

Instructor Expectations

- Begin and end class on time
- Be interactive
- Share experiences and needs
- Less lecture, more discussions
- Keep it simple
- **Make this an enjoyable and informative experience!**



4

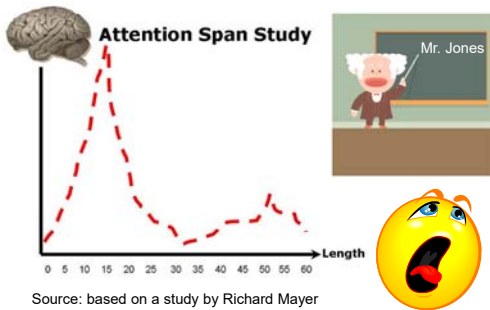
Discussions

- Student involvement will be encouraged in class discussions to:
 - Keep students attentive
 - More importantly, **help students retain and process information**



5

Attention Span - Lectures



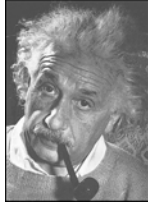
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The Guiding Expectation

“Things should be made as simple as possible -- but no simpler.”

Albert Einstein

www.physik.uni-frankfurt.de/~j/physiceinstein.html



7

Ground Rules

- Discussion is encouraged
- Participate at your own comfort level
- Use terms we all can understand
- Everyone is different, so please show respect for others in the room
- Listen with an open mind
- Express opinions - of things, not people
- Maintain confidences



8

Ice Breaker

- Before we start, let's introduce ourselves:
 - Name,
 - What do you do, and
 - What do you know/don't know about chlorination/dechlorination with...?
 1. Gases – Chlorine and Sulfur Dioxide (Cl_2 and SO_2)
 2. Liquids – Sodium Hypochlorite and Sodium Bisulfite (NaOCl and NaHSO_3)
 3. Solids – Calcium Hypochlorite and Sodium Metabisulfite (Ca(OCl)_2 and $\text{Na}_2\text{S}_2\text{O}_5$)

9

Class Objectives

10

Learning Objectives

- To explain disinfection requirements:
 - Regulatory framework
 - Disinfection requirements
 - Disinfection By-products
 - Chlorination theory
 - Chemistry
 - Breakpoint chlorination
 - Dechlorination requirements
 - Switch to liquid chemicals

11

Learning Objectives

- To discuss O&M, process control, and safety practices
 - Chemical properties
 - Truck unloading
 - Storage
 - Conveyance:
 - Transfer pumps
 - Metering pumps
 - Dosing (Chlorination and Dechlorination)

12

Focus of Class

- Disinfection
- Breakpoint Chlorination
- Chlorine products:
 - Chlorine (Cl_2 , gas)
 - Sodium Hypochlorite (NaOCl , solution) **(Emphasis)**
 - Calcium Hypochlorite (Ca(OCl)_2 , solid/solution)
- Dechlorination products
 - Sulfur dioxide (SO_2 , gas)
 - Sodium bisulfide (NaHSO_3 , solution) **(Emphasis)**
- Summary and Conclusions

13

Presentation Goals

- Discuss chlorination:
 - Disinfection regulations
 - Theory and breakpoint chlorination
 - Dechlorination requirements
- Discuss types of sodium hypochlorite systems:
 - Chemical properties
 - Bulk storage
 - Conveyance
 - On-site generation

14

Presentation Goals

- Discuss sodium bisulfite systems
 - Chemical properties
 - Bulk storage
 - Conveyance
- Identify acceptable materials of construction for:
 - Bulk storage tanks
 - Piping and valves
 - Transfer pumps and metering pumps
 - Expected equipment service life

15

Class Agenda

- Introduction/Overview
- Chlorination Chemistry
- Breakpoint Chlorination
- Regulatory Framework
- Unit Treatment Processes:
 1. Chlorination/dechlorination
 - ✓ Chlorine gas/Sulfur dioxide
 - ✓ Sodium hypochlorite/Sodium Bisulfite (**Emphasis**)
 2. Equipment and Construction of Materials
 3. Chlorine Residual Monitoring
- Summary

16

Need for Disinfection

Overview

17

What is Disinfection?

