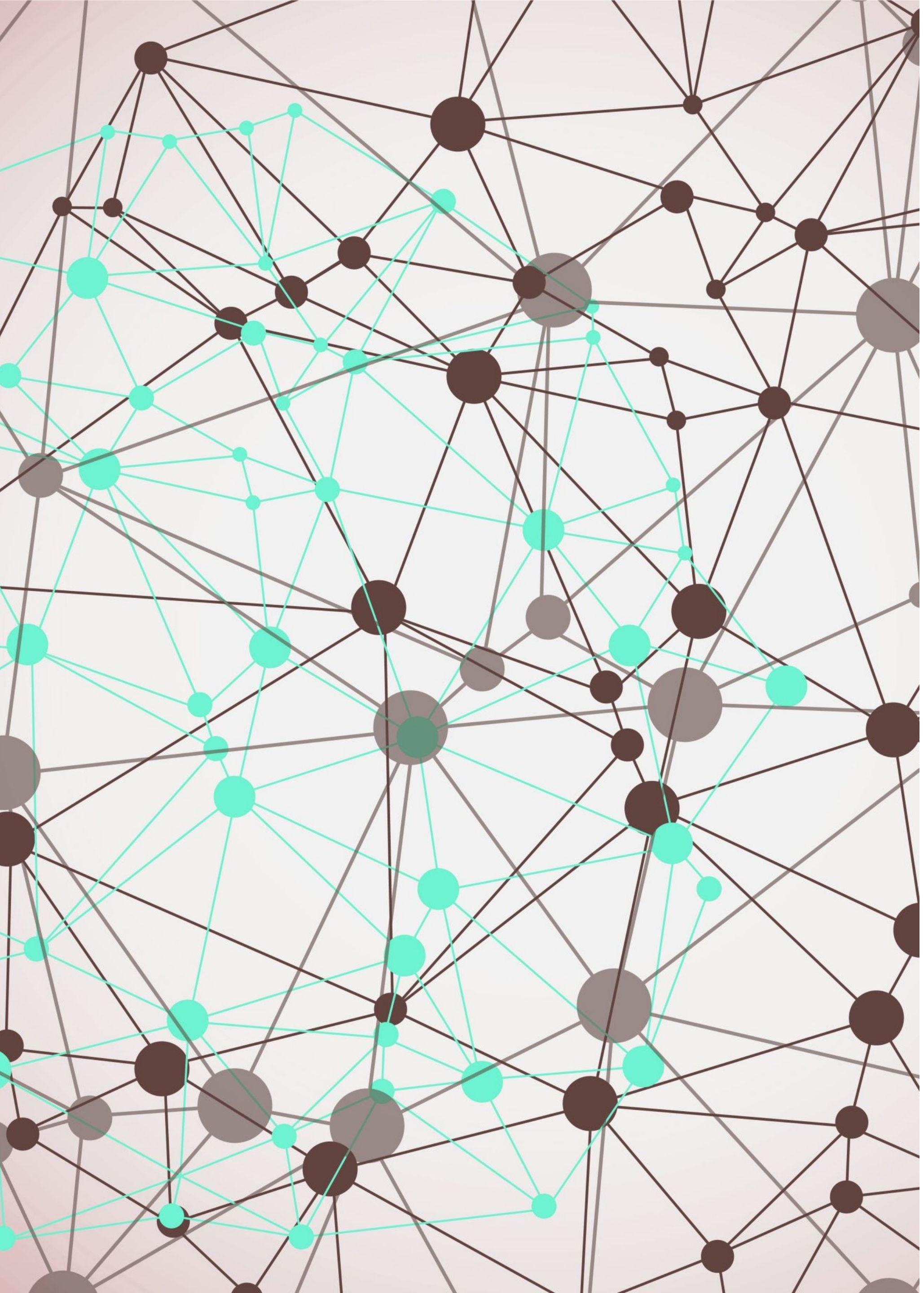


Drinking Water Disinfection

Presenter: Jim Kenney

Marin Water Superintendent of Operations, Water Treatment

Adjunct Instructor SRJC –Water and Wastewater Chemistry

What is Disinfection?

Disinfection is the destruction or inactivation of pathogens in a water supply.

This should clear up everything right?

- We need to know that a **Pathogen** is simply a disease-causing organism.
- **Destruction** is the killing of that organism.
- **Inactivation** means that the organism is no longer able to reproduce.
- That fact that it is in a water supply means it is a water borne pathogen.

What is the difference between destruction and inactivation?

