American Water Works Association

Dedicated to the World's Most Important Resource™

Disinfection Overview

Workshop developed by RCAP/AWWA and funded by the USEPA

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



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

Viruses | Bacteria (e.g. *E. coli*) | Protozoa



What are the types of disinfection?

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

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

Which disinfectants provide protection in the distribution system?

- Chlorine
- Chloramines

Disinfectants that do not provide distribution system residuals (*and not covered in this training*):

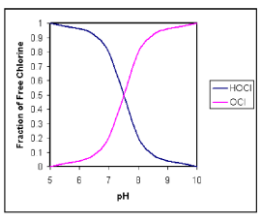
- Chlorine dioxide
- Ozone
- UV (Ultraviolet disinfection)

Chlorination

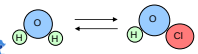
- Chlorine is the most common disinfectant used in the U.S.
- Common forms are:
  - Chlorine gas
    - $Cl_{2(g)} + H_2O \rightarrow HCl + HOCl + Cl^-$
    - $HOCl \longleftrightarrow H^+ + OCl^-$
  - Bleach (NaOCl)
  - Chlorine powder (High Test Hypochlorite (HTH), $Ca(OCl)_2$)

Impacts of pH on Chlorine Disinfection

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



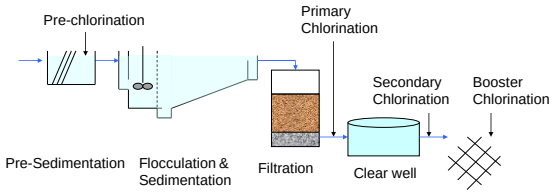
water H_20 hypochlorous acid HOCl



pH dependent

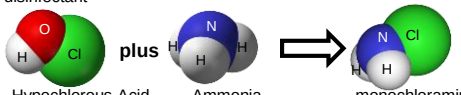
Chlorination

Typical surface water chlorination



Chloramination (Combined Chlorine)

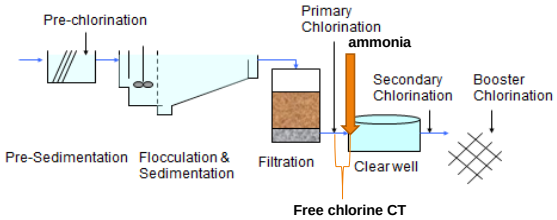
- React free chlorine with ammonia to form chloramines, a weaker disinfectant
  - **$HOCl + NH_3 \rightarrow NH_2Cl + H_2O$ (monochloramine) GOOD**
  - $NH_2Cl + HOCl \rightarrow NHCl_2 + H_2O$ (dichloramine)
  - $NHCl_2 + HOCl \rightarrow NCl_3 + H_2O$ (trichloramine) **BAD**
- Typically, monochloramine is the dominant species and is best disinfectant



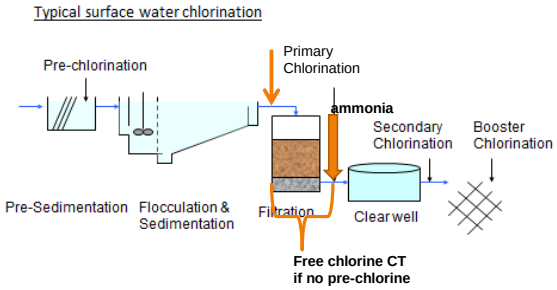
Hypochlorous Acid (free chlorine) | Ammonia | monochloramine

Chloramination

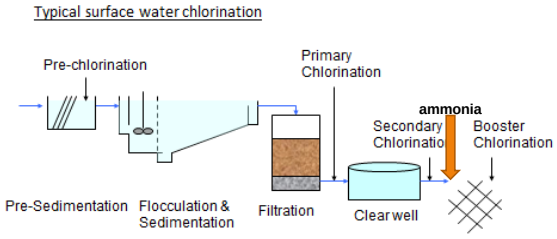
Typical surface water chlorination



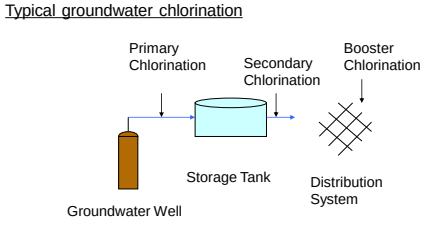
Chloramination



Chloramination

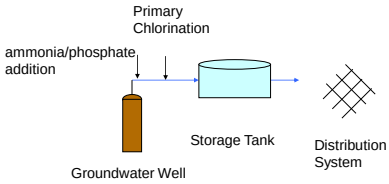


Chlorination



Chlorination with no free chlorine

Typical groundwater chlorination



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

Free, Combined and Total Chlorine

- Which do you use?

