Learning Objectives

• Be able to discuss the purpose and types of disinfection

• Be able to discuss the basics of chlorination and chloramination
Topics to be Covered

• Why is disinfection needed?
• Types of disinfectants
• Chlorination basics
• Chloramination basics
• Unintended consequences of chloramination (nitrification)
Why do water systems disinfect?

- To kill pathogens in water (from source or distribution system contamination)
- Residuals prevent biofilm buildup in the distribution system
- Adds an additional barrier to protect the public from waterborne disease

Viruses

Bacteria (e.g. *E. coli*)

Protozoa

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Why do we need multiple barriers?

- **Any barrier can fail**
- Not all microbes are easily filtered (viruses)
- Not all microbes are disinfected by chlorine (Crypto)
- The cumulative effect of multiple barriers greatly reduces the likelihood of pathogens reaching the consumer
What are the types of disinfection?

- Chlorine
- Chloramines
- Chlorine dioxide
- Ozone
- UV (Ultraviolet disinfection)

Which disinfectant(s) provide protection in the distribution system?
Chlorination

- Chlorine is the most common disinfectant used in the U.S.
- Common forms are:
  - **Chlorine Gas** (Elemental Chlorine)
    - $\text{Cl}_2(g) + \text{H}_2\text{O} \rightarrow \text{HCl} + \text{HOCl} + \text{Cl}^-$
    - $\text{HOCl} \leftrightarrow \text{H}^+ + \text{OCl}^-$
  - **Bleach** (NaOCl) (Sodium Hypochlorite)
  - **Chlorine Powder** Ca(OCl)$_2$ (High Test Hypochlorite (HTH), (Calcium Hypochlorite)
Impacts of pH on Chlorine Disinfection

- pH impacts the form of Chlorine
- Chlorine is most effective between pH 5.5 – 7.5

water $\text{H}_2\text{O}$

hypochlorous acid HOCl

pH dependent

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Chlorination

Typical surface water chlorination

Pre-chlorination

Pre-Sedimentation  Flocculation & Sedimentation

Primary Chlorination

Filtration

Clear well

Secondary Chlorination

Booster Chlorination

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Chloramination (Combined Chlorine)

- React free chlorine with ammonia to form chloramines, a weaker disinfectant
  - $\text{HOCl} + \text{NH}_3 \rightarrow \text{NH}_2\text{Cl} + \text{H}_2\text{O}$ (monochloramine) GOOD
  - $\text{NH}_2\text{Cl} + \text{HOCl} \rightarrow \text{NHCl}_2 + \text{H}_2\text{O}$ (dichloramine)
  - $\text{NHCl}_2 + \text{HOCl} \rightarrow \text{NCl}_3 + \text{H}_2\text{O}$ (trichloramine) BAD

- Typically, monochloramine is the dominant species and is best disinfectant

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Chloramination

Typical surface water chlorination

Pre-chlorination

Pre-Sedimentation  Flocculation & Sedimentation

Filtration

Primary Chlorination

Secondary Chlorination

ammonia

Clear well

Booster Chlorination

Free chlorine CT
Chloramination

Typical surface water chlorination

Pre-chlorination

Primary Chlorination

ammonia

Secondary Chlorination

Booster Chlorination

Pre-Sedimentation  Flocculation & Sedimentation  Filtration  Clear well

Free chlorine CT if no pre-chlorine
Chloramination

Typical surface water chlorination

- Pre-chlorination
- Flocculation & Sedimentation
- Filtration
- Clear well
- Secondary Chlorination
- Booster Chlorination

ammonia
Chlorination

Typical groundwater chlorination

Groundwater Well

Primary Chlorination

Secondary Chlorination

Booster Chlorination

Storage Tank

Distribution System

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Chlorination with no free chlorine

Typical groundwater chlorination

Groundwater Well → Primary Chlorination → Storage Tank → Distribution System

- ammonia/phosphate addition
Booster Disinfection

- Chlorine decays in the distribution system

- Dosing chlorine in the distribution system (booster chlorination) maybe be required to maintain an acceptable chlorine residual

- Booster chlorination may pick up any free ammonia to produce chloramine

- Booster chloramination may be undertaken
What are the different types of chlorine?