- Simply put the **destruction** refers to the actual killing of the pathogenic organism. So, if it is dead, it can’t infect a human.
- The **inactivation** on the other hand is treating the pathogen in a way that it can no longer reproduce. Say for example, you have of drink water that is contaminated with a pathogenic bacteria. Are you immediately ill? No. It take time for the infection/bacterial load reproduce inside you to make you sick. But if that single bacteria has been inactivated, it can’t reproduce so you can never get a high enough bacterial load to be ill.

Waterborne Pathogens are usually associated with disease outbreaks.

Known waterborne diseases that plagued man kind over the centuries:

Cholera	Legionnaire’s Disease
Amoebic Dysentery	Bacterial Dysentery
Typhoid	Giardiasis
Cryptosporidiosis	Hepatitis

These disease represent three different type of pathogens: Bacteria, Viruses and Protozoa.

How do we know if pathogens are present?

- Pathogen are found in very small numbers. So simply putting a drop on a microscope slide isn’t going to give us the results we are looking for.
- In water treatment we use a common bacteria as an indicator species, the **coliform bacteria.**
  - These bacteria are very common and come in two forms fecal and non-fecal.
    - Fecal coliforms come form the intestinal track of warm-blooded animals.
    - Non-fecal leaf bacteria found in dirt and on plants.
  - If the water is sufficiently disinfected that no coliform bacteria grow under incubated circumstances, then this indicates that no other pathogens exist either and this water is considered to be disinfected.

History of Water Disinfection

- The first American water supply to be widely disinfected happened in 1908 in Jersey City, New Jersey.
- This system used chlorine gas dissolved in the water as the Disinfectant.
- The goal of disinfection is to prevent waterborne disease breakouts and the many deaths associated with these breakouts.

Chlorine Disinfection

Chlorine has been used as a primary disinfectant throughout the USA and is probably the most widely used disinfectant.

- **Very effective disinfectant**
- **Economical Chemical to use**
- **Commonly available**
- **Leaves you with a traceable chlorine residual in the system letting you know that the chlorine is there and available to react with pathogens.**

Issues caused by Chlorine Disinfection

In 1974 researchers discovered cancer causing chemicals in the Drinking water that were not in the water prior to treatment. Free chlorine residual combined with organics found in the water to produce cancer causing compounds. Because of these by-products operators only want to feed as little chlorine as possible to remain the necessary residual in the system. *More is not always better.*

These products became known as Disinfection By-products:

- Trihalomethanes (THMs)
- Halo-acetic Acids (HA5)

Disinfection By-product Rule

The discovery of these disinfection by-products spurred research into alternate forms disinfection and new regulations: **The Disinfection By-product Rule**.

Chorine in its various forms is still the most widely used disinfectant today because some of its benefits cannot be duplicated.

The responsibility to ensure the health of the communities being served falls to the Water Treatment Plant Operators.

- **The goal is to find the proper balance between adequate chlorine disinfection and acceptable levels of disinfection byproducts.**

CHLORINE GAS

Properties:

- First isolated in 1774.
- Yellow/Green gas.
- 2.5 times as heavy as air. So, it hovers near the ground.
- Very strong oxidizing agent. Causes chemical reactions to occur.
- Strong unpleasant odor. Very noticeable.
- Corrosive to metals.
- Corrosive to flesh.
- Reacts with organics, metals and ammonia.

How Elemental Chlorine reacts with water

Chlorine reacts with water to produce Hydrochloric acid and Hypochlorous acid.

Reaction looks like this:

$$\mathbf{H_2O + Cl_2 \rightarrow HCl + HOCl}$$

In this reaction the goal is to create the Hypochlorous acid which provides the disinfection we are looking for.

Since this reaction produces two form of acid, it will slightly reduce the pH of the water.

Forms of Chlorine used in Disinfection

Elemental Chlorine (Cl_2)

- Comes in 100, 150 cylinders, ton tanks, or by rail cars in 15-90 tons.
- Applied to the water through a vacuum chlorinator.
- Elemental chlorine lowers the pH of the treated water.