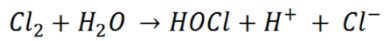
- Destruction or inactivation of pathogenic microorganisms
- Prevents spread of waterborne diseases by protecting:
 - Potable water supplies
 - Recreational users
 - Shellfish consumers
 - Irrigation sources



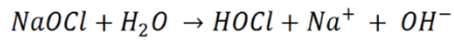
18

Chlorination

- Chlorine Gas (Cl_2)



- Sodium Hypochlorite (NaOCl)



- $HOCl \rightleftharpoons H^+ + OCl^-$ (in equilibrium)

– HOCl – Hypochlorous acid

– OCl^- – Hypochlorite ion

19

Chlorination

- Reduces pathogens in wastewater effluents
 - Chlorine use began more than 100 years ago
 - Good viral and bacterial reductions:
 - ✓ Typically, 99.9+%
 - ✓ Meets fecal coliform limits for WWTP discharges
- Toxicity of chlorine and its disinfection by-products (DBPs) on aquatic life is a major drawback
- Need dechlorination with or without (membrane) filtration to remove chlorine residual

20

History of Chlorine Gas Use

- 1847 - Chlorine was first used as a disinfectant in Vienna
- 1890's - The use of chlorine becomes commonplace in England
- 1908 - Initial U.S. applications of chlorination in Chicago and Jersey City water districts
- 1918 - Over one-thousand cities in USA use chlorination for drinking water supplies
- 1970 - Twenty-thousand chlorinated water municipalities exist in the United States

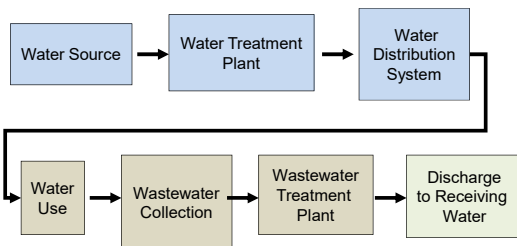
21

History of Hypochlorite Use

- 1789 – France – bleaching in textile industry
- 1897 – England – disinfection of drinking water
- 1930 – United States – Use in household laundry and drinking water disinfection
- 1970 – United States – Public water and wastewater treatment systems begin replacing chlorine gas with hypochlorites

