylinders hold 150 lbs of chlorine gas and are placed on a scale.

An automatic device allows a second cylinder to come online.

The scale is set to a tare weight of 150 lbs, so operators can track how much chlorine has been used and how much remains in the cylinder.



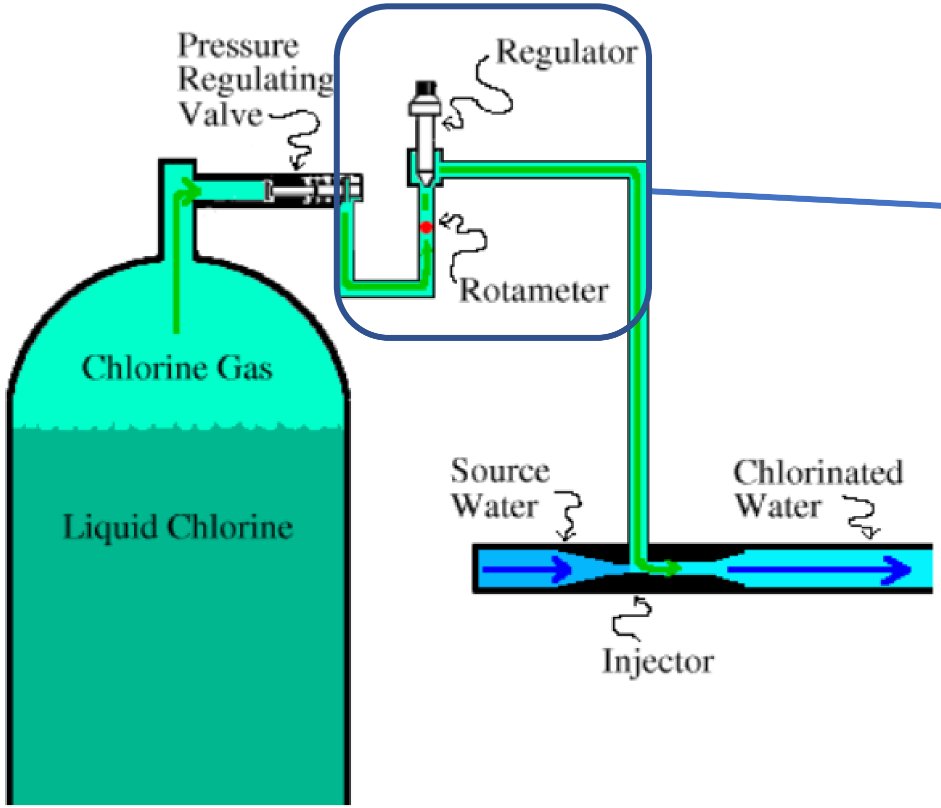
Chlorine gas is fed into a water stream side flow.

A venturi decreases the water pressure at the injection point, creating mixing.

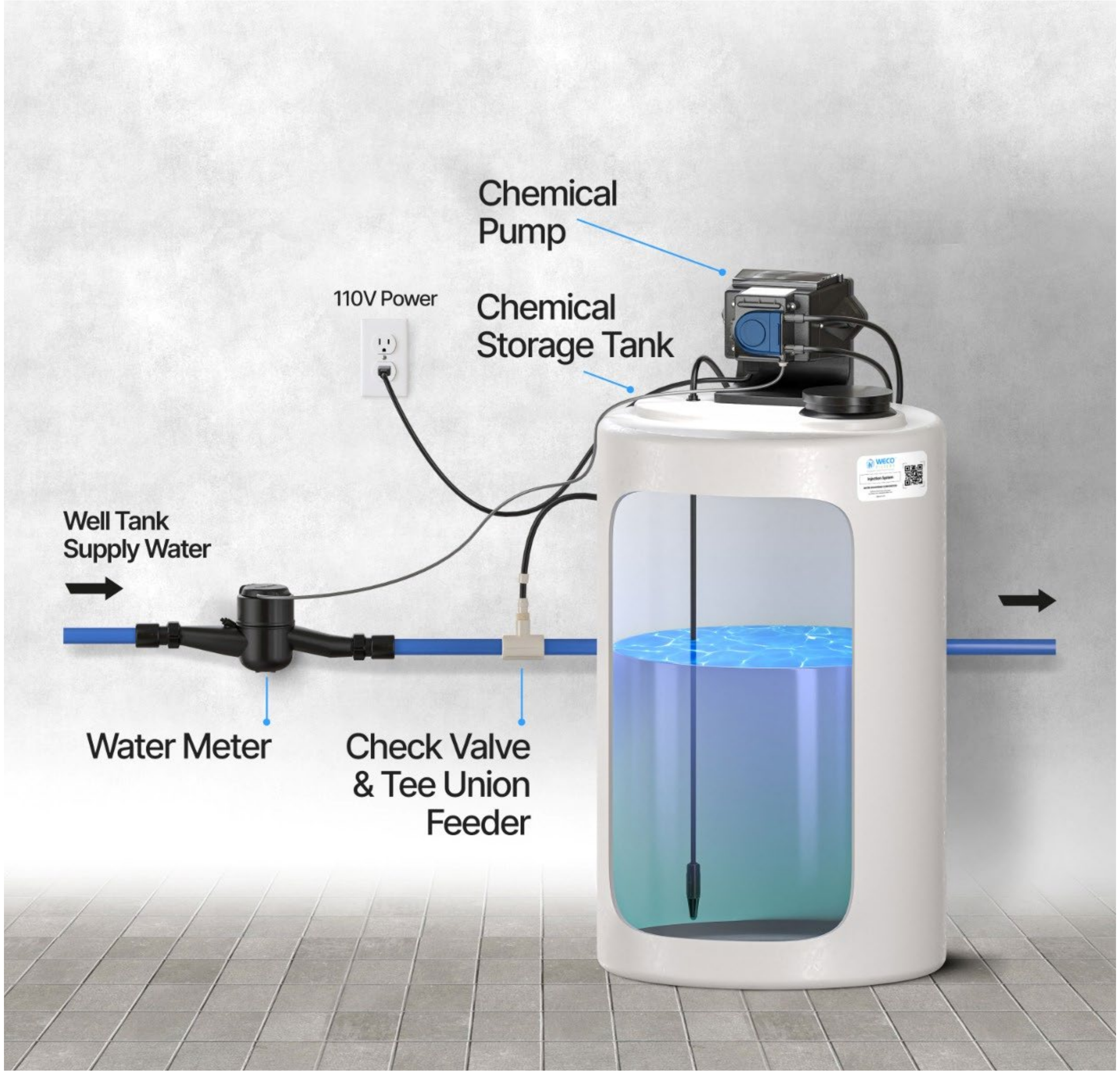
The chlorinated flow stream connects back to the main water flow

Rotameter

A small ball that floats up in a gauge due to the vacuum from the venturi downstream. The rotameter reads out in units of pounds per day.
A needle valve, the regulator, controls how much vacuum pulls on the chlorine gas in the cylinder and, therefore, the feed rate.

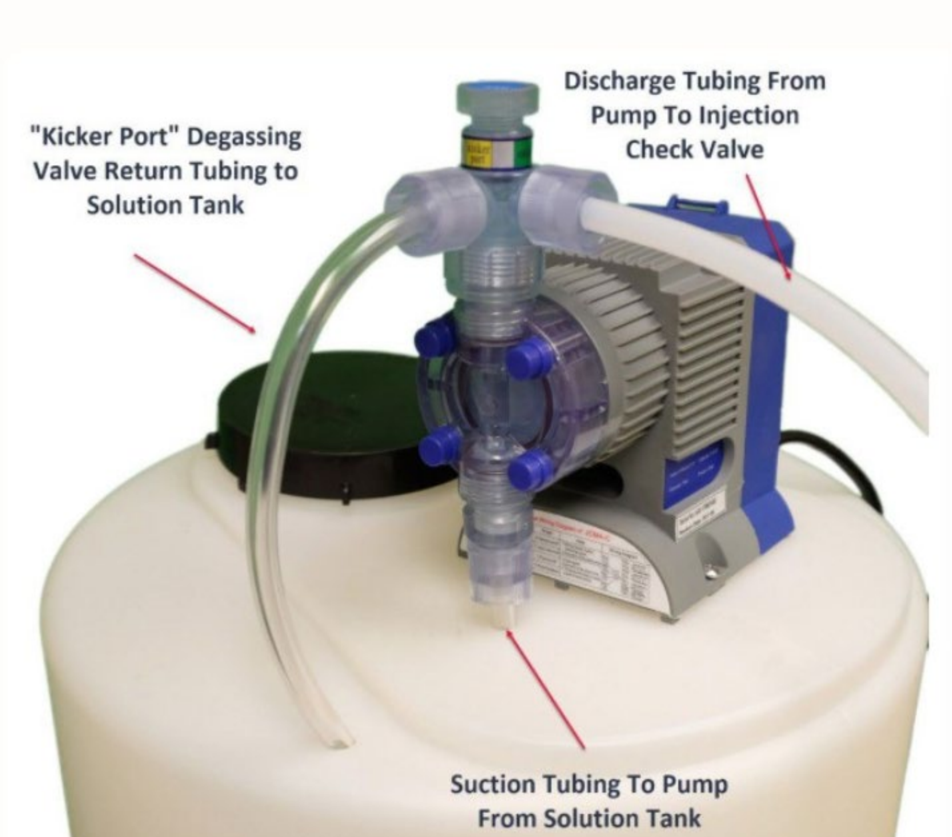


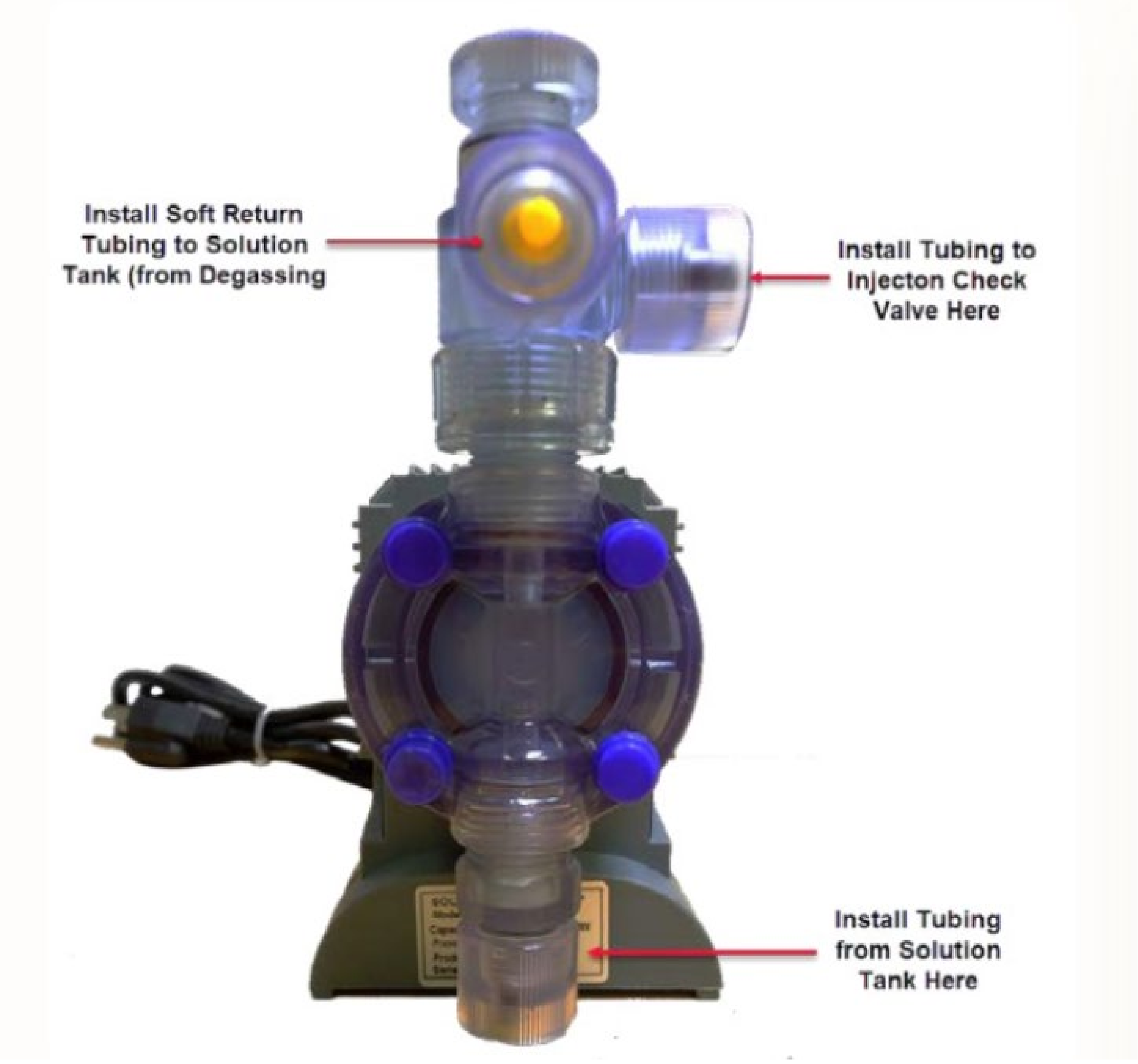
Chemical Feed Pump and Tank



Typical Chlorine Feed Pump

- Magnetic solenoid moves a plunger that causes sodium hypochlorite to be pumped into water flow.
- Some pumps have a degassing or priming valve to remove air or gasses from line.





Typical Pump Controls

Stroke: Controls how much liquid is injected with each stroke of the plunger

Speed: Controls how many strokes per unit of time

- 100% stroke and 100% speed represent the rated output of the pump.
- Output is typically rated in gallons per hour (GPH) but can also be given in gallons per day (GPD)

Pump Sizing and Output

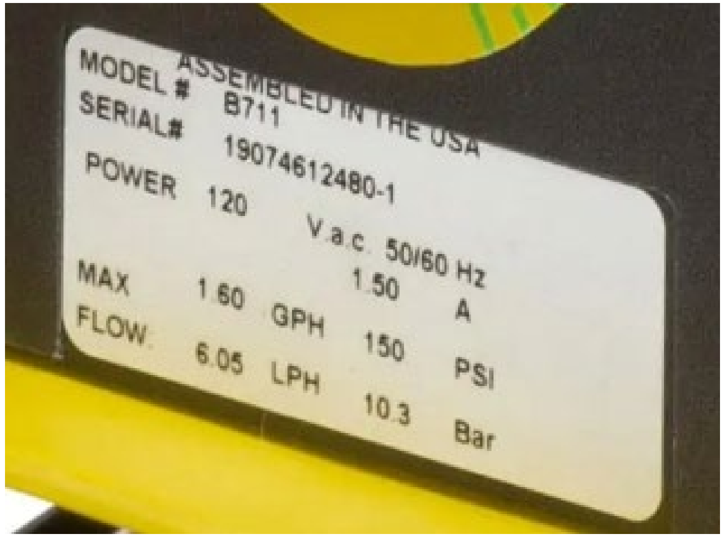
This pump shows a max output of 1.6 GPH which represents the output when both stroke and speed are at 100%

Stroke% x Speed% x max flow = output

To set for 50% output

- 100% stroke x 50% speed x 1.6 GPH = 0.8 GPH
- 70% stroke x 70% speed x 1.6 GPH = 0.784 GPH

When choosing a pump, it is best to select one that can deliver the needed output at 50% to 70% of its capacity.



Flow Pacing

- Some chemical feed pump are designed to be paced with the water flow using a 4 – 20 mA signal from a flow meter.
- The speed of the pump is controlled by the pacing signal, and the knob typically controls the stroke length.

Calibration

Pump draws **from** a known volume in a graduated cylinder.

$$\text{Flow Rate (mL/min)} = \frac{\text{Volume Withdrawn (mL)}}{\text{Time (minutes)}}$$

To convert to Gallons Per Day (GPD), multiply the result by 0.38 (approximate conversion factor).

The conversion factor is based on:

$$\frac{1{,}440 \text{ min/day}}{3{,}785.41 \text{ mL/gal}} = 0.3804$$

**min and mL cancel

$$\frac{\cancel{\text{mL}}}{\cancel{\text{min}}} \times \frac{1440 \cancel{\text{min}}\text{/day}}{3{,}785.4 \cancel{\text{mL}}\text{/gal}} = \frac{\text{gal}}{\text{day}}$$

Example: We have a pump rated at 1.6 GPH, which represents 24 hrs x 1.6 = 38.4 GPD.

A calibration test was conducted for 5 minutes, and 500 mL was withdrawn from the graduated cylinder. The flow rate is therefore 100 mL/min.

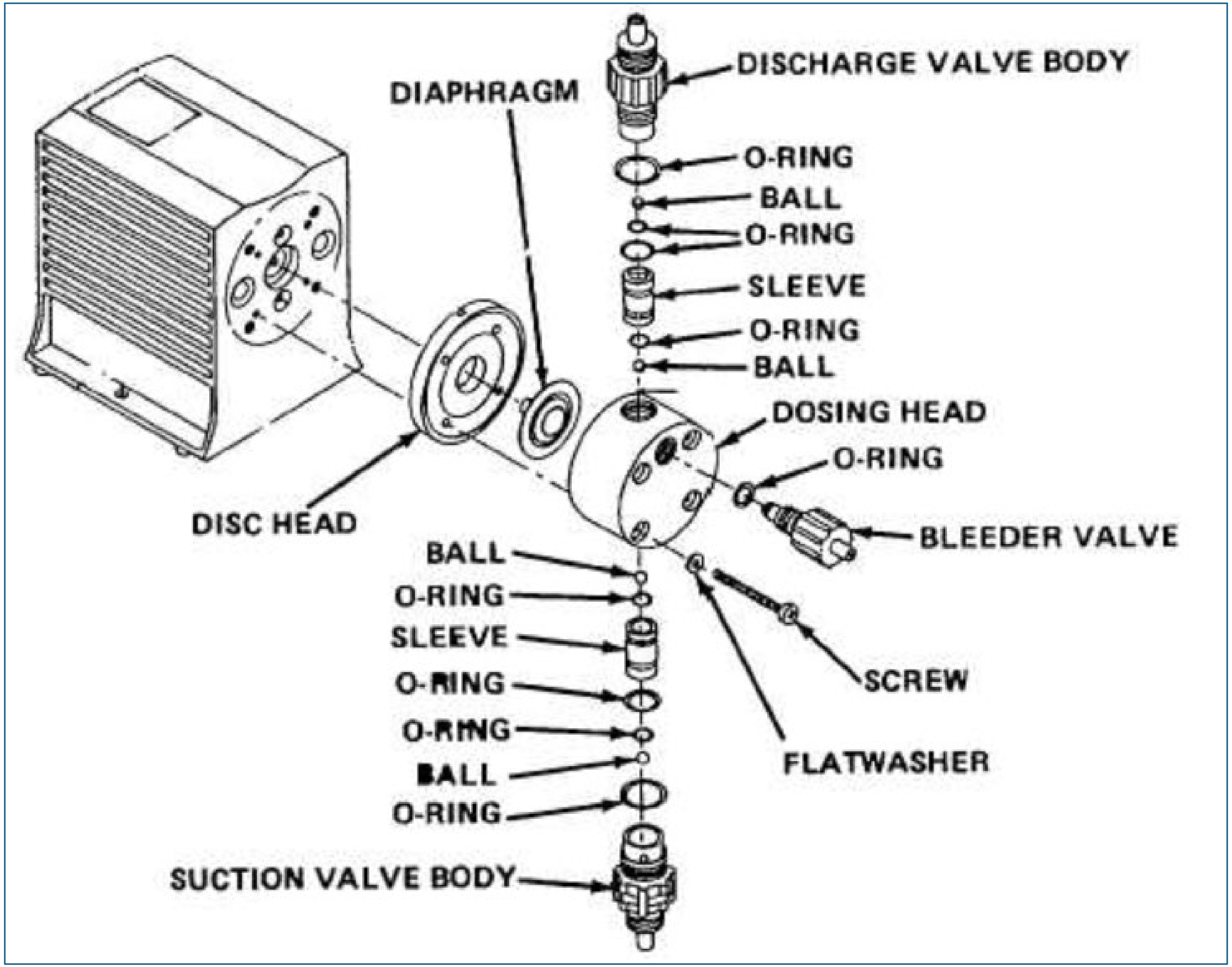
We multiply by 0.38: 100 mL/Min x 0.38 = 38 GPD.
The output is slightly below the rated capacity.