Chlorine gas is a highly toxic chemical

• Least detectable by odor	Below 3.5mg/L in air
• Produces coughing	30mg/L in air
• Dangerous after 30 min. exposure	40-60mg/L in air
• Rapidly fatal	1,000mg/L in air

Forms of Chlorine Used in Disinfection

Hypochlorites:

- Sodium hypochlorite (bleach). The reaction looks like:

$$\mathbf{NaOCl + H_2O \rightarrow NaOH + HOCl}$$

- Calcium hypochlorite. The reaction looks like:

$$\mathbf{Ca(OCl)_2 + 2H_2O \rightarrow Ca(OH)_2 + 2HOCl}$$

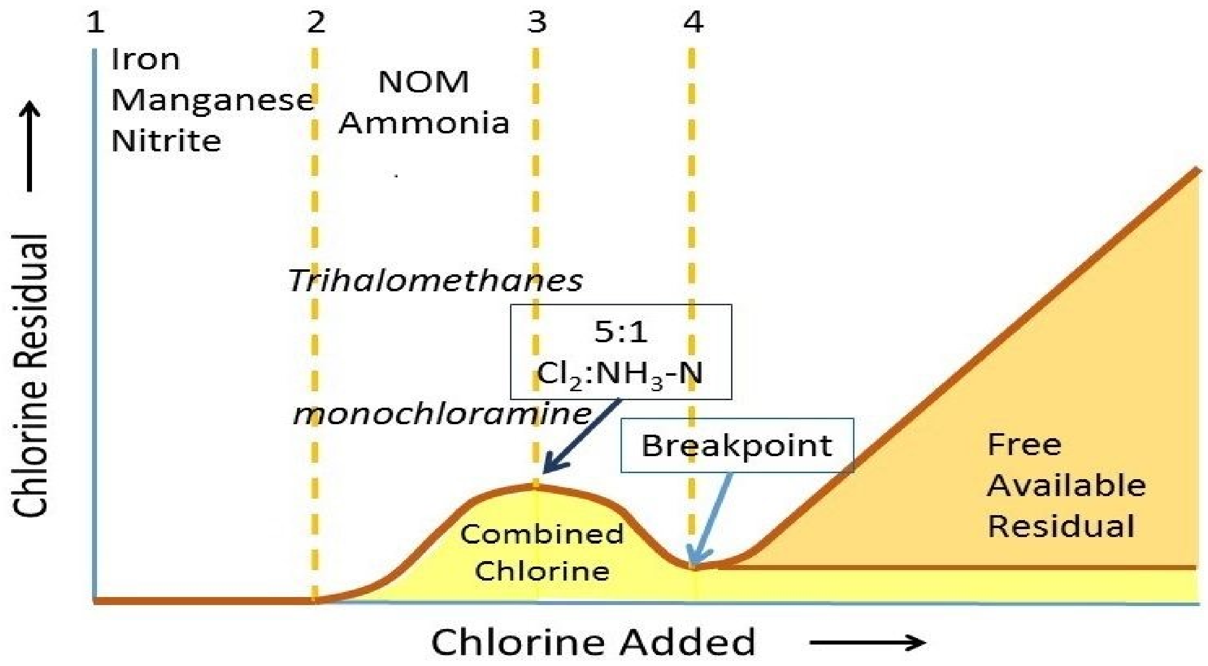
Disinfection with hypochlorite increases the pH of the the water slightly due to the production of a strong base Sodium hydroxide (Caustic Soda) or Calcium hydroxide. Both chemical reactions produce the Hypochlorous acid needed for disinfection.

Breakpoint Chlorination

Breakpoint Chlorination is a technique used in the chlorination of water containing organic matter and ammonia to ensure the proper disinfection by producing a **Free Chlorine Residual**.

- A **free chlorine residual** is produced when all the chlorine demand posed by the organic matter and ammonia are used up, after which point there is no combined chlorine and only free chlorine residual in the water.
- After Breakpoint Chlorination every part of chlorine added produces a part of free chlorine residual.

Breakpoint Chlorination Curve



Explanation of the Break Point curve.

Breakpoint chlorination is a four-step process. As the diagram shows the X-axis is the increasing chlorine dose and the Y-axis is the measured residual. Chlorine does not react with everything equally.

1. Chlorine reacts with reducing agents such as Iron, Manganese, Hydrogen sulfide and Nitrite that neutralize the chlorine giving us no residual.
2. Chlorine reacts with Organic matter including micro-organisms to produce chloro-organic compounds include the disinfection by-products.
3. Chlorine reacts with ammonia producing mono-chloramines up until it reaches the top of the hump. The reaction is: $NH_3 + HOCl \rightarrow NH_2CL + H_2O$. This give us a measured combined chlorine residual.
4. Destruction of the combined chlorine residual begins after the hump as we continue to add chlorine. The additional chlorine reacts with the chloro-organics and the chloramines and gets neutralized resulting in the drop of the combined residual. This continues down to break point, but while the combined chlorine residual drops it will never reach zero because there will be some remaining un-reducible compounds. All chlorine residual after break point is free residual chlorine.