22

Water Use Cycle

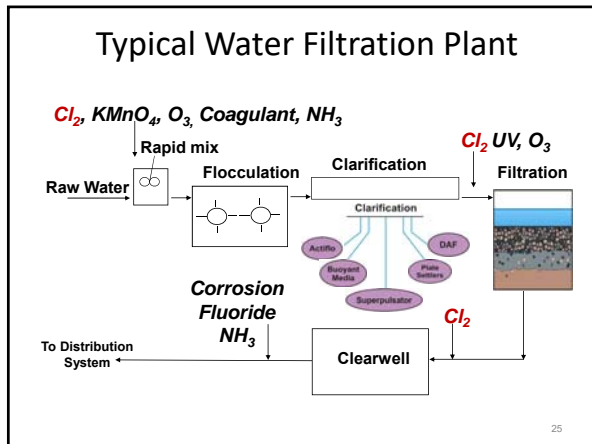


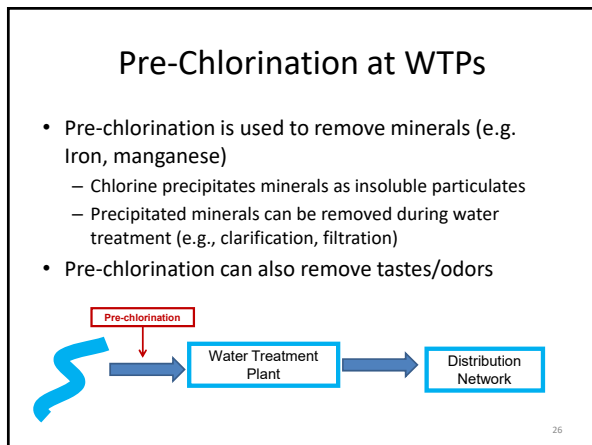
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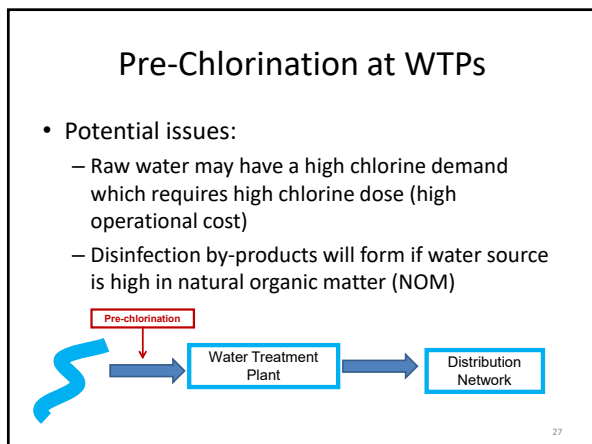
Chlorine Addition

- In Public Water Systems:
 - Pre-chlorination at WTP
 - Primary disinfection at WTP
 - Secondary “booster” disinfection in distribution system
 - SDWA Regulation, chlorine residual:
 - ✓ Minimum: 0.2 mg/L
 - ✓ Maximum: 4.0 mg/L

24

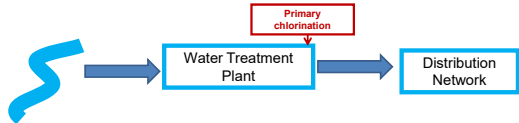






Primary Chlorination at WTPs

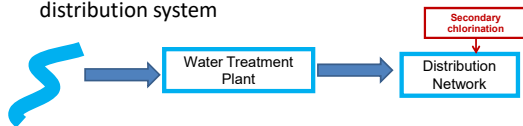
- Used for disinfection; most common & effective point of application; 100+ years of experience
- Most effective to add chlorine when turbidity is low; ideally <math><0.3\text{ NTU}</math> (i.e., after clarification, filtration)
 - Use less chlorine
 - Less risk of disinfection by-product formation



28

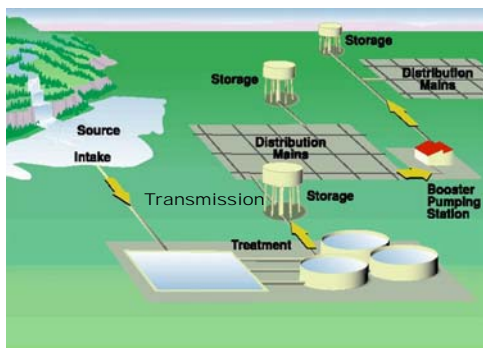
Secondary Chlorination in Distribution System

- Used to maintain chlorine concentration during distribution (i.e. $\geq 0.2\text{ mg/L}$)
- 'Booster station' adds more chlorine to the water at strategic points during distribution if chlorine concentration is too low
- Helps keep the water safe throughout the distribution system



29

Public Water System



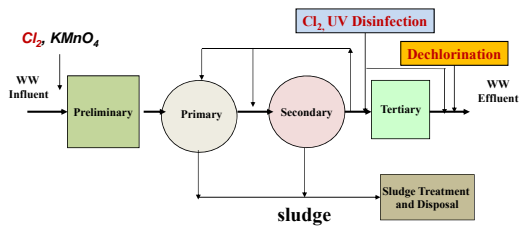
30

Chlorine Addition

- At WWTPs:
 - Pre-chlorination
 - Effluent disinfection
 - ✓ Minimum 0.5 mg/L chlorine concentration before dechlorination
 - Need for dechlorination
 - ✓ Maximum 0.05 mg/L chlorine concentration after dechlorination

31

Conventional WWTP Process



32

Pre-Chlorination at WWTPs

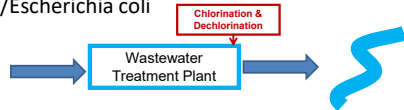
- Objectives of pre-chlorination are:
 - Odor control
 - Protection of plant structures from H₂S
 - Aid in sedimentation
 - Reduction or delay of biochemical oxygen demand (BOD).