Chemical Feed Pump

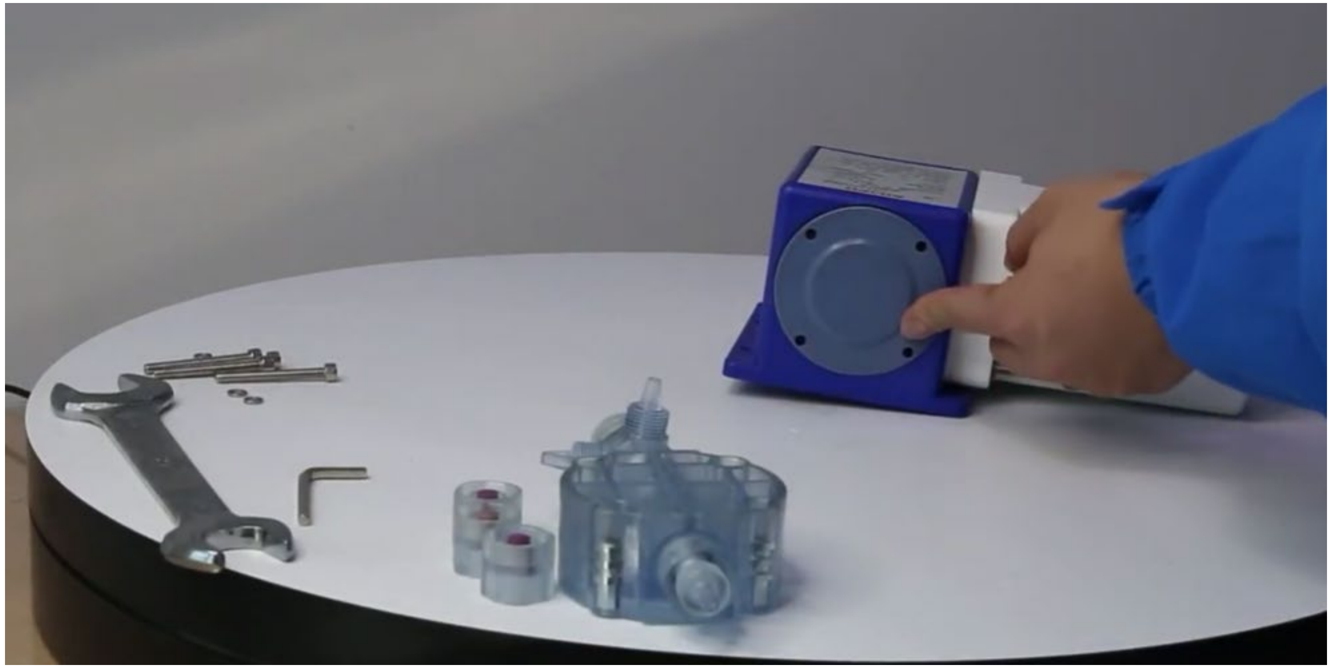
Typical components that are replaced

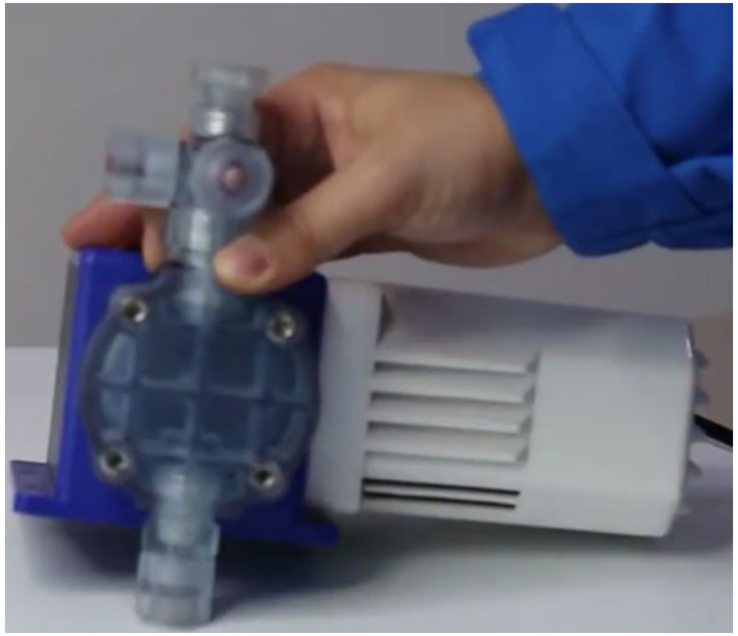
- Diaphragm
- Check balls
- O-rings

- Also, suction and pressure tubing and connectors.
- Some manufacturers also recommend replacing the dosing head if cracks or warping is evident.



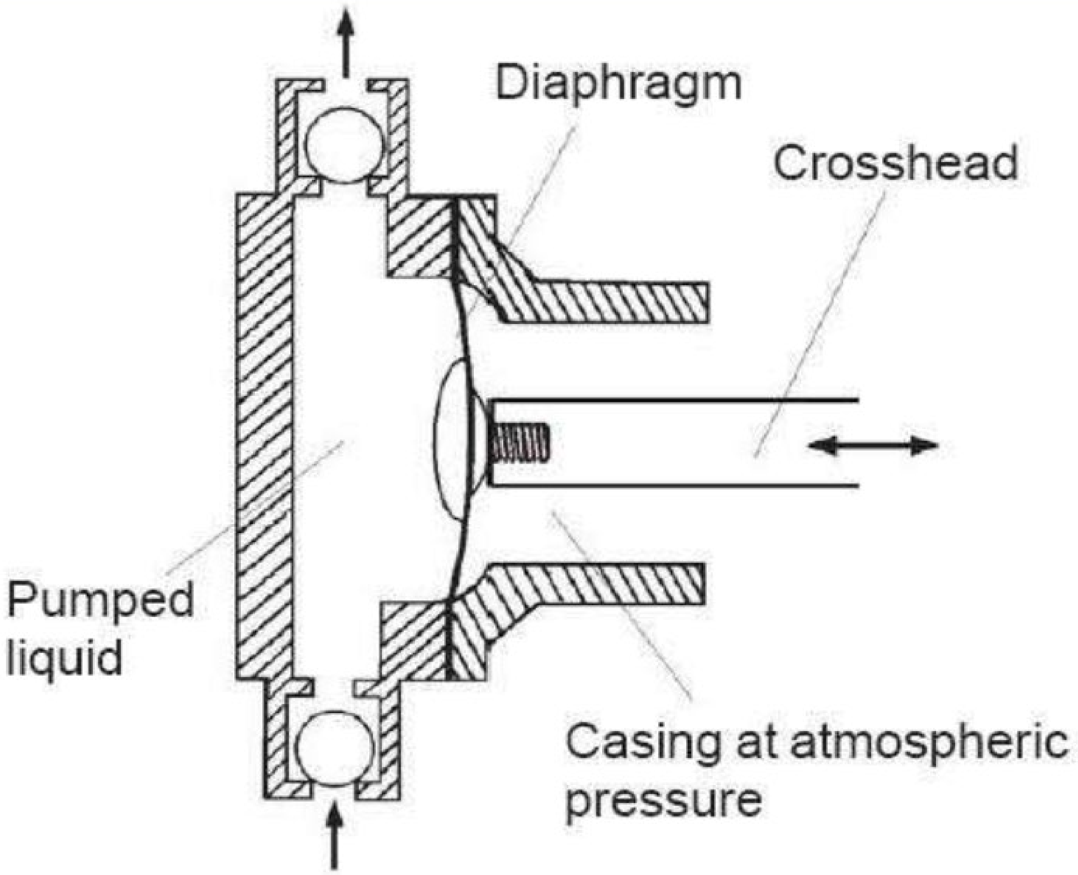
Pump Head and Diaphragm





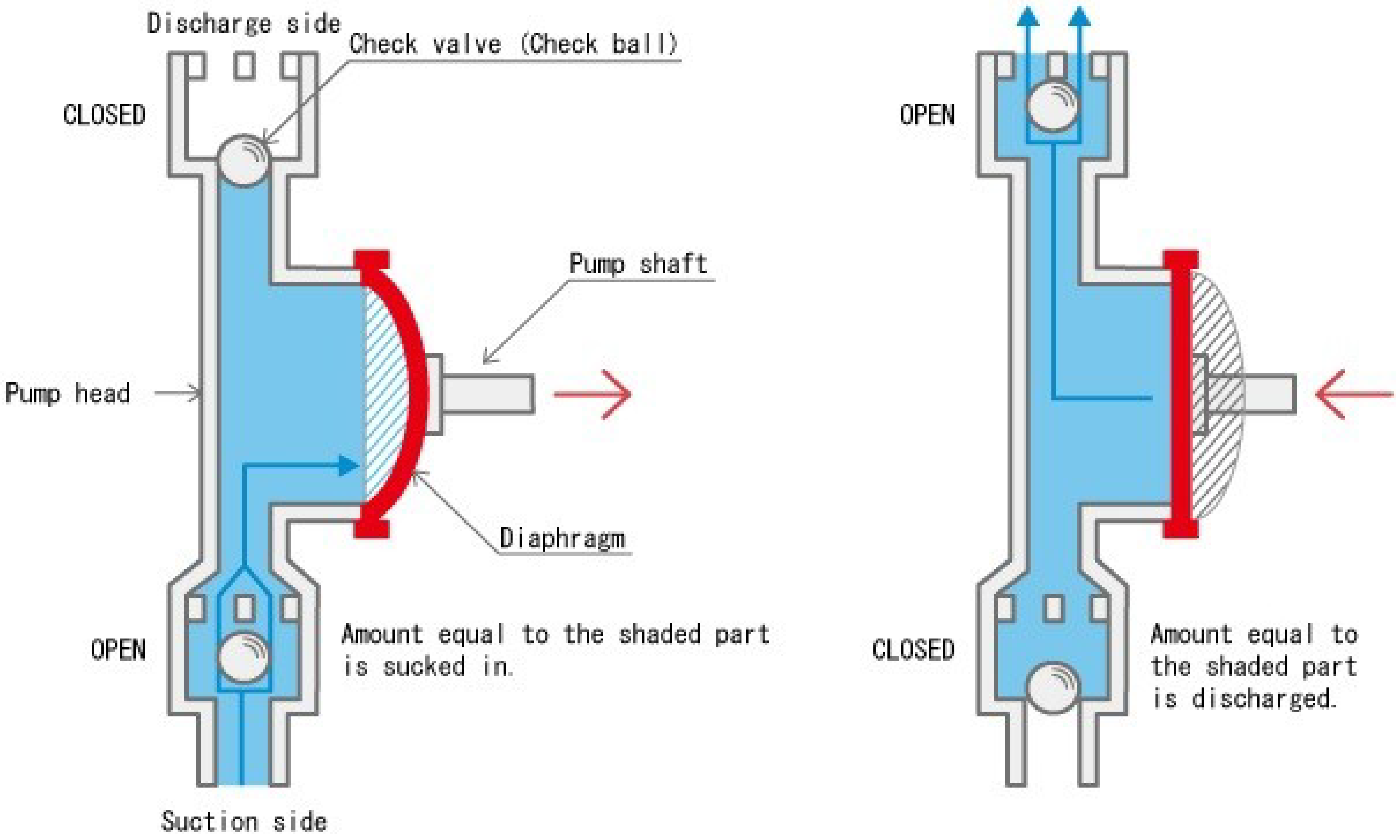
Output: When the plunger (crosshead) pushes toward the chamber pressure is created. The upper ball moves out of the way allowing fluid to flow out, and the lower ball is forced closed.

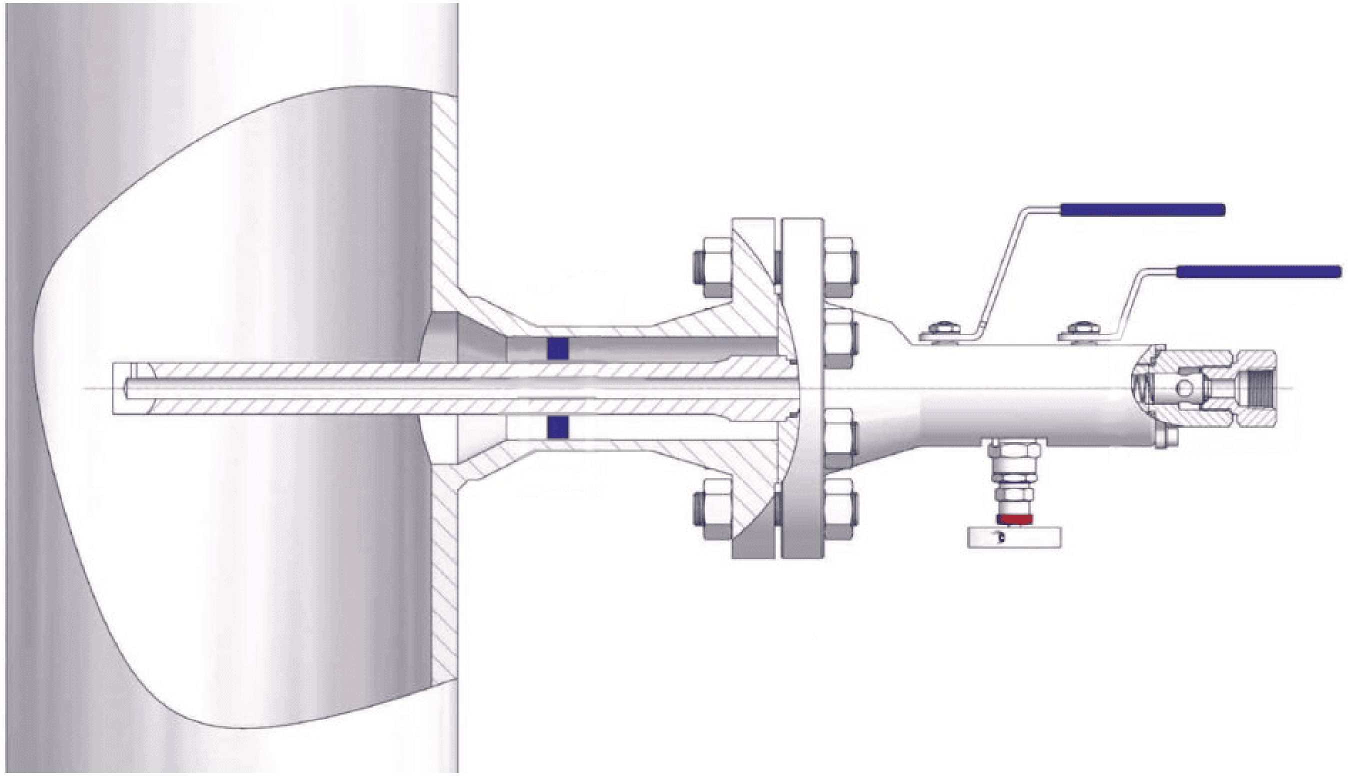
The check balls function as valves to ensure suction and discharge take place



Intake: When the plunger draws back, suction is created. The bottom check ball is lifted and allows fluid to flow into the chamber. The upper check ball closes.

The motion of the shaft causes the diaphragm to move a certain amount of fluid with each stroke.





Injection Quill

- Used to direct the output of chemical feed pump into water piping.
- Has a spring-loaded check valve so fluid flows in only one direction.
- Fitted with a corporation stop style valve for maintenance purposes.
- Periodically cleaned by soaking in a vinegar or muriatic acid solution, and scrubbing

Maintenance Tasks for Chlorine Feed Pumps

Daily: Check for leaks, pump operation, and chlorine residual

1 Month: Check the tightness of head screws and tubing connections.

3 Months: Calibration check

6 Months: Flush pump with 5% vinegar. Circulate 5% vinegar for 30 minutes to dissolve and clean mineral deposits. To circulate cleaning solution, you place both suction and output tubing ends in the same basin. A diluted solution of muriatic acid can also be used (4 parts water to 1 part acid) if more aggressive cleaning is required.