Drinking Water Chlorine Demand

Chlorine Demand in drinking water in system is the amount of chlorine that must be added to get to break point.

This can be presented as the mathematical equation below:

Chlorine Demand = Chlorine Dose – Free Available Chlorine Residual

Chlorine Demand Example

EXAMPLE:

Your Plant is making 10 MGD. Your Chlorine Dose is 12 ppm. Your Chlorine Free Chlorine Residual is 2.5 ppm. What's your Chlorine Demand?

Chlorine Demand = Chorine Dose – Chlorine Residual

Chorine Demand = 12ppm – 2.5ppm = **9.5ppm**

Your plant is making 25 MGD. Your chlorine residual goal is 1.75ppm. Your Chlorine Demand is 7ppm. How much chlorine must be feed to meet your goal?

7ppm = Chorine Dose – 1.75ppm

Chorine Dose = 7ppm + 1.75ppm = **8.75ppm**

Factors Affecting Chlorination

pH: The pH of the water affects the amount of Hypochlorous acid formed.

- pH between 6.0-7.5 Hypochlorous acid (HOCl) predominates.
- pH between 7.5-9.0 The Hypochlorite ion (OCl-) predominates (very poor disinfectant)

Contact Time: Chlorine requires requires a certain amount of time to react with the pathogen's cells. The longer the chlorine contact time the better the disinfection. Operators use the CT concept to determine proper disinfection. Where: C = concentration in mg/L and T = time in minutes. CT= C X T

Factors Affecting Chlorination

Temperature: The effectiveness varies with temperature. The higher the temperature the faster the Disinfection. The warmer the temperature the lower the required **contact time**. Of course, the opposite is true as well as temperatures fall.

Dosage: The higher the dose the lower the **contact time**. You have more chemical available to react with whatever it finds in the water. Dosages of 0.5 to 1.0 will effectively disinfect water. The maximum allow able dose for Chlorine is 4.0mg/L. As we attempt to minimize the formation of disinfection by products, we should work to minimize the required chlorine doses.

Factors Affecting Chlorination

Combined Residual Chlorine: This is caused by combining chlorine with ammonia in the disinfection process called **chloramination.** Chloramines are not as effective as a free chlorine residual and thus require a higher dose and longer contact time. This is the normal residual created in wastewater treatment based on the amount of ammonia present in the plant influent.

Other Disinfectants

Ozone: zone is a colorless gas with a particular pungent odor, is a triatomic form of oxygen (O_3). It is generated by passing air or oxygen through a high-voltage arc between two electrodes or ultraviolet radiation.

Pros:

- Very powerful oxidizer.
- 20 times more soluble in water than oxygen.
- Ruptures cell walls of pathogens immediately upon contact.
- Treats taste and odor compounds by oxidation of organics.

Cons:

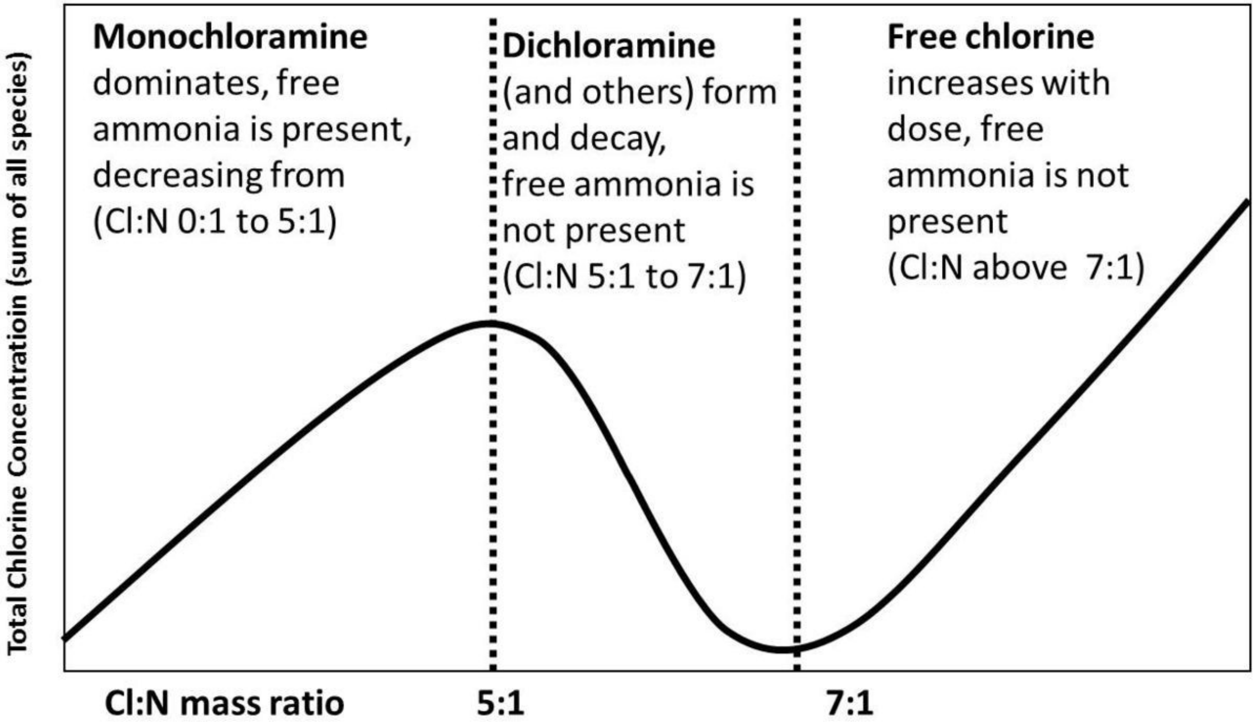
- Expensive to produce.
- No residual present after disinfection
- No disinfection by products.