What are the different types of chlorine?

- Free chlorine – residual comprised of hypochlorite and hypochlorous acid
  - HOCL and OCL^-
- Combined chlorine – chlorine combined with other water quality constituents
  - Chloramines
- Total chlorine – sum of free and combined chlorine

Free Chlorine + Combined Chlorine = Total Chlorine

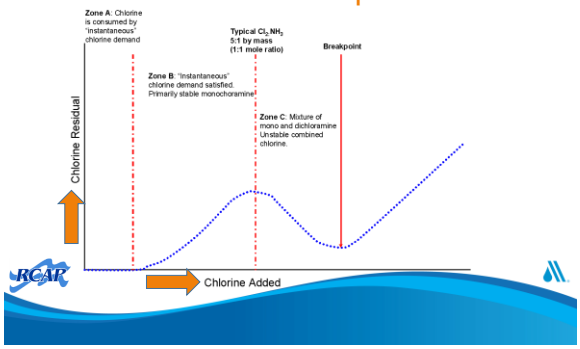
Free and Combined Chlorine

- Free chlorine
  - Stronger oxidant
  - Less stable, faster decay
- Combined chlorine (*mostly chloramines*)
  - Weaker oxidants
  - More stable, slower decay
  - Do you chloraminate?

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

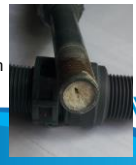
Interaction between Chlorine and other Water Components



Chlorination Dose

- How to ensure the right dosage is applied?
  - Measure Cl_2 residual in the distribution system
  - Make sure metering pump is working properly
  - Check Cl_2 stock strength regularly

Hypochlorite injector clogged with calcium



Chlorination Dose

- Chlorine decays over time in the distribution system
  - Inadequate chlorine residual may enable pathogens to survive or multiply
  - It is important to maintain an acceptable residual at all locations at all times

Chlorine Dose Calculation

- What is the initial Cl_2 dose if:
  - Stock chlorine solution is 10%
  - Flow rate is 200 gpm
  - Chlorine feed rate is 1.2 gph

- Chlorine concentration
  - 1% NaOCl = 10,000 ppm = 10,000 mg/L
  - 10% NaOCl = 100,000 ppm = 100,000 mg/L
  - 1 gallon = 3.78 liters

Chlorine Dose Calculation Solution

- What is the initial Cl_2 dose if:
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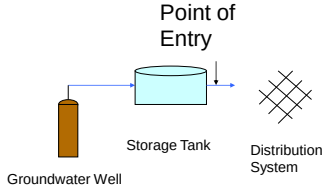
- Chlorine concentration
  - 1% NaOCl = 10,000 ppm = 10,000 mg/L
  - 10% NaOCl = 100,000 ppm = 100,000 mg/L
  - 1 gallon = 3.78 liters
- Chlorine feed rate: 1.2 gph X 100,000 mg/L = (1.2 X 3.78)/60 X 100,000 mg/min = 7560 mg/min
- Chlorine concentration: chlorine feed rate / flow = 7560 / (200 X 3.78) mg/L = 10 mg/L

Disinfection Monitoring – Point of Entry



Monitoring Chlorine Concentration – Point of Entry

- Residual disinfectant concentration cannot be less that 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

Monitoring Chlorine Concentration – Point of Entry

SHOW OF HANDS:

- How many have continuous analyzers?
- How often are they calibrated?
  - *weekly*
  - *monthly*
  - *don't know*

Monitoring Chlorine Concentration in the Distribution System

- Cannot be undetectable in more than 5% of the samples collected from the distribution system
- Should be taken from the same location and at the same time as Total Coliform sample

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

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

Remediating Nitrification

- Complete DS Flushing
- Tank Draining (dropping the tank)
- Booster chlorination
- Free chlorination (DS burn)
- Source water break point chlorination (if you are not already)
- 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

Chloramination Recommendations

Systems that chloraminate should have a ***Nitrification Control Plan*** that includes:

- The chlorine to ammonia ratio target
- Historical data graphed for analysis
- Operational targets:
- Procedures for chemical adjustment, monitoring and review of data
- The monitoring equipment/test kits and/or lab procedures that are approved/acceptable by USEPA/local regulatory agency

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?