Safety precautions:

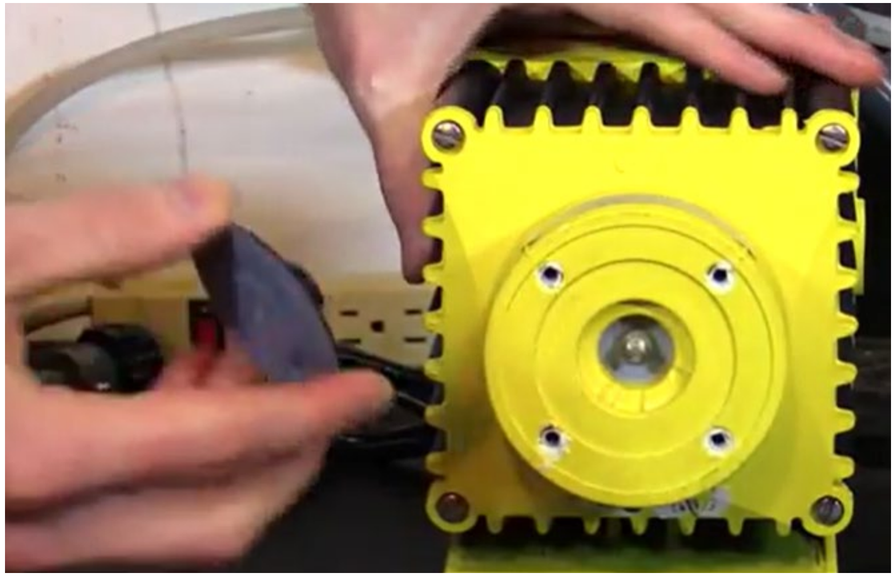
- *You must flush with fresh water prior to and after flushing because both vinegar and muriatic acid will react with sodium hypochlorite to create chlorine gas.*
- *Use protective gloves and goggles*
- *Remember to always add acid to water (adding water to acid can cause a reactive splash)*

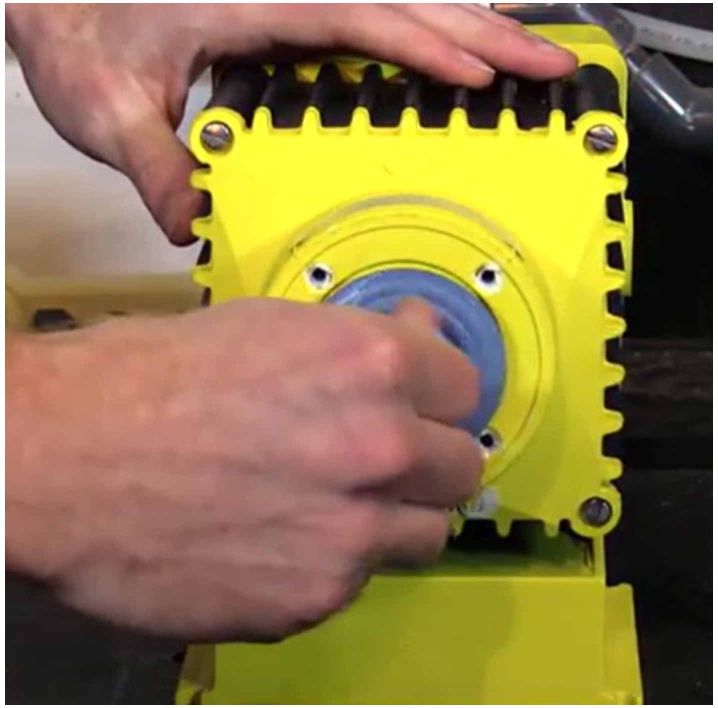
Maintenance – Rebuilding Chlorine Feed Pumps

12 Months: (Typical rebuilding tasks

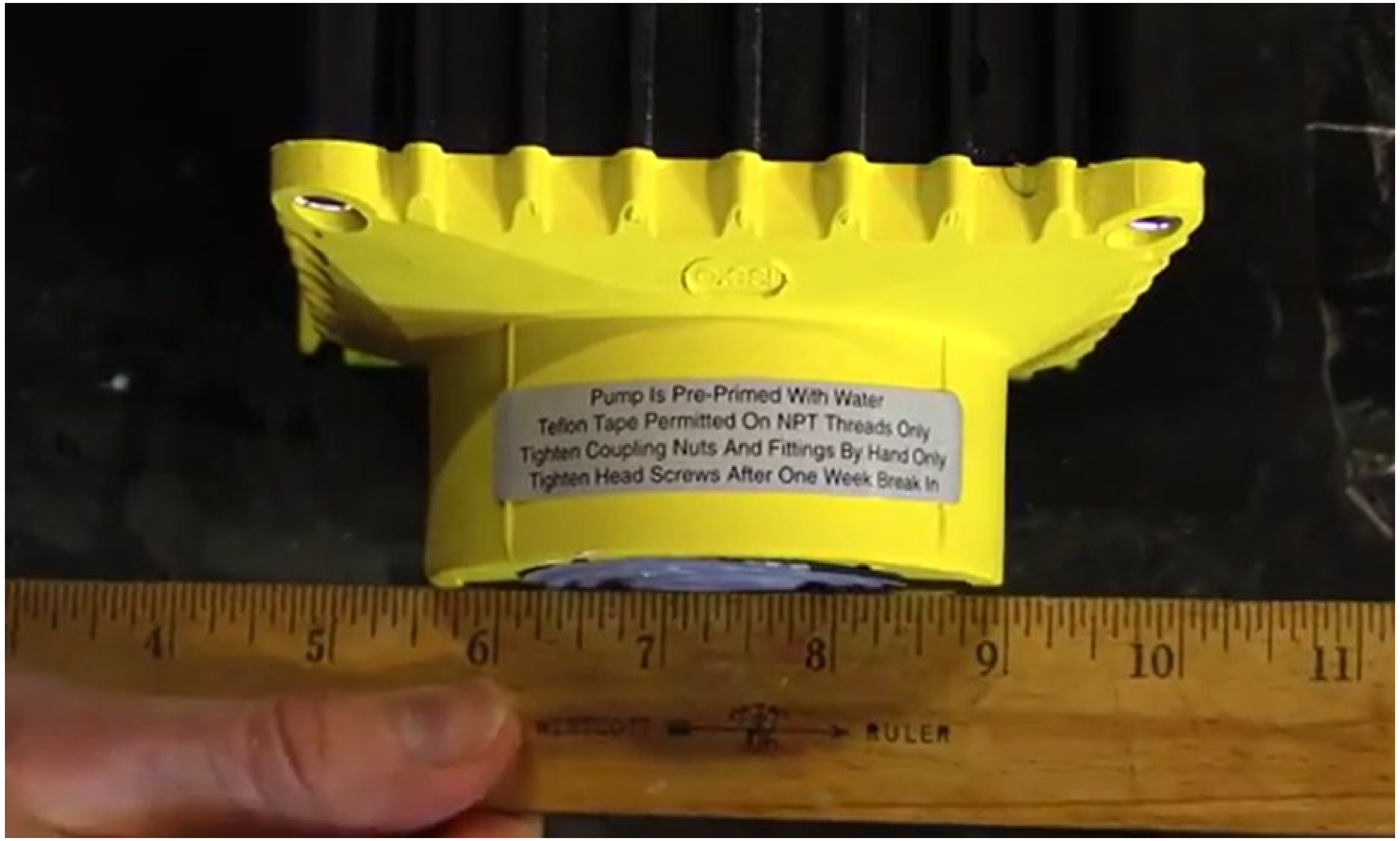
- Install New Diaphragm
- Inspect entire pump and head
- Replace check balls (Check balls can wear due to operating thousands of times each day; symptoms of worn check balls include air locking, loss of prime, inconsistent or decreased pump output.) Ensure check balls are the correct material type - ceramic, PTFE (Teflon), and synthetic sapphire are recommended for chlorine.
- Replace discharge tubing. (If tubing appears to still be in excellent condition, and you want to reuse it, you still must at least trim the ends and replace the ferrules)

Replacing the Diaphragm

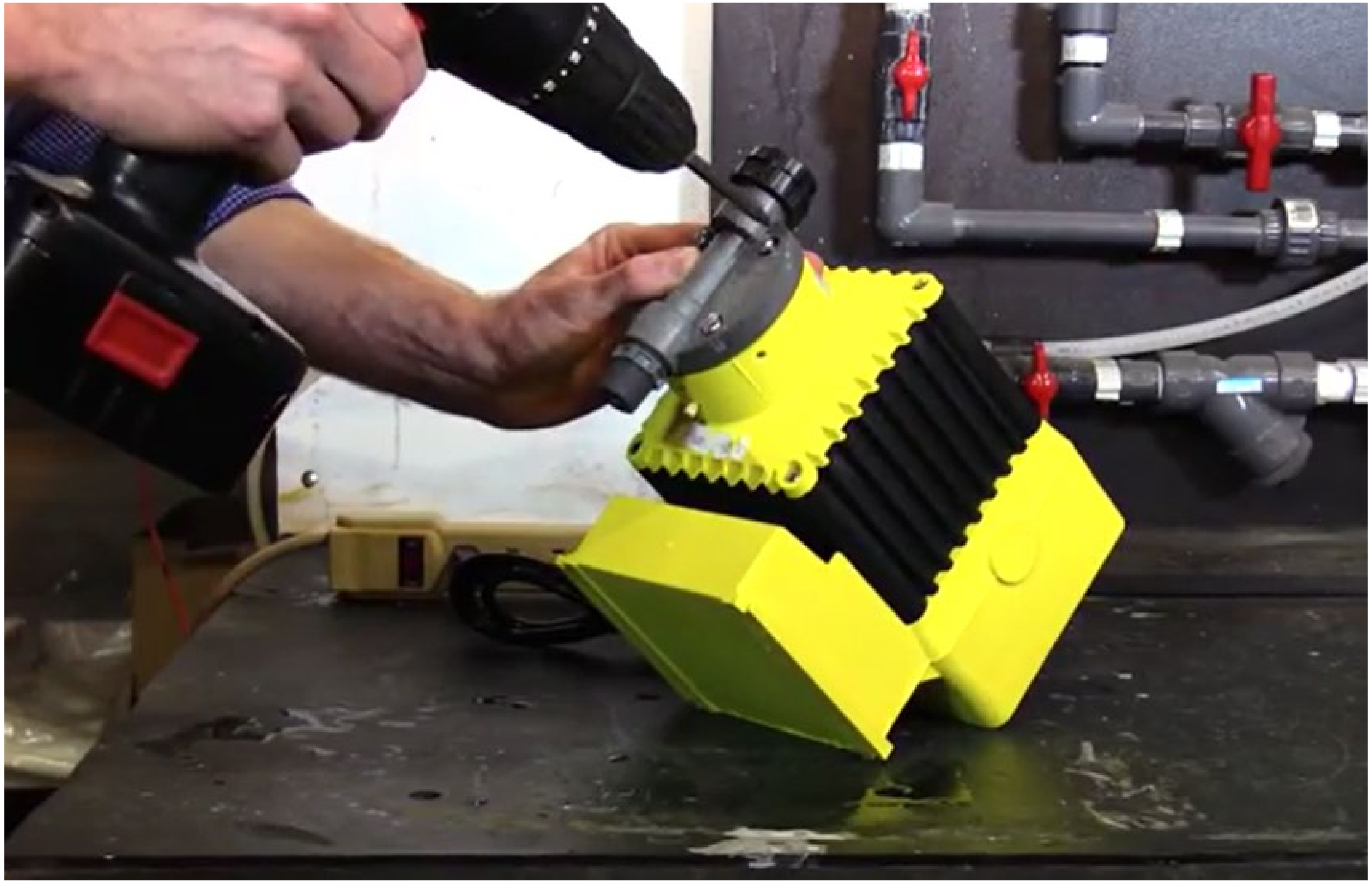




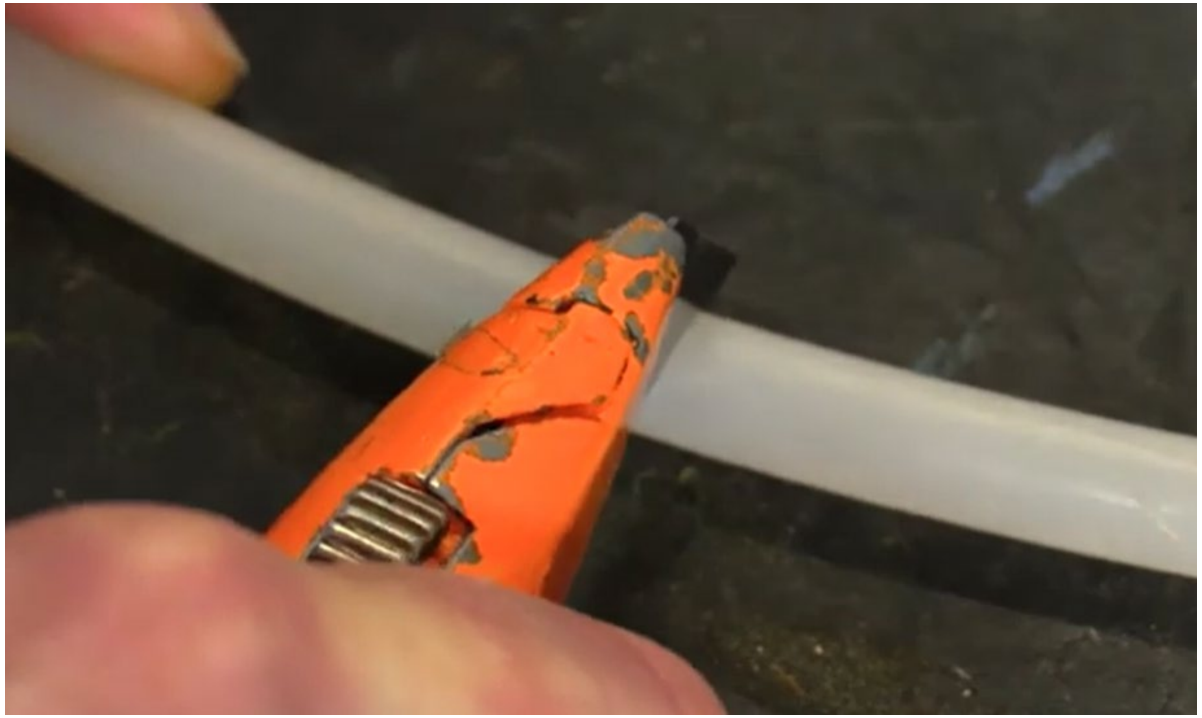
Diaphragm typically screws onto the threaded end of the plunger.



Making sure the center of the diaphragm is flush with the casing body. You may have to run the pump as you screw on the diaphragm.



Re-attaching the head after installing diaphragm Bring screws up evenly and do not over-torque.



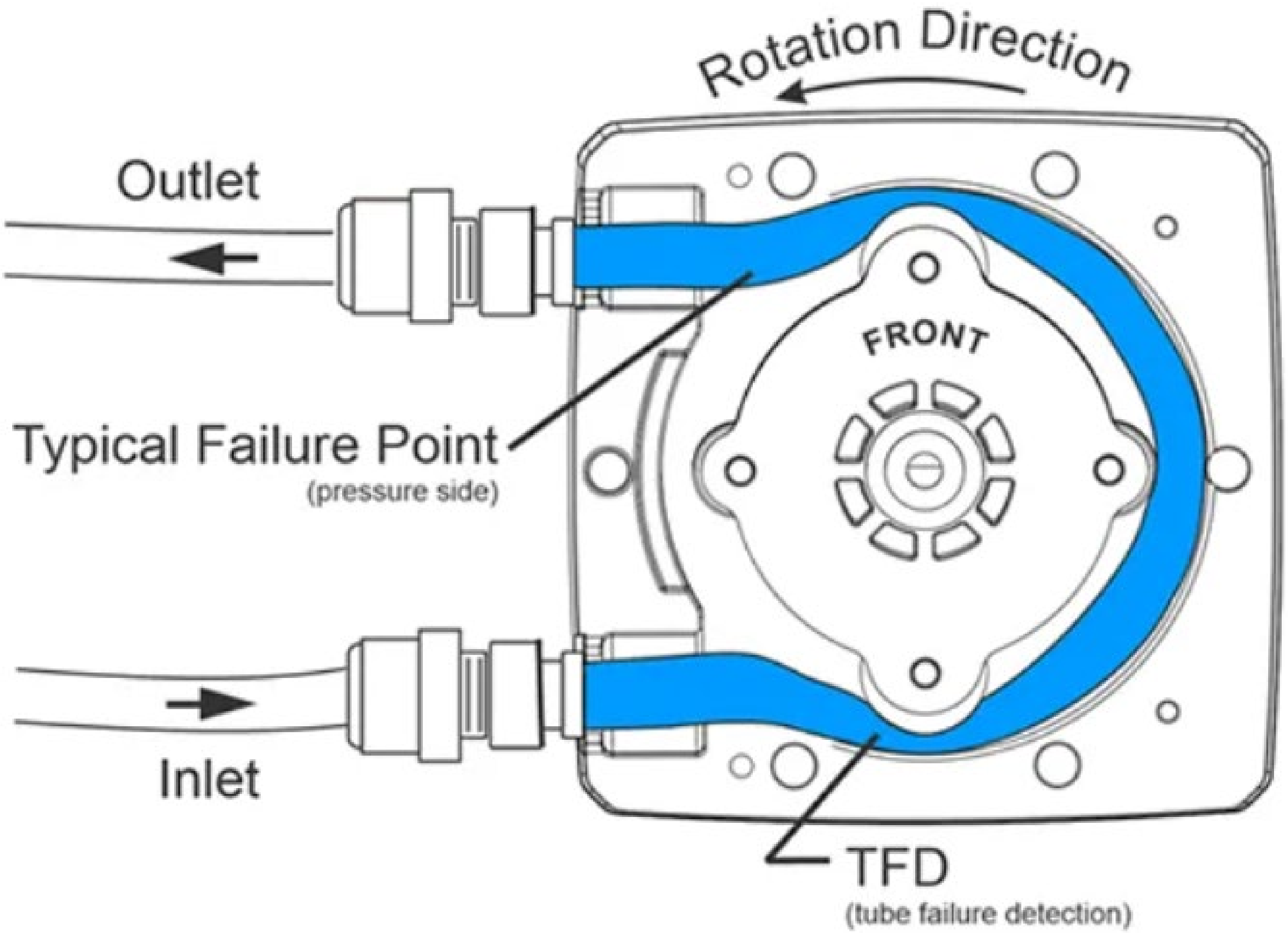

When replacing tubing make a straight, clean cut with a razor knife.

Always use new ferrules when installing tubing.

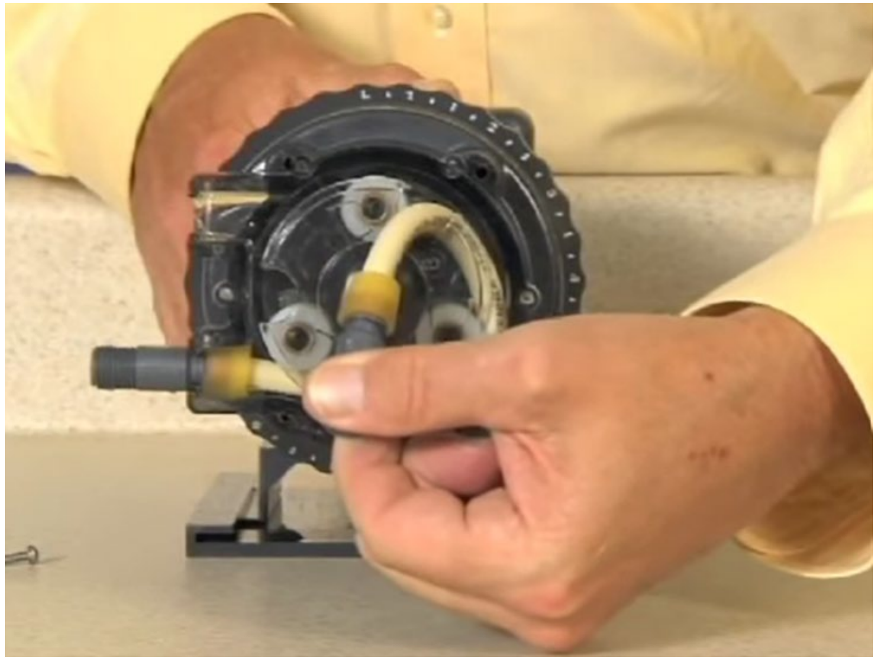
Insert the tubing into the pump, slide down the coupling nut and tighten.
Check for leaks.

Peristaltic Pump

- Rollers create flow using rollers and a flexible tube.
- Flow is initiated by a squeezing action.