Other Disinfectants

Chloramination: This is the purposeful combination of chlorine and ammonia under controlled situations to create a new disinfectant. While chloramines are not as effective as a free chlorine residual and requires a higher dose and greater contact time it does provide benefits to systems with large and complicated distribution systems.

- Prevents the formation of Disinfection By-products.
- Maintains a residual longer than free chlorine throughout the distribution system.
- The goal is to create monochloramines at a maximum of 5:1 chlorine to ammonia ratio.

Other Disinfectants



Other Disinfectants

There are three types of of Chloramines that can be created. The types of chloramine created depends on the ratio of Chlorine to Ammonia. The goal is to create only Monochloramines.

- Monochloramines – require a ratio 1:1 up to 5:1. Best disinfectant, no odor.

$$NH_3 + HOCl \rightarrow NH_2Cl + H_2O$$

- Dichloramines – a ratio from 5:1 to 6:1. Poor disinfectant, creates odors.

$$NH_2Cl + HOCl \rightarrow NHCl_2 + H_2O$$

- Trichloramines – a ratio of 6:1 to 7:1. Poor disinfectant, creates odors.

$$NHCl_2 + HOCl \rightarrow NCl_3 + H_2O$$

Other Disinfectants

Ultraviolet Light/Radiation: UV works well as a disinfectant. For UV to work the water must be clear and colorless. The UV light rays must come into contact with the pathogens to kill or inactive them.

Pros:

Effective disinfectant.

Cons:

Must have clear, colorless, and shallow water.

High energy use, so expensive.

Leave no residual after disinfection.

Other Disinfectants

Bromine: Bromine is a halogen similar chlorine and has similar properties. It is a dark red liquid 3.5 times heavier than water. In water it forms Hypobromous acid and hypobromic acid. Hypobromic acid is an excellent disinfectant.

- $Br_2 + H_2O \rightarrow HOBr + HBr$

Is normally used in swimming pools and waters with high ammonia content.

Cons:

- Scarce element so it is more expensive than chlorine.
- It is more physiologically active to humans.

Other Disinfectants

Iodine: Is a bluish black solid and the third member of the Halogen family of elements with great disinfection properties. Iodine forms Hypoiodous acid in water which is an effective disinfectant.

- $I_2 + H_2O \rightarrow HOI + HI$

Pros:

- Does not react with ammonia
- Not affected by pH.

Cons:

- Expensive compared to chlorine.
- Physiologically active to humans.

Other Disinfectants

Chlorine Dioxide: First used in the US for taste and odor control. By 1997 used by about 400 water utilities for predisinfection. It used more often to assist in the efficiency of chlorine or chloramine disinfection. Chlorine Dioxide is a strong disinfectant.

Pros:

- It is not affected by ammonia.
- Does not create disinfection by-products.

Cons:

- Expensive to generate.
- Explosive above a concentration of 10% in air.
- Reverts to Chlorite which can be a health hazard.

Other Disinfectants

Silver Ions: Very low concentration on silver ions (0.01mg/L) are sometimes used for water disinfection. The effectiveness of silver ions is decreased in the presence of organic substances.

Cons:

- This is a precious metal so way too expensive to use to disinfect water supplies.