- **Free chlorine** – residual comprised of hypochlorous acid and hypochlorite ion
  - HOCl and OCl-  
- **Combined chlorine** – chlorine combined with other water quality constituents
  - Chloramines

- **Total chlorine** – sum of free and combined chlorine

\[ \text{Free Chlorine} + \text{Combined Chlorine} = \text{Total Chlorine} \]
Chloramines

• Produce very little TTHM and HAA5
  – Many utilities have switched to chloramination to comply with the Stage 2 DBPR

• Ammonia may cause biological growth or nitrification in the distribution system
Interaction between Chlorine and other Water Components

Zone A: Chlorine is consumed by "instantaneous" chlorine demand

Zone B: "Instantaneous" chlorine demand satisfied. Primarily stable monochloramine

Typical Cl$_2$NH$_3$ 5:1 by mass (1:1 mole ratio)

Zone C: Mixture of mono and dichloramine Unstable combined chlorine.

Breakpoint

Chlorine Residual

Chlorine Added
Chlorination Dose

• How to ensure the right dosage is applied?
  – Measure Cl₂ residual in the distribution system
  – Make sure metering pump is working properly
  – Check Cl₂ stock strength regularly

*Hypochlorite injector clogged with calcium*
Activity (Chlorine Dose Calculation)

• **What is the initial Cl₂ dose if:**
  - Stock chlorine solution is 10%  
  - Flow rate is 200 gpm
  
  — 10% NaOCl = 100,000 ppm = 100,000 mg/L

• **Chlorine feed rate:** 1.2 gph x 100,000 mg/L

\[
\frac{(1.2 \text{ gph} \times 3.78 \text{ L/gal}) \times 100,000 \text{ mg/min}}{60 \text{ min/h}} = 7560 \text{ mg/min}
\]

• **Chlorine concentration:** Chlorine feed rate / flow

\[
\frac{7560 \text{ mg/min}}{200 \text{ gpm} \times 3.78 \text{ L/gal}} = \frac{7560 \text{ mg} \times \text{min} \times \text{gal}}{200 \text{ gal} \times \text{min} \times 3.78 \times \text{L}} = 10 \text{ mg/L}
\]
Disinfection Monitoring – Point of Entry

Point of Entry

Groundwater Well → Storage Tank → Distribution System
Monitoring Chlorine Concentration – Point of Entry

• Residual disinfectant concentration cannot be less than 0.2 mg/L entering the distribution system for more than 4 hours

• Larger systems must be monitored continuously
  – Lowest value must be recorded each day

• If the continuous monitoring equipment fails:
  – Grab sampling every 4 hours, but for no more than 5 working days
Nitrification

Nitrifying bacteria feed on ammonia…
producing Nitrites…
which exert a chlorine demand…
which decreases the residual…
which allows microbes to flourish…
to produce more nitrites…
which continues the spiral…
until your residual is gone!

aka … “feeding the beast”
Nitrification rates affected by:

- pH
- Temperature
- Dissolved oxygen concentration
- Free ammonia
- Water age
Controlling Nitrification

• Keep the residual high during summer (4 mg/L not uncommon)

• Tank cycling (routine and deep…but can lead to feeding the beast)

• Targeted DS Flushing
  − At dead ends
  − Throughout DS (unidirectional)
  − At points of low chlorine
  − Associated with tank cycling

• Chlorite addition (chlorite is regulated)
Can nitrification be experienced in free chlorine systems?

• Some free ammonia may exist in natural waters

• What is your reaction when you get a complaint on a strong chlorine taste and odor?

• Trichloramines have the strongest chlorine odor and you actually need to increase the chlorine dose to achieve breakpoint/eliminate “chlorine” odor
Questions

- Does your system apply free chlorine only?
- Where is it applied?
- What is applied dose?
- What is measured residual at POE?
- What is measured residual in the distribution system?
- Does your system booster chlorinate?