Peristaltic Pump Maintenance

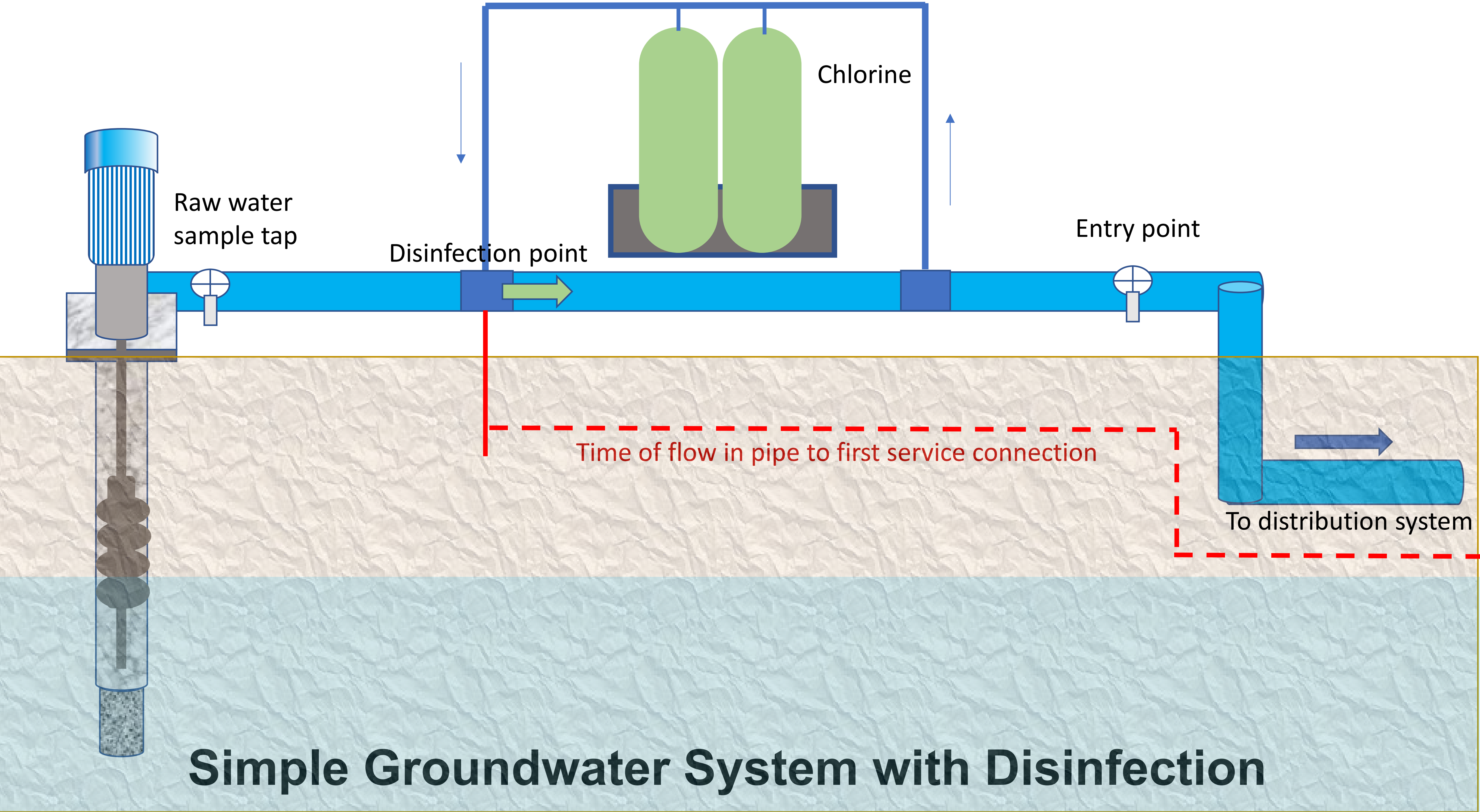


The only maintenance tasks for peristaltic pumps are

(1) Tubing replacement, and

(2) applying a thin layer of lubricant such as silicone grease to the tube and rollers (type depends on manufacturer specifications.

The tubing is also typically rotated (reversing the ends' locations) partway through its expected life to prevent wear in a single area and extend its life.



Simple Groundwater System with Disinfection

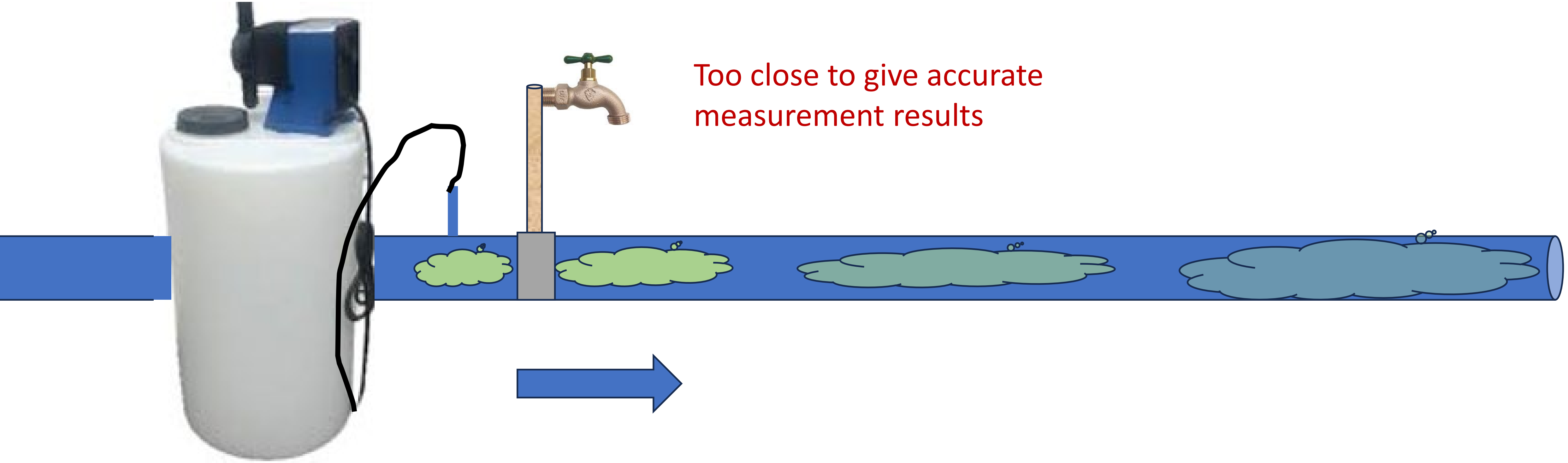
Measuring or Adjusting the Residual at the Disinfection Point.

The chlorine residual needs to be taken a distance downstream of the application point to

(1) Allow time for feed pump pulses to even out,

(2) Allow proper mixing to take place,

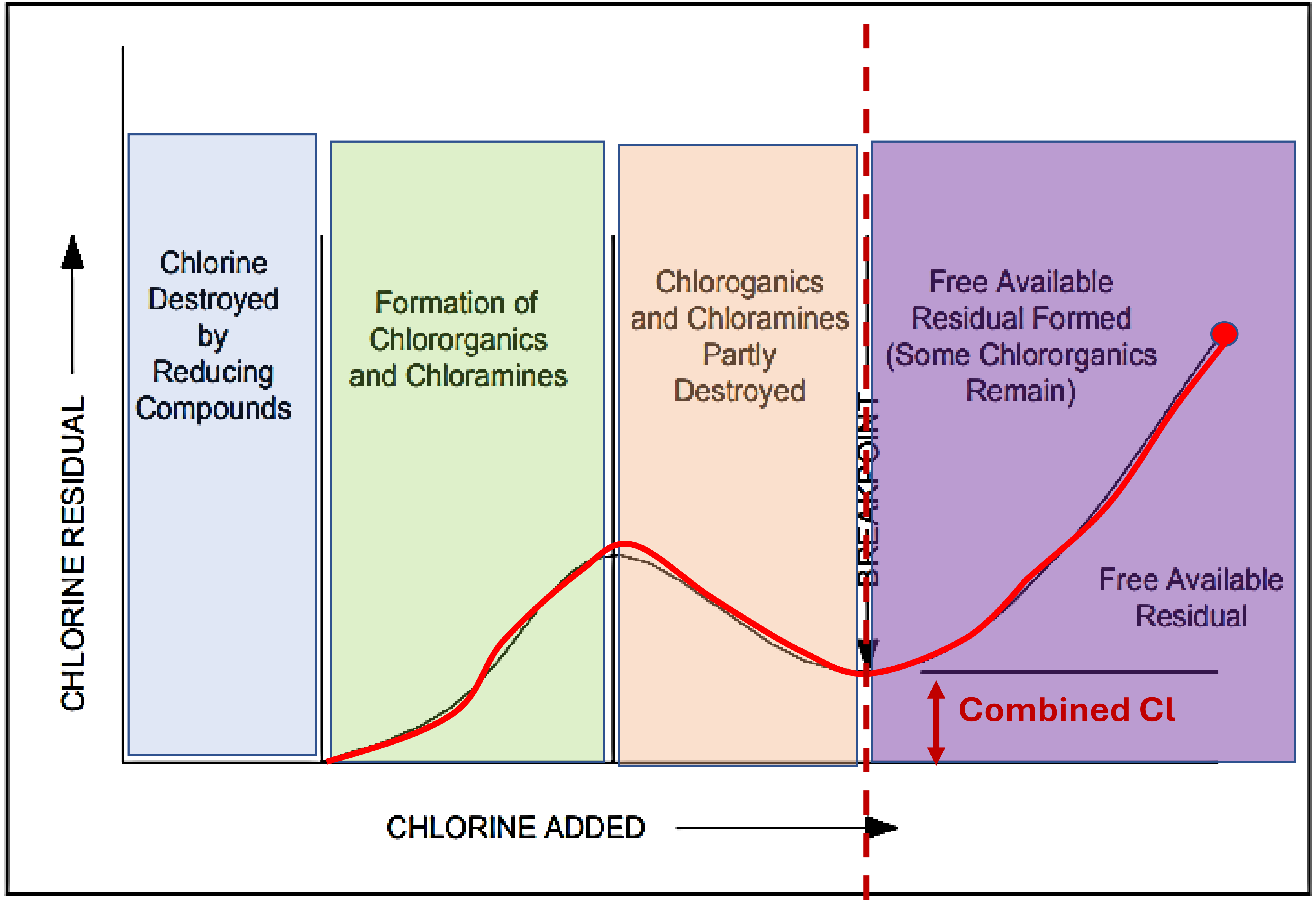
(3) Allow time for reducing compound reactions to be completed



Too close to give accurate measurement results

DOSAGE AND DEMAND

Chlorine Curve (total residual as chlorine is added)



Legend:

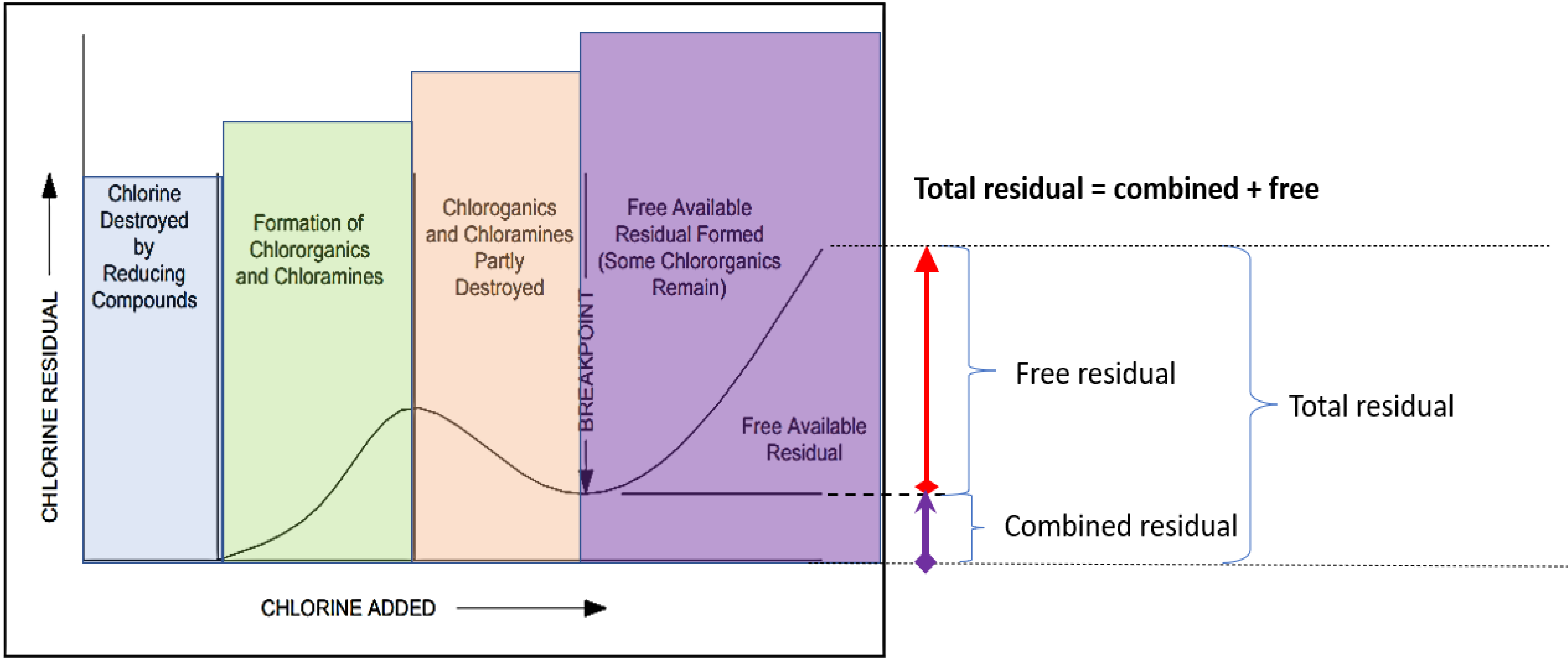
A: Reducing compounds use up chlorine.

B: Chloramines produced (combined chlorine)

C: Chloramines partly destroyed (also di and trichloramines produced)

----- Breakpoint -----

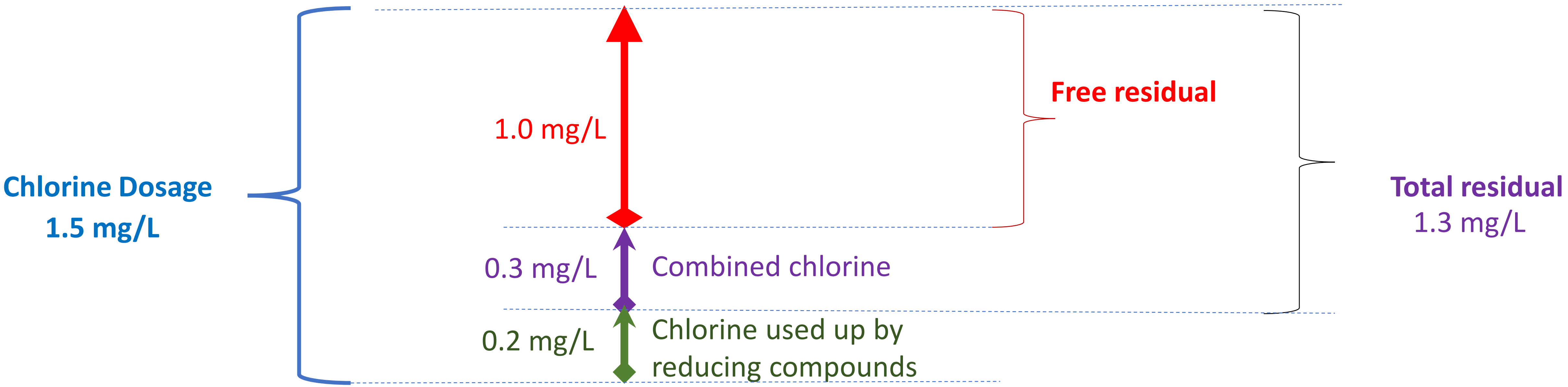
D: After "breakpoint" free residual begins to build



Total residual = combined + free
CHLORINE RESIDUAL
Chlorine Destroyed by Reducing Compounds
Formation of Chlororganics and Chloramines
Chloroganics and Chloramines Partly Destroyed
Free Available Residual Formed (Some Chlororganics Remain)
BREAKPOINT
Free Available Residual
Free residual
Combined residual
Total residual
CHLORINE ADDED

Dose = Demand + Residual

A dose of 1.5 mg/L chlorine is added to water resulting in a measured free residual of 1.0 mg/L and a total residual of 1.3 mg/L. What is the demand from reducing compounds?



How do we find the demand? (Dose – total residual)

1.5 mg/L – 1.3 mg/L = 0.2 mg/L demand

1.5 mg/L = 1.0 mg/L free residual + 0.3 mg/L combined + 0.2 mg/L demand

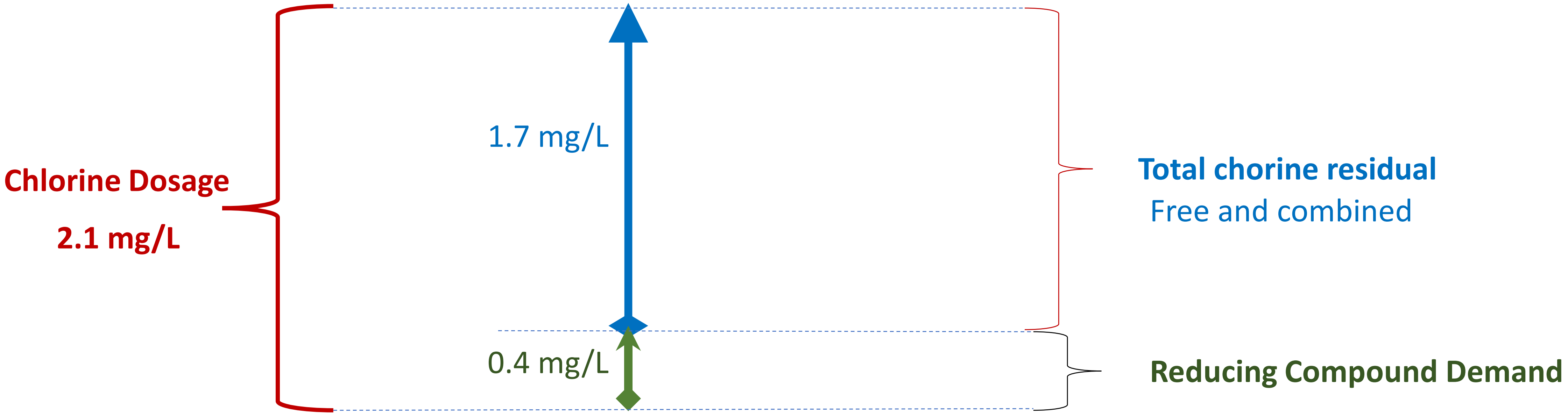
Poll 1

Knowledge Check – Dosage and Demand

A drinking water with a demand of 0.4 mg/L has a total chlorine residual of 1.7 mg/L. What was the chlorine dose?

a. 1.3 mg/L
b. 1.4. mg/L
c. 2.1 mg/L
d. 5.7 mg/L

Dose = Residual + Demand



Dose = **0.4 mg/L** demand + **1.7 mg/L total** residual = **2.1 mg/L**

Chlorine Stoichiometry

In this exercise, we will investigate the following

Chlorine Demand from Reducing Compounds

Chlorine Demand from Ammonia

Reducing Compounds (Fe and Mn)

- Every 1 mg/L of Iron uses up 0.64 mg/L of chlorine
- Every 1 mg/L of manganese uses up 1.29 mg/L of chlorine

Example: **A water source has 0.3 mg/L iron and 0.05 mg/L manganese. The dose is 2.0 mg/L chlorine. What is the remaining residual?**

1. Chlorine Demand for Iron (Fe):

0.3 mg/L Fe × 0.64 mg/L Cl_2/Fe = **0.192 mg/L Cl_2**

2. Chlorine Demand for Manganese (Mn):

0.05 mg/L Mn × 1.29 mg/L Cl_2/Fe= **0.065 mg/L Cl_2**

3. Total Chlorine Demand (Metals):

0.192 + 0.065 = **0.257 mg/L Cl_2**

Residual = 2.0 mg/L dose – 0.257 demand = **1.743 mg/L residual**

Ammonia

Ammonia uses 7.6 mg/L of chlorine for every 1.0 mg/L of ammonia-nitrogen. It creates chloramines but uses up free chlorine.