33

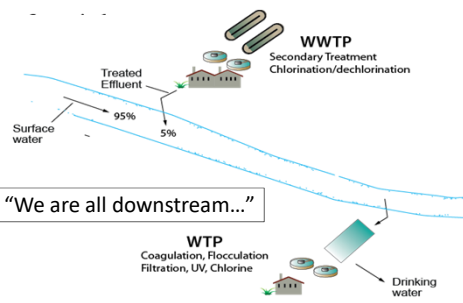
Chlorination at WWTP Effluents

- Chlorination
 - 100 years of experience
 - Gas versus liquid;
 - Dechlorination required
- Eliminates harmful organisms
 - Coliform bacteria
 - Fecal/*Escherichia coli*



34

De facto Reuse of Wastewater



35

Wastewater Treatment

- Sewage is an environmental health hazard (wastewater effluent)
- Purpose of municipal wastewater treatment is to limit pollution in the receiving waterway
- Receiving waterways are usually sources of drinking water

36

Wastewater Impacts to Natural Receiving Waters

- Treated wastewater is often discharged to nearby natural waters
 - Biological oxygen demand (BOD)
 - Chemicals (nitrogen, phosphorus)
 - Synthetic Chemicals
 - Antibiotics
 - **Microbial Pathogens**
 - **Total Residual Chlorine**
 - Metals

37

Chlorine Disinfection

- Chlorine - long established chemical disinfectant
- Excellent against bacteria and viruses; not so good against Giardia and Cryptosporidium
- $CT = \text{Concentration} \times \text{Time}$
- $\text{Dose} = \text{Demand} + \text{Residual}$
- Residual, mg/l
 - Regulations/permit limits, pH, TSS
- Dechlorination

38

Mechanisms of Disinfection

- Oxidation or rupture of cell wall
- Diffusion into cell and interference with cellular activity

Therefore, the ability to oxidize biological molecules and the ability to diffuse through the cell walls are the requirements of any effective disinfectant

What does chlorine do to cells?

- HOCl enters cell wall efficiently, permeating and poking holes in cell walls of exposed bacteria
- Enzyme systems of microbes are affected, deactivating organisms and their ability to reproduce
- In most bacteria, HOCl causes adverse reactions of respiratory, transport, and nucleic acid-DNA systems

40

Comparative Effectiveness of Disinfectants

<u>Treatment Process</u>	<u>Microorganisms</u>		
	<u>Viruses</u>	<u>Bacteria</u>	<u>Protozoans</u>
Free chlorine	Very effective	Very effective	Less effective
Chlorine dioxide	Effective	Very effective	Effective
Iodine	Effective	Effective	Not effective
UV light	Effective	Very effective	Very effective
Natural sunlight	Effective	Effective	Less effective
Boiling (heat)	Very effective	Very effective	Very effective
Membrane Filtration	Variably effective	Very effective	Very effective

41

Comparative Effectiveness of Disinfectants

	Crypto	Giardia	Viruses	Residual
Chlorine	NE	G	E	G
Chlorine dioxide	P/F	G	G	F
Ozone	P/F/G	E	G/E	P
Chloramines	NE	P	P	G
UV	E	E	F	none

NE – not effective; P – poor; F – fair; G – good; E – excellent

42

Who Does What?

	WWTPs > 1 mgd In USA, 2008
Chlorine (gas or liquid)	75.3 %
UV	20.6 %
Ozone	0.2 %
None	3.9 %

Source: Disinfection of Wastewater Effluent – Comparison of Alternative Technologies, WERF, 2008.