Example: **Reducing compounds reduced our remaining residual to 1.75 mg/L, and we now add in an ammonia concentration of 0.1 mg/L**

0.1 mg/L $NH3$ x 7.6 mg/L $Cl_2/NH3$ = **Chlorine demand of 0.76 mg/L**

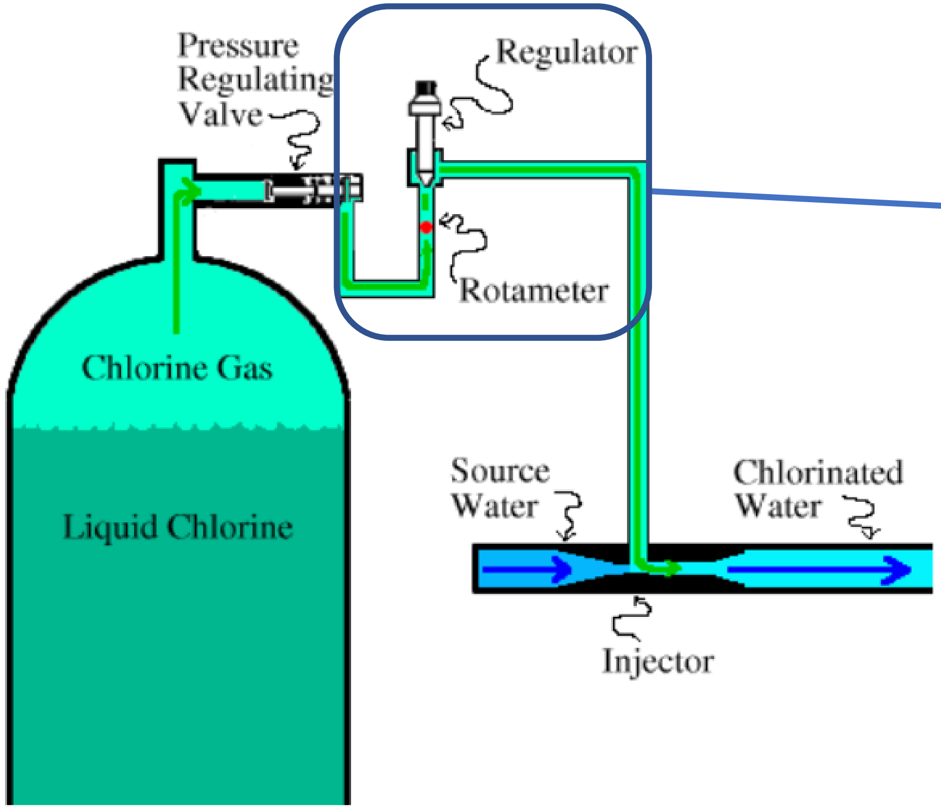
Resulting free residual = 1.75 mg/L – 0.76 mg/L = **0.99 mg/L**

Feed Rate Calculations

Gas Chlorine Feed Rate

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

Note that pounds per day is a **rate** of feed.



Rotameter will provide units in lbs/day

Up to approximately 40 lbs/day

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

Solution: Plug in 1.2 MGD for flow, and 1.5 mg/L for dosage into the formula. Remember, the constant 8.34lbs/gal does not change.

Chlorine Feed in lbs/day =

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

The lbs. Formula

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

1 MG = 1 million gal
(how many MG in total?)

Parts per million
(how many millionths in each MG?)

Weight of water
(Weight of 1 gal of water. Weight of substance is considered a portion of the total water weight)

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

water weight = 1,200,000 gal x 8.34 lbs./gal = 10,008,000 lbs

$$\frac{\text{1.5 parts chlorine}}{\text{1,000,000 parts water}} \times \text{10,008,000 lbs} = \text{15 lbs (the weight of chlorine)}$$

Pounds formula can be arranged to solve for dose.

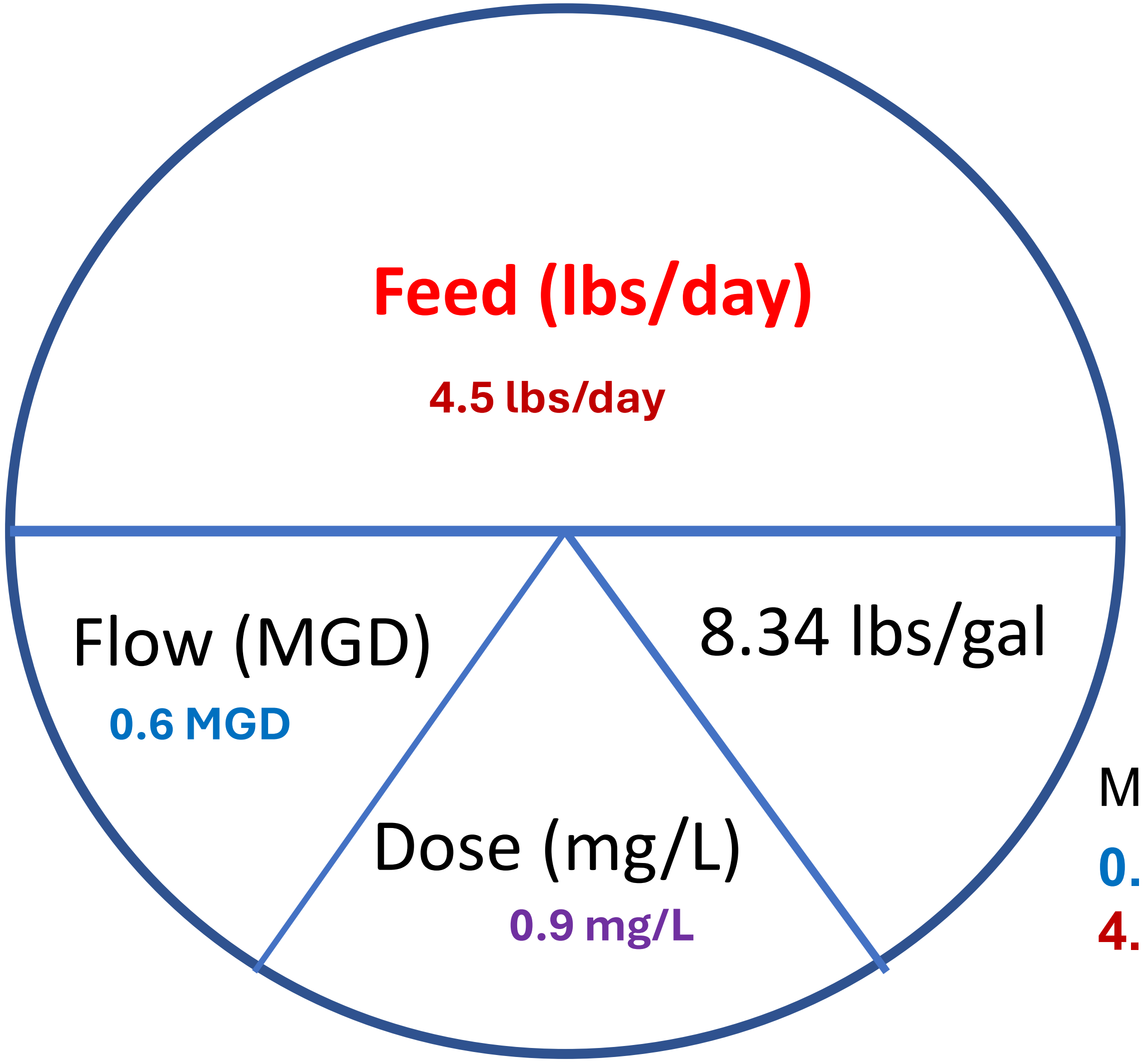
Pounds per Day = MGD(flow) x mg/L(dose) x 8.34 lbs/gallon

$$\frac{\text{Pounds per day}}{[\text{Flow(MGD)} \times 8.34\text{lb/gal}]} = \frac{\text{Dose (mg/L)} \times \text{Flow (MGD)} \times 8.34\ \text{lbs./gal}}{[\text{Flow (MGD)} \times 8.34\text{lb/gal}]}$$

$$\text{Dose (mg/L)} = \frac{\text{Pounds per Day}}{[\text{Flow(MGD)} \times 8.34\text{lb/gal}]}$$

Pie Formula

Example: Calculate the gas chlorine feed rate for a plant with a flow of **0.6 MGD** and a dose of **0.9 mg/L**

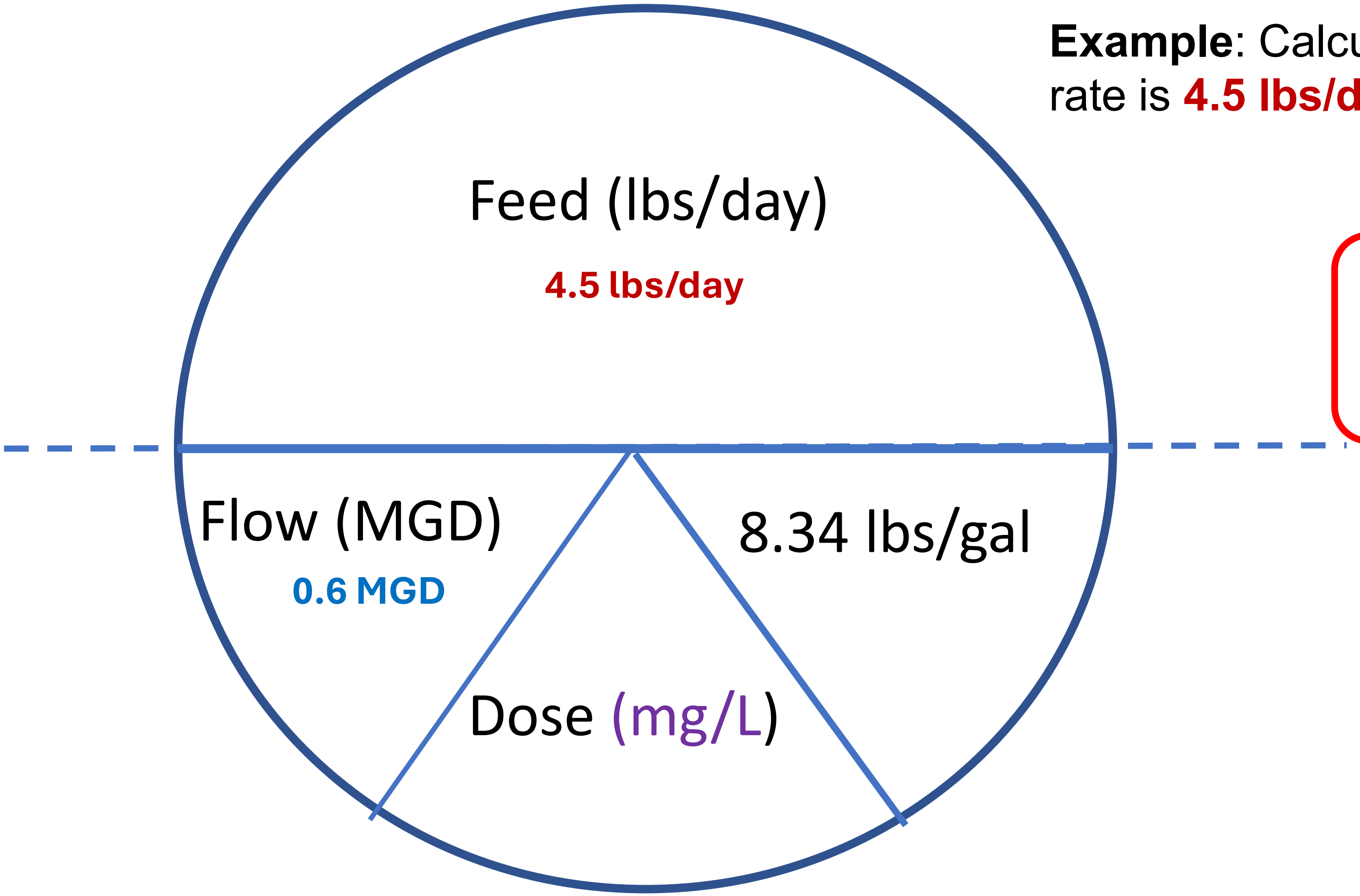


Multiply across bottom to solve top of chart.

MGD x mg/L x 8.34lb/gal = lbs/day

0.6 MGD x 0.9 mg/L x 8.34lb/gal = 4.5 lbs/day

Pie Formula (When solving for an unknown in the bottom.)



Example: Calculate the dose if gas chlorine feed rate is **4.5 lbs/day** and the plant flow is **0.6 MGD**.

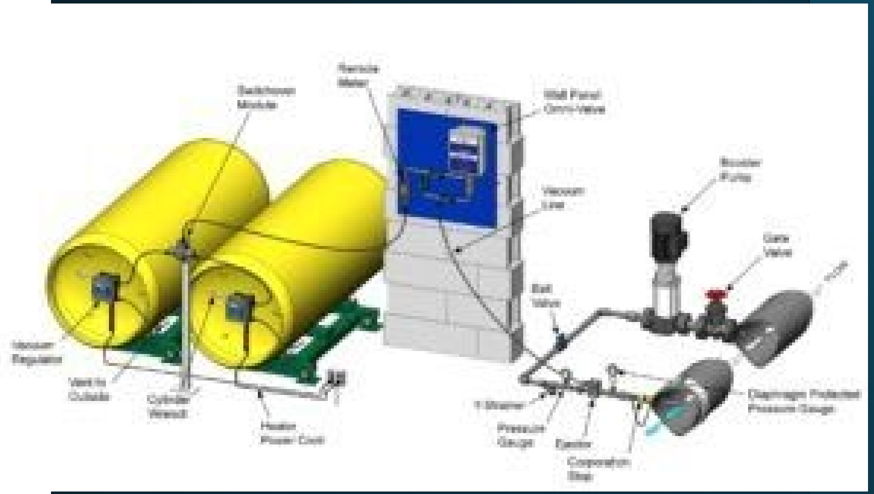
Dose = $\dfrac{\textbf{Feed in Pounds per day}}{\textbf{MGD x 8.34 lb/gal}}$

Dose = $\dfrac{\textbf{4.5 pounds per day}}{\textbf{0.6 MGD x 8.34 lbs/gal}}$

Dose = 0.9 mg/L

Poll 2

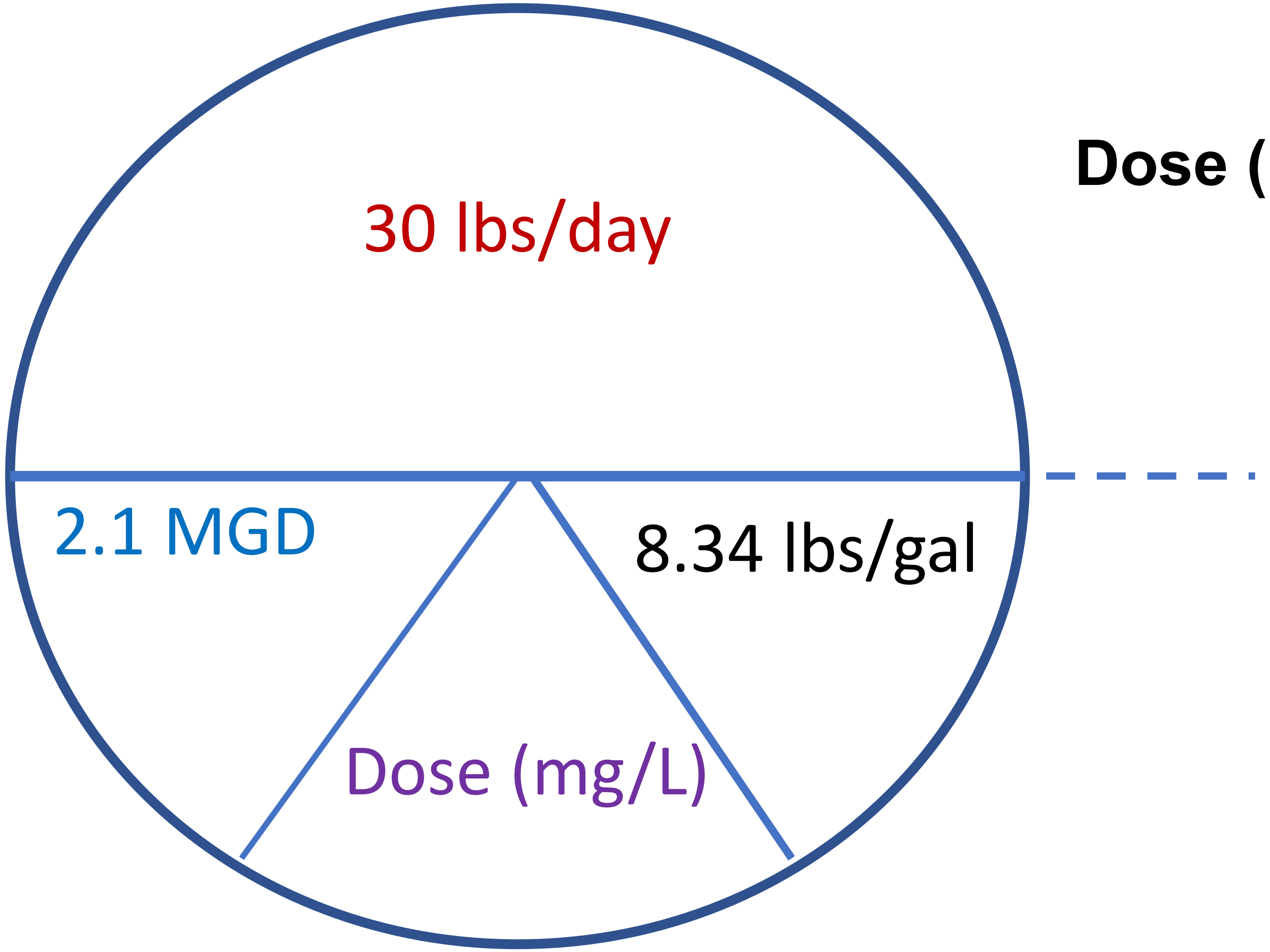
Knowledge Check – Feed and Dosage



An operator checks the settings at a treatment plant and notes that the gas 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?

a) 1.71 mg/L
b) 0.58 mg/L
c) 0.33 mg/L
d) 0.15 mg/L

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?



Dose (mg/L) = $\dfrac{\textbf{Pounds per Day}}{\textbf{[Flow(MGD) x 8.34lb/gal]}}$

Dose = $\dfrac{\textbf{30 Pounds per day feed}}{\textbf{2.1 MGD x 8.34 lb/gal}}$

= ***1.71 mg/L***

Calcium Hypochlorite

(Also called high test hypochlorite or HTH).

Top part of equation calculates lbs of pure Cl

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

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.

Disinfecting a Water Main

A new 8-inch water main, 500-feet in length, has been installed and needs to be disinfected with a dose of 50 mg/L. How many pounds of 65% strength HTH will be required?

Step 1: Calculate volume of main in MG

Volume = 0.785 x D² x L x 7.48 gal/cf [Diam and Length in ft.]

$$V = \frac{0.785 \text{ x } 0.67\text{ft x } 0.67\text{ft x } 500\text{ft x } 7.48\text{gal/cf}}{1{,}000{,}000 \text{ gal/MG}} = \mathbf{0.001318 \text{ MG}}$$

Step 2: Use calcium hypochlorite formula

$$\text{Pounds} = \frac{0.001318 \text{ MG x } 50\text{mg/L x } 8.34\text{lb/gal}}{0.65} = \mathbf{0.85 \text{ lbs}}$$

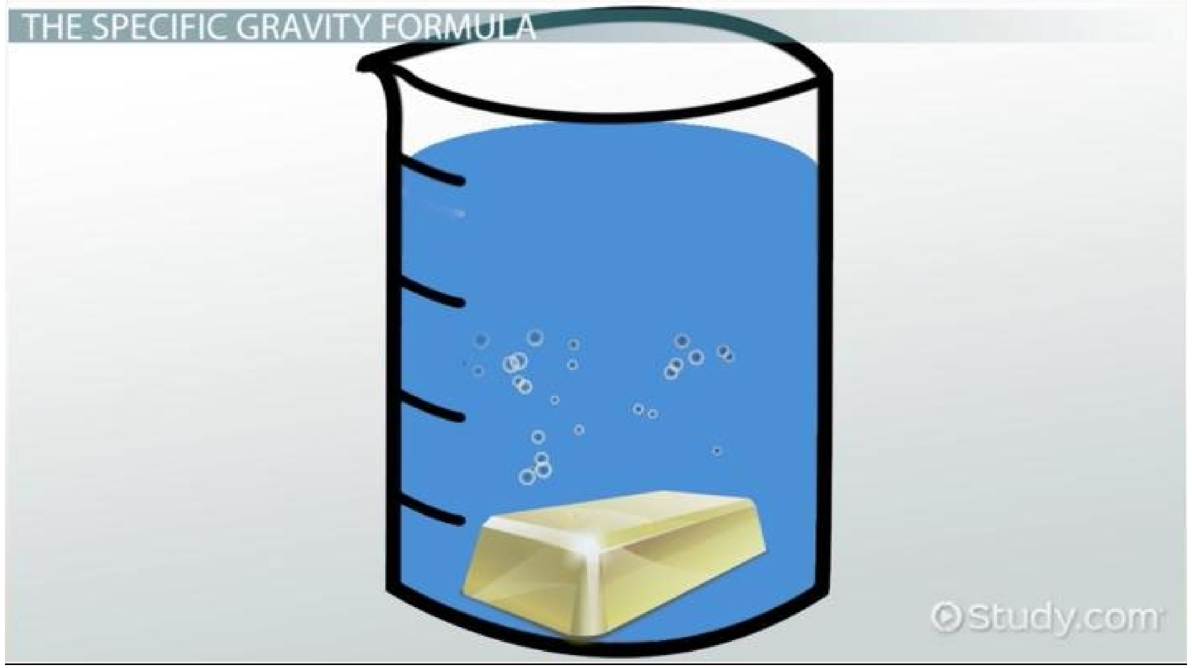
Specific Gravity

Water has a specific gravity of 1.0. The ratio of the weight of a substance to water is called specific gravity.

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

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

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



Calculating Feed Rates for Sodium Hypochlorite

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

Top part of equation calculates lbs of pure Cl

Dividing by % strength gives weight of sodium hypochlorite liquid actually needed. Use the decimal equivalent of percent (i.e. 12.5% = 0.125)

Dividing by weight per gallon will give you the feed rate in gallons

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

Weight per gallon

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

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

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

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

Math Practice – Feed Rates and Dosage

Disinfection Contact Time and CT Values

EPA Disinfection Profiling and Benchmarking: Technical Guidance Document
https://www.epa.gov/system/files/documents/2022-02/disprof_bench_3rules_final_508.pdf

Disinfection Contact Time

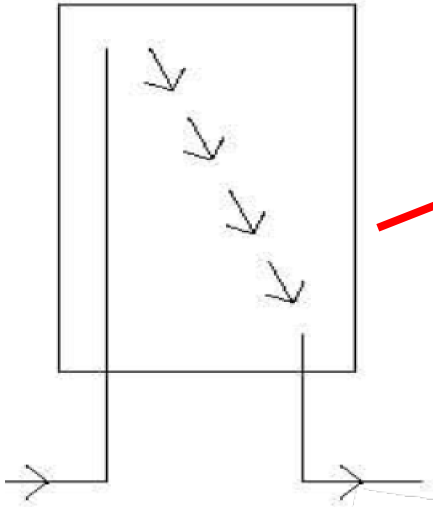
Theoretical Detention Time (assumes no short-circuiting).

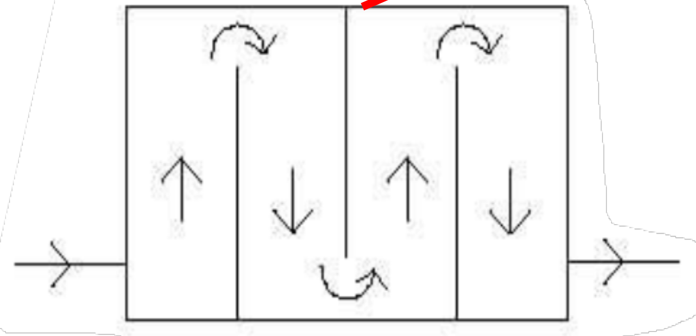
$$\text{Time} = \frac{\text{Volume}}{\text{Flow}}$$

Disinfection Contact Time (Uses a baffling factor to account for short circuiting)

$$\text{Time} = \frac{\text{Volume (gallons) x Baffling Factor}}{\text{Flow (gallons per minute)}}$$

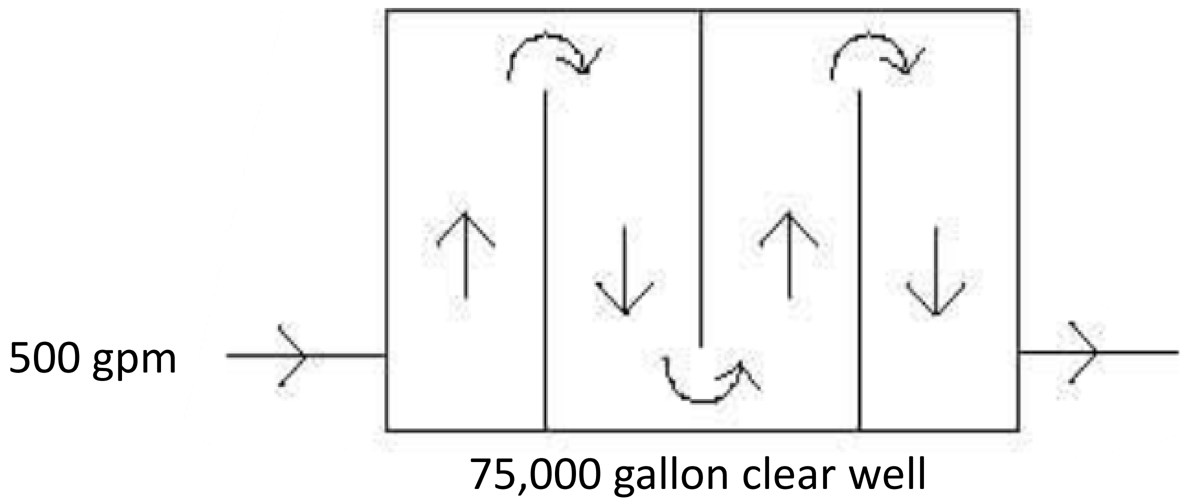
Baffling Factor indicates the degree of short circuiting.





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.

What is the disinfection contact time for a tank that has a volume of **75,000 gallons** and a **baffling factor of 0.5**, if the flow through the tank is **500 gpm**?



Solution:

$$\text{Contact Time} = \frac{75{,}000 \text{ gallons} \times 0.5}{500 \text{ gpm}} =$$

CT Values and Log Inactivation Requirements:

SWTR log treatment requirements for viruses and giardia

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

(The combination of filtration and disinfection must achieve minimum 3 log removal/inactivation of Giardia lamblia cysts and 4 log removal/inactivation of viruses)

Considerations:

- Multiple barriers that are robust (source protection, filtration, testing, etc.)
- Disinfection byproduct formation (need to limit chlorination)
- Specific requirements of regulatory agency (state specific)
- Plant design (removal credits)

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. Disinfection is more effective at higher temperatures

Example: You measure pH and Temp

1. The temperature of your water is 16 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.

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 16 C** and water **pH is 7.5.**

Step 1: Determine contact time.

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

Step 2: Calculate CT being attained

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

Step 3: Compare 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

Example Problem – CT at First Connection?

A groundwater system needs to achieve a CT value of **6 mg-min/L** at the first service connection in the system. There is **500 feet of 8-inch pipe** between the disinfection point and the first connection and the flow is **250 gpm.** The free chlorine residual is **1.5 mg/L.**

Step 1: Convert the flow from gpm to cfs (dividing by 7.48 gives cubic feet, dividing by 60 gives flow in 1 second)

$$\frac{250 \text{ gallons per minute}}{7.48 \text{ gal/cf} \times 60 \text{ sec/min}} = \mathbf{0.557\ cfs}$$

Step 2: Convert pipe diameter to feet (divide by 12 in)

$$\frac{8 \text{ inch}}{12 \text{ in/ft}} = \mathbf{0.67\ ft\ diameter}$$

Step 3: Find the circular cross-sectional area of the pipe in ft^2 (Use 0.785 x D x D)

Area = 0.785 x 0.67ft x 0.67 ft = **0.35 ft^2**

Step 4: Divide the flow in cfs by the area in ft^2 to find velocity (If Flow = Area x velocity, then v = Q/A)

0.557 cfs ÷ 0.35 ft^2 = **1.59 ft per second**

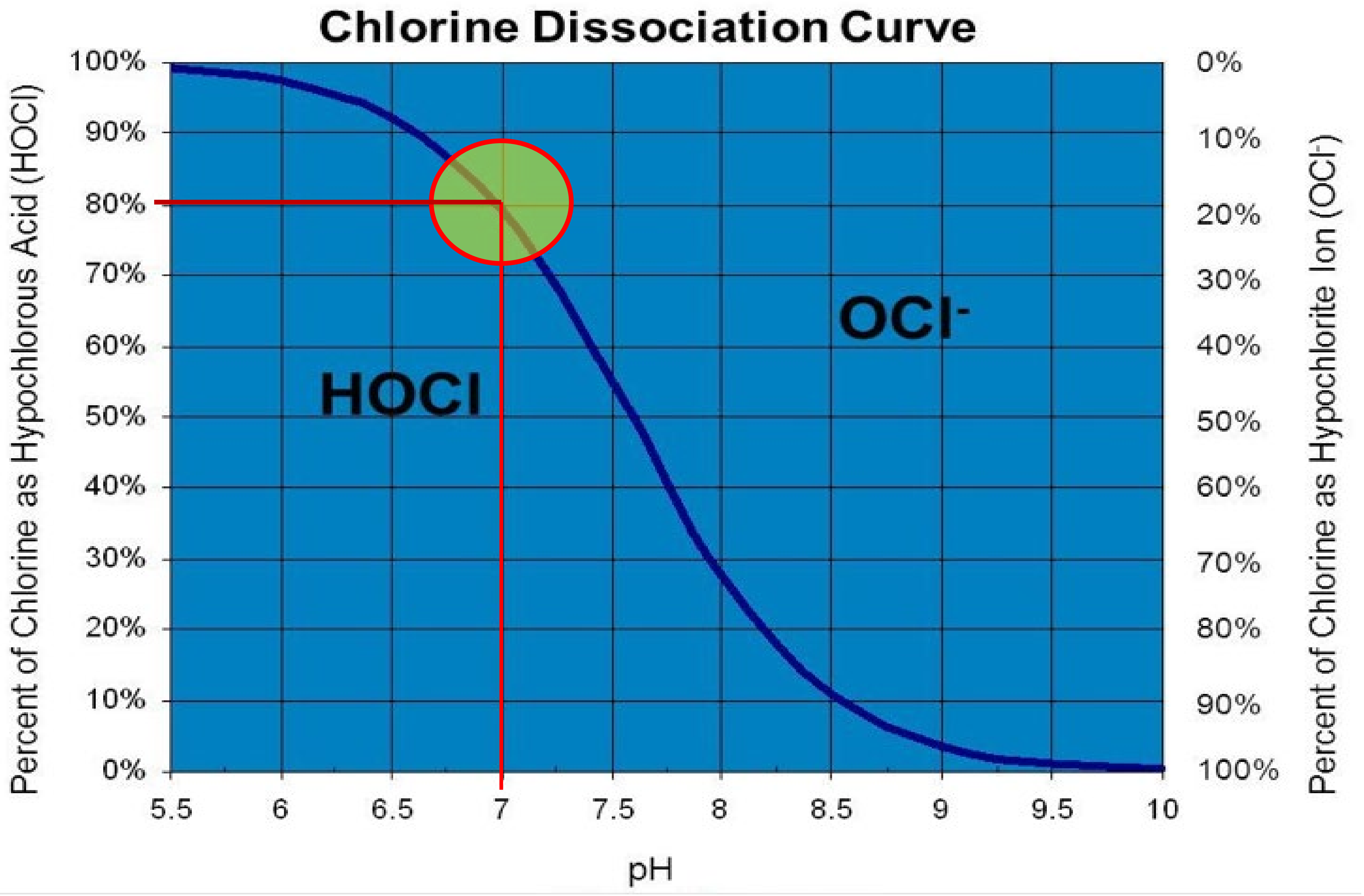
Step 5: Divide the linear foot of the pipe by velocity to find the total contact time in the pipe

500 ft ÷ 1.59 ft/sec = **314.5 seconds** or **5.24 minutes**

Step 6: Calculate the CT achieved

5.24 minutes x 1.5 mg/L = **7.86 mg-min/L** (compliance is achieved!)

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

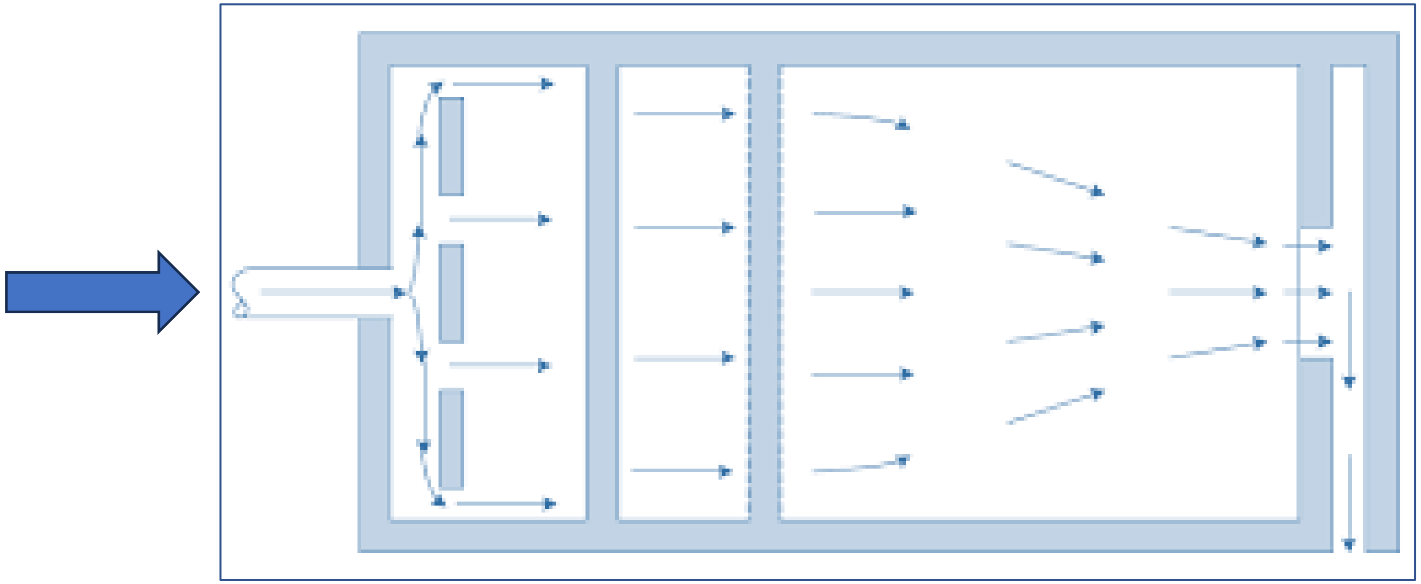
- 80% HOCL and
- 20% is OCL-

Log 3 Giardia Inactivation Problem:

A flow of **800 gpm** water is chlorinated to have a free residual of **1.2 mg/L** and enters a **75,000-gallon** clear well that has a baffling factor of **0.7.**

In the next slide, you will calculate the CT value for this disinfection process (which is the first step in solving this problem).

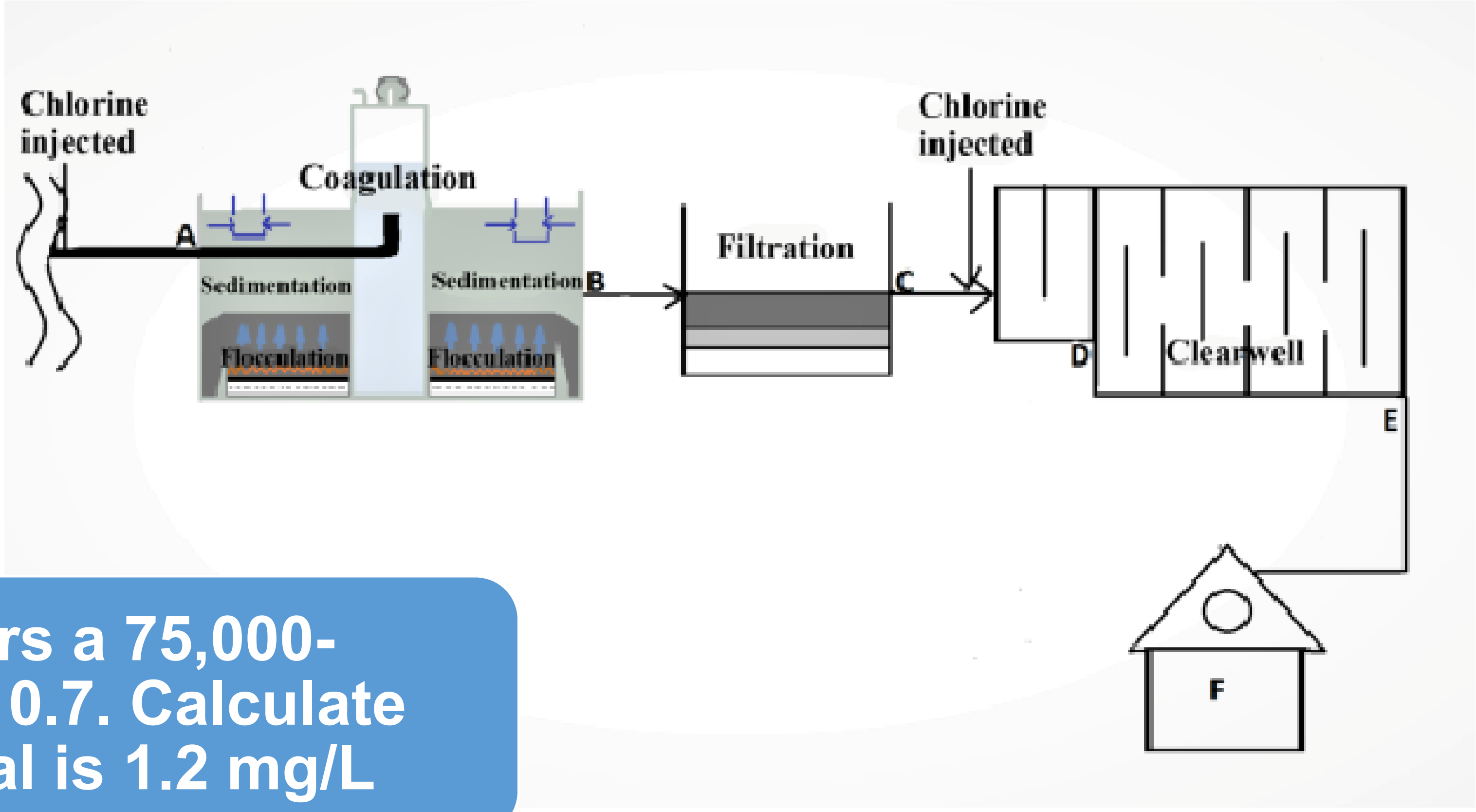
800 gpm



pH = 7.0
Temp = 15 C

75,000 gallon clear well
BF = 0.7

Knowledge Check – CT Calculations

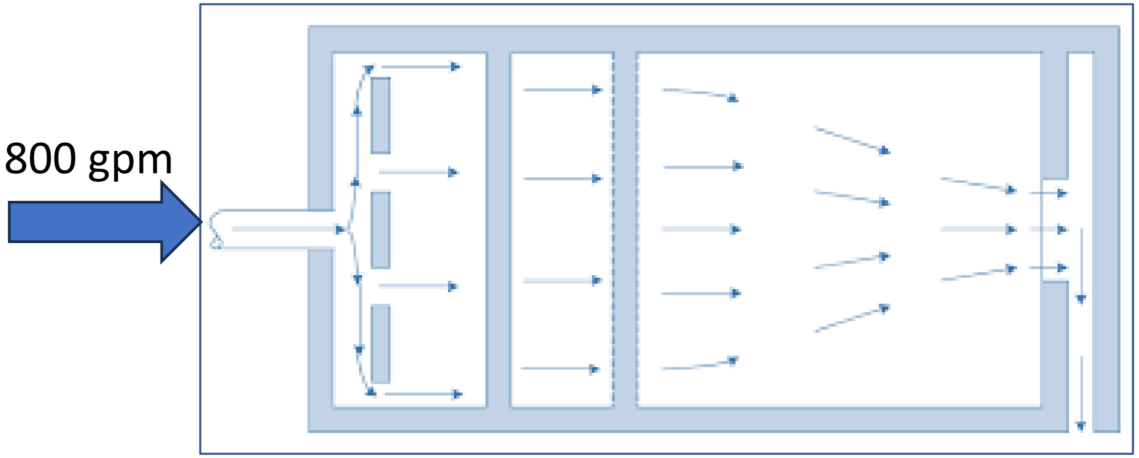


A flow of 800 gpm water enters a 75,000-gallon clear well with a BF of 0.7. Calculate CT if the free chlorine residual is 1.2 mg/L

Log 3 Giardia Inactivation Problem:

A flow of 800 gpm water is chlorinated to have a free residual of 1.2 mg/L and enters a 75,000-gallon clear well that has a baffling factor of 0.7.

Minimum water temperature is 15 C , **maximum pH is 7.0**, and the minimum free **chlorine residual is 1.2 mg/**L. Determine if the system has sufficient contact time and residual to achieve 3-log inactivation for Giardia and meet regulatory requirements.



75,000 gallon clear well
BF = 0.7

Contact time

$$\frac{75{,}000 \text{ gal} \times 0.7}{800 \text{ gpm}} = \mathbf{65.6 \text{ min}}$$

CT

1.2 mg/L x **65.6 min** = **78.7 mg-min/L**

Next: Compare to table

Step 4: Determine Required CT for 3-Log Inactivation

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 1.2 mg/L.

Required CT = 76 mg-min/L

Our calculated CT of 78.7 mg-min/L exceeds the minimum required CT of 76; therefore, compliance has been achieved!

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

Calculating Log Inactivation for Compliance

Log inactivation (99.9) = **3** x $\frac{\text{CT achieved}}{\text{CT required}}$

$$3 \times \frac{78.7 \text{ mg-min/L}}{76 \text{ mg-min/L}} = 3.1 \text{ Log inactivation}$$

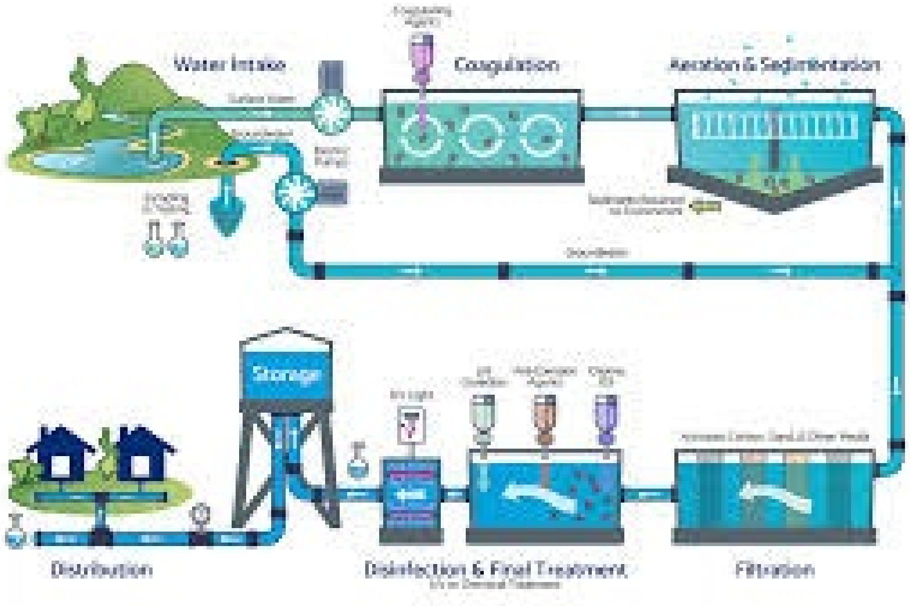
If the surface water treatment plant were credited with **2.0 log removal** (due to a filtration process), the total Log treatment (inactivation + removal) would be:
3.1 log inactivation + **2.0 log** removal = **5.1** total Log treatment.

If inactivation log treatment is lower (i.e. 1.5 log instead of 3.0)

- Count removal credit from filtration (1.5 + 2.0 = 3.5)
- Increase residual and/or improve baffling (Increase CT)
- Add additional clear well volume (Increase contact time)
- Decrease pH of water (more effective disinfection)

Knowledge Check – Log Treatment

A treatment plant achieved a CT of 60 from disinfection, but a total CT of 80 would be required to meet 3-log Giardia requirements with disinfection alone. What is the total log treatment if the plant receives 2.5 log removal credits?



Solution

Log inactivation (99.9)

$$3 \times \frac{60 \text{ mg-min/L}}{80 \text{ mg-min/L}} = \textbf{2.25 log inactivation}$$

Total log treatment

2.25 log inactivation + 2.5 log removal = **4.75 log**

Disinfection of Water Mains (AWWA C651-23)

After main repair, a low-pressure event, or coliform contamination water mains should be first flushed then disinfected.

Continuous Feed: Feed the main to achieve a free chlorine residual of at least 25 mg/L – residual should be at least 10 mg/L after a 24-hour contact time.

Tablet Method: For smaller mains (up to 2,500 feet of 12-inch and smaller diameter mains), place chlorine tablets inside each pipe joint during installation, and fill the main with water. Allow a 24-hour contact time, aiming to maintain at least 25 mg/L free chlorine.

Slug Method: Utilize a column of highly concentrated chlorine solution (300 mg/L) pushed through the main with a minimum 3-hour contact time, particularly for larger diameter mains.

After disinfection, the chlorinated water should be dechlorinated and flushed to waste.

Emergency Disinfection of Storage Tanks (AWWA C652-19)

Before disinfecting a storage tank, it should first be professionally cleaned.

Disinfection procedures

- Spray interior surfaces of tank with a **200 mg/L** solution of chorine and let sit for **3-hours**
- Rinse the tank walls and drain and dechlorinate rinse water
- Refill tank with clean water and take bacti samples to ensure it is coliform negative before putting it back online

Disinfecting Wells – Generally (AWWA C654-21)

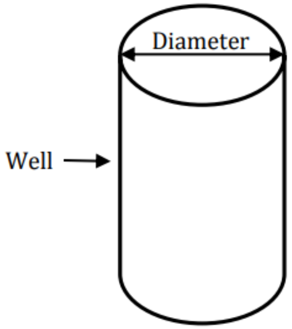
Wells should be disinfected with a dose of chlorine that results in a 50 mg/L residual maintained throughout a 24-hour period.

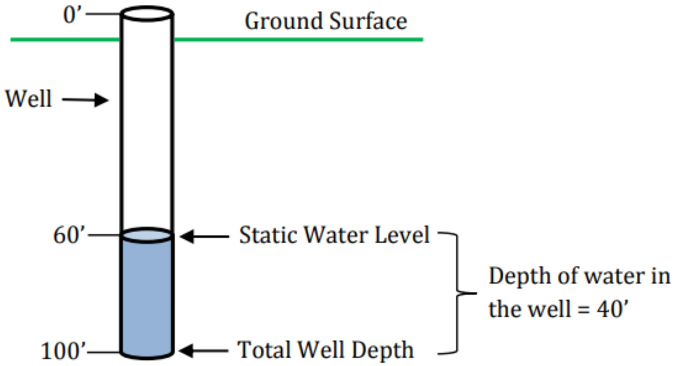
Step 1: Calculate the volume of water in the casing in MG

Step 2: Calculate the gallons of sodium hypochlorite bleach needed for the desired dose (a fraction above 50 mg/L to account for reducing compounds and chlorine decay over the 24-hour period).

Step 3: At the end of the disinfection period flush and dechlorinate the well water to waste

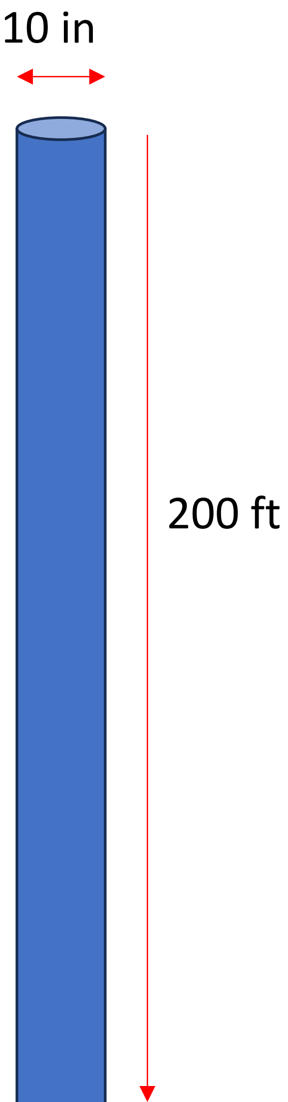
Step 4: Ensure a negative bacti sample result for the **raw** well water





Disinfecting Well Example

A well has a 10-inch diameter casing and a total water column of 200 feet. Calculate the gallons of 12.5% bleach needed for a dose of 75 mg/L. (use 1.2 for specific weight of liquid chlorine)



Step 1: Calculate volume in gallons

$$\frac{10\ \text{inch}}{12\text{in/ft}} = 0.833\ \text{ft}$$

V = 0.785 x 0.833 ft x 0.833 ft x 200 ft x 7.48 gal/cf = 814.9 gallons

Step 2: Convert to MG

815 gallons ÷ 1,000,000 gal/MG = 0.000815 MG

Step 3: Sodium hypochlorite formula

$$\frac{0.000815\ \text{MG} \times 75\ \text{mg/L} \times 8.34\ \text{lb/gal}}{0.125 \times 1.2 \times 8.34\ \text{lb/gal}} = \mathbf{0.408\ gal}$$

Sodium Hypochlorite Safety

Personal protective equipment (PPE) should include, at a minimum, eye protection and gloves. Sodium hypochlorite should be stored and handled away from chemicals that could cause hazardous interactions.

Hazards

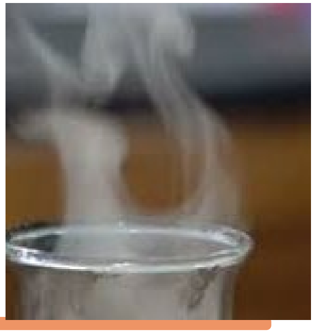
Skin Contact: Concentrated solutions (above 5%) are highly corrosive and can cause irritation and burns. (It will also damage clothing).

Eye Contact: Can cause irreversible eye damage.

Inhalation: Inhaling mists or vapors severely irritates the nose, throat, and respiratory tract.

Chemical Interactions to Avoid: Mixing sodium hypochlorite with **acids** or **ammonia** can release highly toxic chlorine gas or chloramine gases.

Calcium Hypochlorite Safety



Calcium hypochlorite, typically 65% to 70% strength, is a ***very*** strong oxidizer.

Hazards

- Contact with organic materials (such as oils, grease, gasoline, kerosene, brake fluid, rags, or organic pool chemicals) can cause spontaneous combustion or fire.
- Never Mix with Acids: Contact with acids instantly releases massive amounts of highly toxic, lethal chlorine gas (Cl_2).
- Contact or dust can cause irritation and permanent damage to skin, eyes, mucus membranes, and lungs.

PPE

- Goggles and a face shield
- Chemical-resistant gloves (nitrile, neoprene, or PVC) and long sleeves.
- Respirator if material handling causes dust (NIOSH-approved particulate respirator (N95 or higher)

Gas Chlorine Safety

- **Chlorine gas is deadly**. A self-contained breathing apparatus SCBA is necessary to repair chlorine leaks. SCBAs should be stored near, but outside of the chlorine room. Respirators may sometimes be used in environments with low chlorine levels up to 10 ppm.
- 0.5 ppm: NIOSH 15-minute maximum exposure ceiling. 10 ppm is Immediately Dangerous to Life or Health (IDLH)
- When attaching a new cylinder, a new lead gasket should always be used, and the valve is just barely cracked and then closed to check for leaks before putting it online
- Special sensors are installed to alert operators of leaks

Lead washer

Chlorine gas sensor

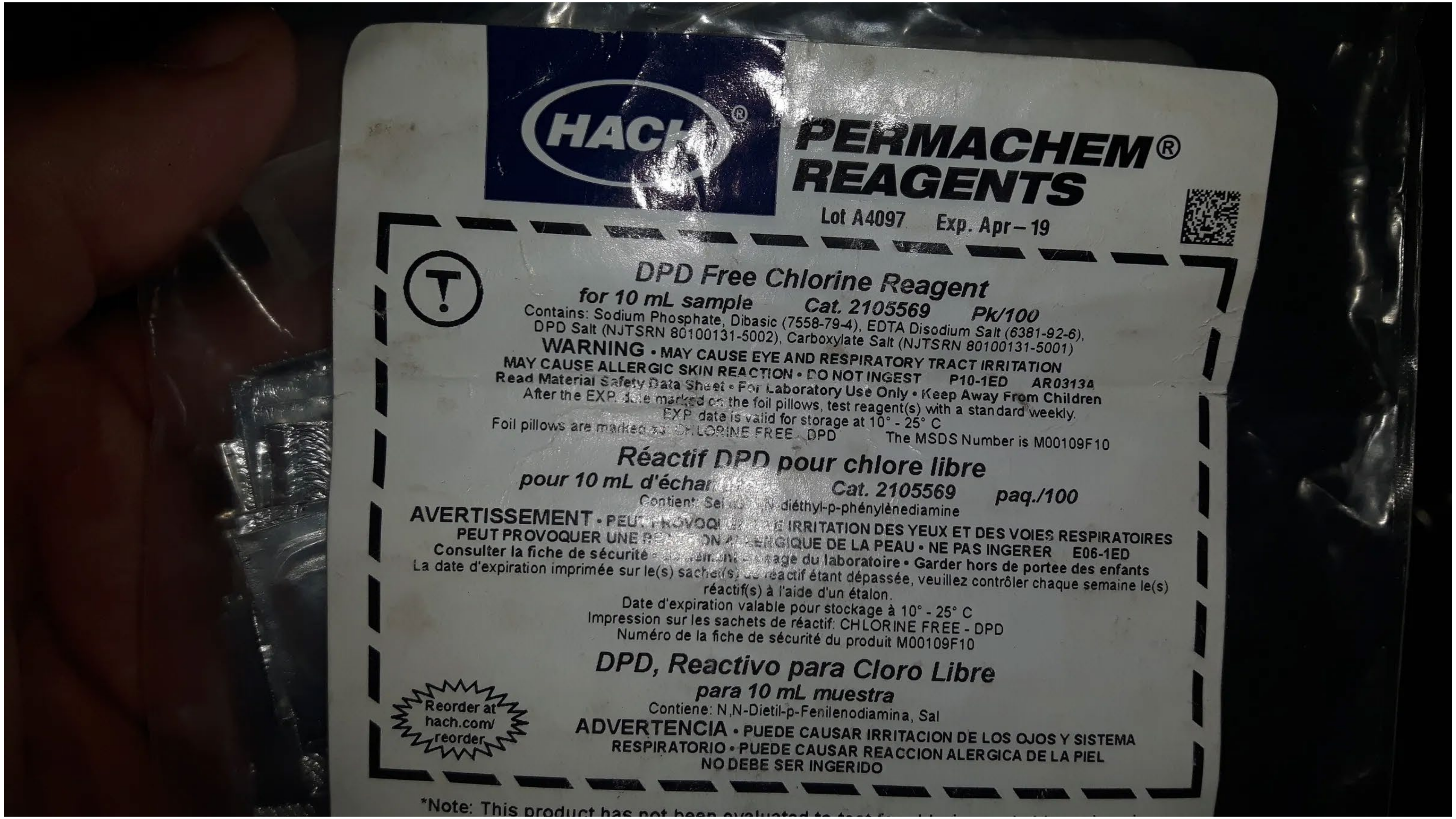
Secondary containment vessel

Performing a Chlorine Residual Test (DPD)

Add a DPD reagent to a 10-mL sample of drinking water.
Reagents are labeled either free or total. The amount of color change (pink to magenta) indicates the chlorine concentration in mg/L

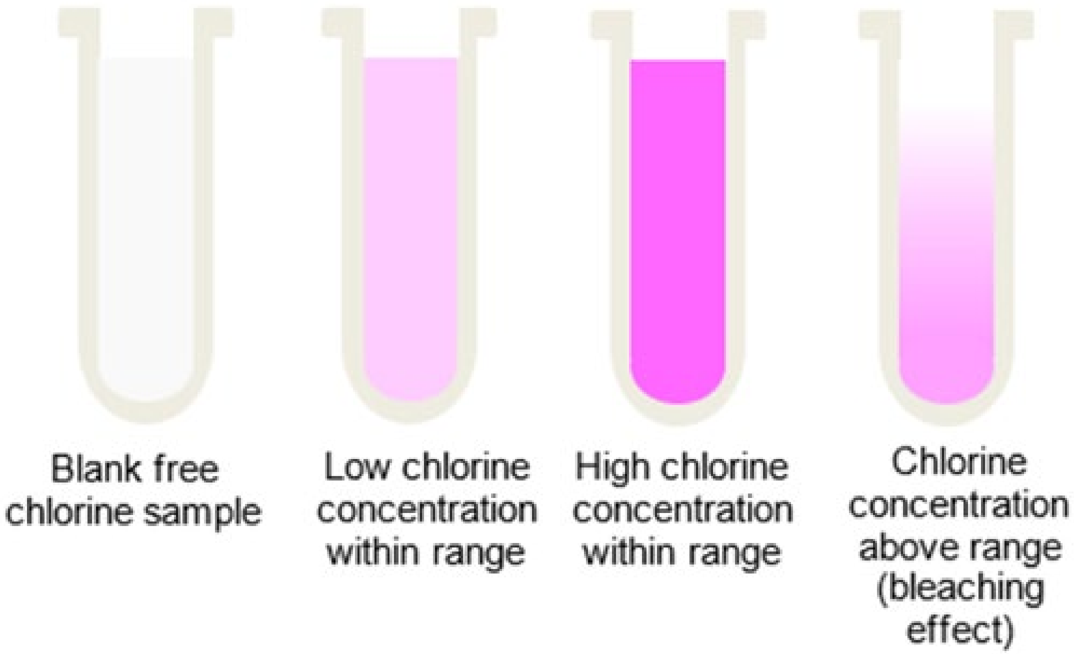
Insert the sample vial into the Colorimeter.
After the reagent has time to react (30 to 60 sec), the sample vial is placed into a digital colorimeter, which measures the chlorine concentration by passing an LED light through the sample. The light has a green wavelength of 525-530 nm, which will be blocked or absorbed by the complementary color in the sample.

Reagent for Free Chlorine Residual



Example

This sample has a deep red color, and the residual is 3.9 mg/L

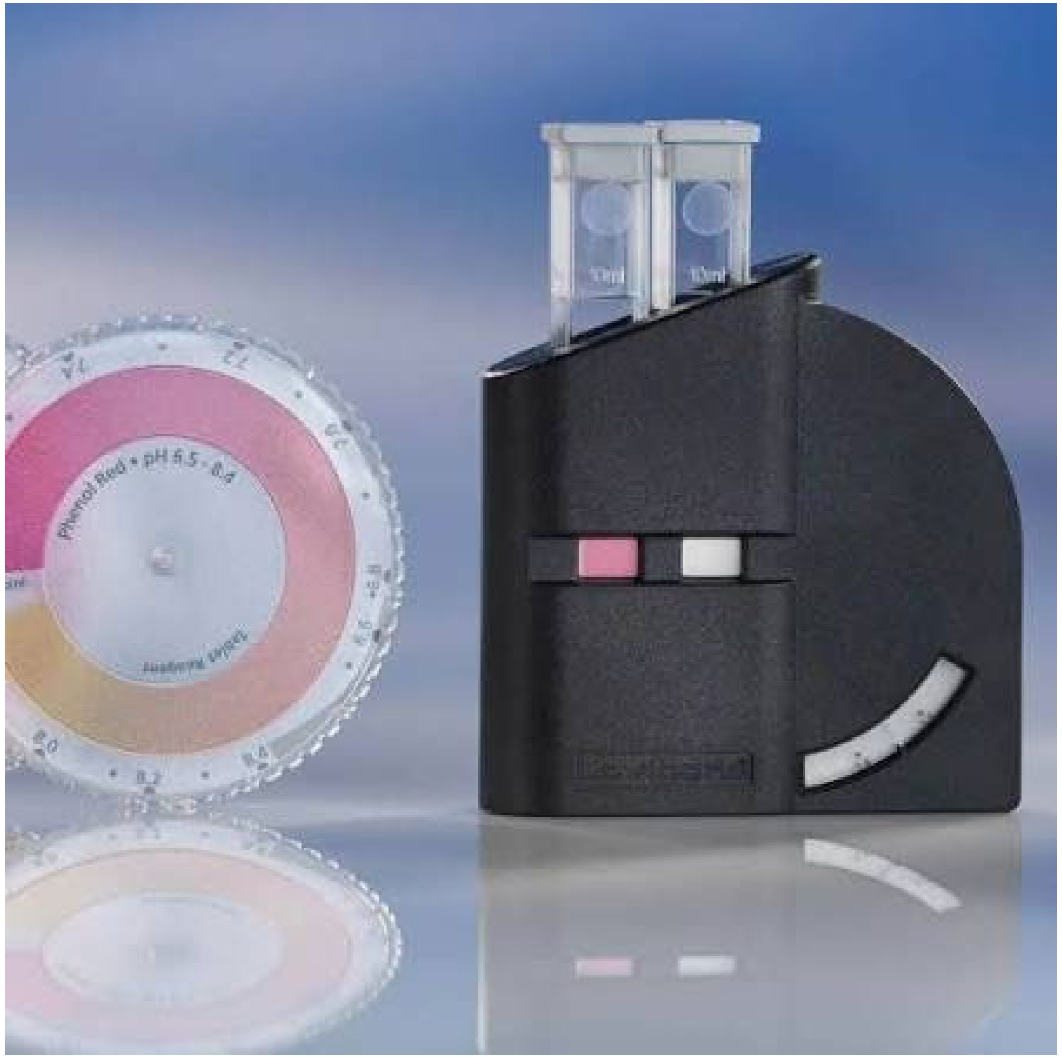


Example 2

In this example, the operator has a chlorine sample with a slight color change and a much lower residual.

This residual could be acceptable at remote points in the distribution system because it exceeds 0.2 mg/L, but it is likely much too low for initial disinfection.

Color wheel measurement



In the color wheel method, the sample and the wheel are compared side by side. The wheel is rotated until the colors match, and then the scale is read. It still uses DPD reagents.

Monitoring Chlorine Residuals

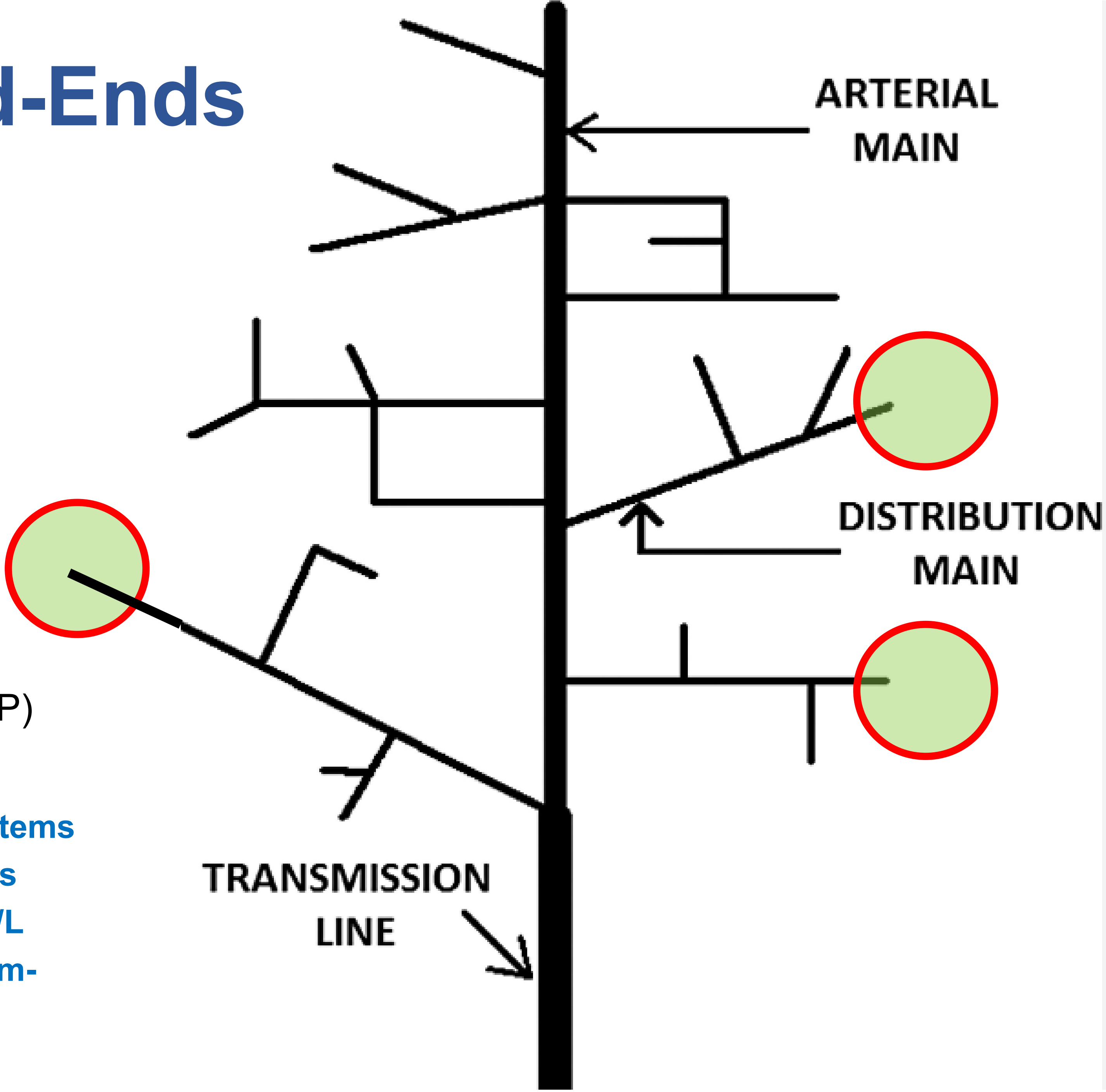
Range of acceptable chlorine residuals

- At least 0.2 mg/L in the remote limits of the distribution system.
- Never greater than 4.0 mg/L

Falling chlorine residual levels (or no residual) can mean

- Contamination has entered (sanitary defect or cross connection)
- Formation of disinfection byproducts in dead-ends.

Dead-Ends



- Higher water age
- Loss of chorine residual
- Increased sedimentation
- Increased biofilm growth
- Increased scale formation
- 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.

Disinfection Byproducts (DBPs) - How Do They Form?

Rainfall carries organic material from the forest into the reservoir.

Filters remove most of the organic material but some excess can remain.

When chlorine is added to filtered water, it reacts with the remaining organics, forming DBPs.

DBPs flow into the distribution system, where sampling takes place.

Disinfection byproduct formation

Total Trihalomethanes (TTHM)

- Chloroform
- Bromodichloromethane
- Dibromochloromethane
- Bromoform

Trihalomethanes are the 4 volatile organic compounds found in drinking water that pose a cancer risk over the **MCL of 0.080mg/L**

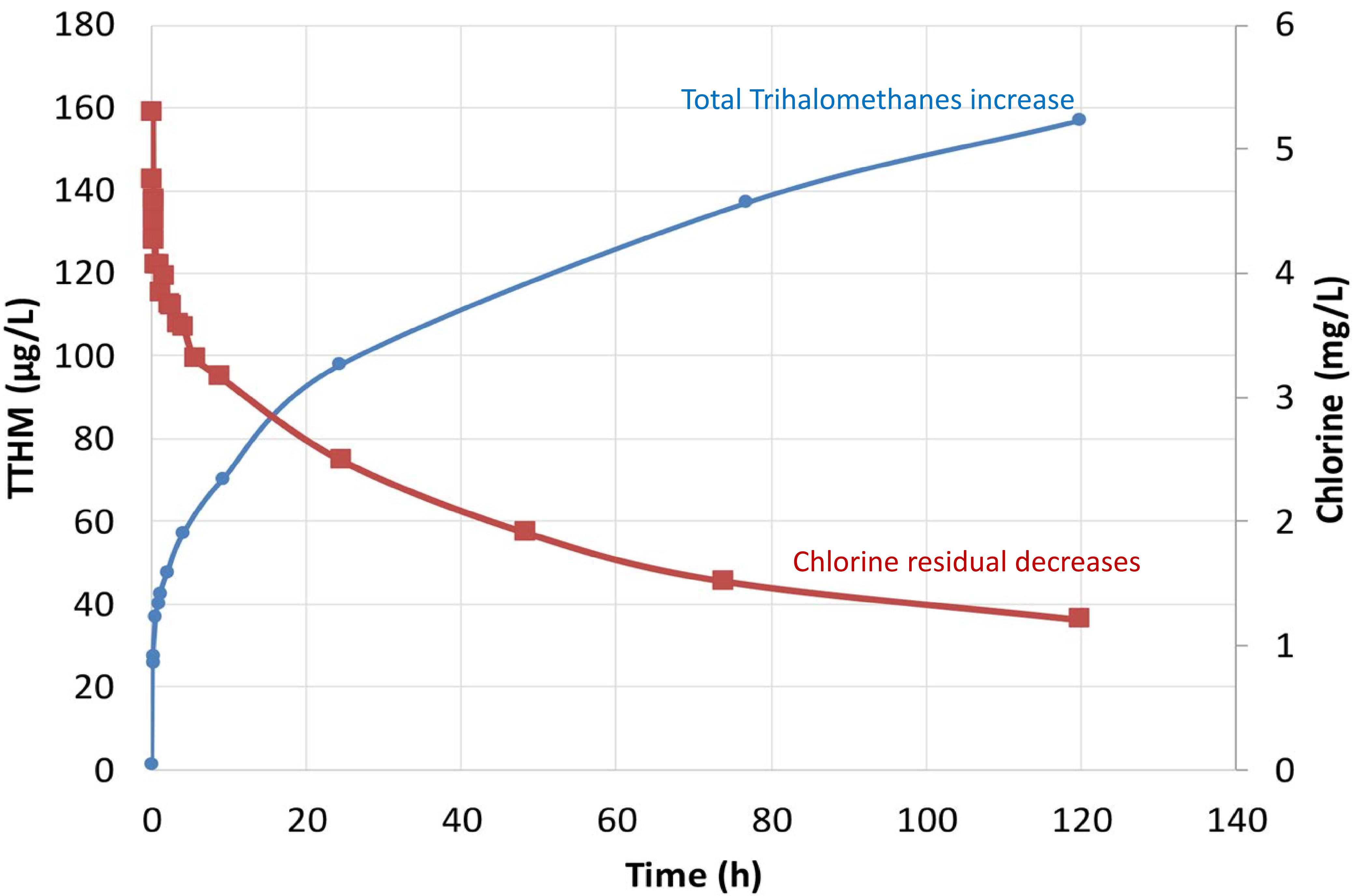
They are formed from a reaction between naturally occurring organic matter (NOM) and chlorine.

Haloacetic Acids (HAA5)

- Monochloroacetic acid
- Dichloroacetic acid
- Trichloroacetic acid
- Bromoacetic acid
- Dibromoacetic acid

HAA5 are weak acids that pose a cancer risk when over the **MCL of 0.060 mg/L**.

Both TTHM and HAA5 compounds are the result of reactions with NOM and the decay products of plant and animal materials (humic and fulvic acids.)



Total Trihalomethanes increase
Chlorine residual decreases
TTHM (µg/L)
Chlorine (mg/L)
Time (h)
180
160
140
120
100
80
60
40
20
0
6
5
4
3
2
1
0
0
20
40
60
80
100
120
140

Prevention of TTHMs and HAA5

Distribution System

- Adding mixing to storage tanks
- Ensure tank turnover 5 days or less
- Use chloramines for a disinfectant residual
- Gentle flushing of dead-ends and high retention areas
- Regular tank cleaning and water main flushing to remove debris

Disinfection Profiling and Benchmarking Technical Guidance Manual (USEPA, 2020).
https://www.epa.gov/system/files/documents/2022-02/disprof_bench_3rules_final_508.pdf

For More Resources and Contact

Environmental Finance Center Network
https://efcnetwork.org/

- Funding guides
- Request technical assistance
- Register for training events
- Tools, resources, videos, articles

Great Lakes Environmental Infrastructure Center
at Michigan Tech
https://gleic.org/

Instructor contact,
Daryl Gotham, PE
djgotham@mtu.edu

Evaluation Survey

Please scan this code and complete the survey. Completion of the survey is appreciated for all but required for those receiving continuing education units or contact hours.

Instructor contact,
Daryl Gotham, PE
djgotham@mtu.edu

Thank you for participating!

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Recommended Reference Materials

1. **The CT Method: A Reference Guide: North Carolina Area Wide Optimization Program Team. April 21, 2020.** https://deq.nc.gov/media/16645/download

2. **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

3. **USEPA Guidance Manuals for the Surface Water Treatment Rules.** https://19january2017snapshot.epa.gov/dwreginfo/guidance-manuals-surface-water-treatment-rules_.html

4. **Pipe disinfection calculator**: https://moruralwater.org/water-tools-files/tool_pdfc.php

5. **Drinking Water Regulations**. https://www.epa.gov/dwreginfo/drinking-water-regulations

6. **Surface Water Treatment Rules**. https://www.epa.gov/dwreginfo/surface-water-treatment-rules