43

Potential Health Issues

- **Microbial Health Concerns**
 - *Cryptosporidiosis* and *Giardiasis*
 - ✓ Vomiting and diarrhea, potentially life threatening for immune compromised, elderly and young
- **Disinfection By-Product Health Concerns**
 - Cancer
 - ✓ Bladder, colon and rectal
 - **Reproductive**
 - ✓ Neural tube defects and miscarriages
 - Brominated compounds are thought to pose a greater health risk than chlorinated compounds
 - Nitrogenated compounds may be even worse???

44

When is Wastewater Disinfection Required?

- **Discharge to surface waters:**
 - Near water supply intakes
 - Used for primary contact recreation
 - Used for shellfish harvesting
 - Used for irrigation of crops
 - Other direct and indirect reuse and reclamation purposes
- **Discharge to groundwaters:**
 - Used as a water supply source
 - Used for irrigation of crops and greenspace
 - Other direct and indirect reuse and reclamation purposes

45

Waterborne Diseases

- Many human diseases are caused by infectious microorganisms in drinking water
- Most of the bacteria, viruses, and protozoa that cause waterborne diseases affect the digestive system and thus propagate themselves via sewage
- Wastewater disinfection provides part of a multi-barrier to prevent disease spread in drinking water
- Wastewater disinfection is the only barrier to disease spread from direct contact activities like swimming

46

Waterborne Diseases

Bacteria	<i>Escherichia coli</i> (gastroenteritis) <i>Salmonella typhi</i> (typhoid fever) <i>Vibrio cholerae</i> (cholera) <i>Shigella</i> (dysentery)
Viruses	Norovirus (gastroenteritis) Rotavirus (gastroenteritis) Hepatitis A virus (infectious hepatitis) Adenovirus (respiratory, gastroenteritis)
Protozoa	<i>Giardia lamblia</i> (gastroenteritis) <i>Cryptosporidium parvum</i> (cryptosporidiosis)

47

Bacteria

- Single celled organisms that can self replicate
- 0.5 – 5 μm (500 – 5000 nm) in size
- Feces of a healthy person contains 10^6 to 10^9 of each of the following bacteria groups per gram of feces:
 - Enterobacteria, enterococci, lactobacilli, clostridia, bacteroides, bifidobacteria, and eubacteria
 - *Escherichia coli* (common fecal coliform) is in the enterobacteria group
- Diarrhea is the major symptom for many bacterial infections
- The most serious waterborne diseases are typhoid fever, paratyphoid fever, dysentery, and cholera

48

Viruses

- Intracellular parasites that replicate only in living hosts' cells
- Lack the metabolic systems required for self replication
- 20 – 100 nm in size (about 1/50 that of bacteria cell)
- Human feces contain over 100 serotypes of enteric viruses

49

Protozoans

- Intestinal parasites that replicate in the host and exist in two forms
 - Attached to the intestinal wall where they actively feed and reproduce
 - Floating through the intestine while transforming into a **Cyst**
- Cysts
 - Infectious to others
 - 10 – 15 um in length
 - Commonly cause diarrhea or dysentery

50

Common Waterborne Diseases

Disease	Organism	Organism Source	Symptom
Gastroenteritis	Salmonella (bacteria)	Animal/human Feces	Acute diarrhea and vomiting
Typhoid	Salmonella typhosa (bacteria)	Human Feces	Inflamed intestine, high temperature – fatal
Dysentery	Shigella (bacteria)	Human Feces	Diarrhea
Cholera	Vibrio comma (bacteria)	Human Feces	Severe diarrhea and vomiting – fatal
Infectious hepatitis	Virus	Human Feces	Yellowed skin, enlarged liver
Amoebic dysentery	Entamoeba histolytica (protozoa)	Human Feces	Diarrhea
Giardiasis	Giardia lamblia (protozoan)	Animal/human Feces	Diarrhea
Cryptosporidiosis	Cryptosporidium (protozoa)	Animal/human Feces	Acute diarrhea and vomiting

Water Quality Regulations

- Federal Water Pollution Control Act 1972
 - Secondary treatment
 - Disinfection criteria
- EPA recommended indicator organisms
 - Fecal coliform, fresh & marine waters (1968)
 - E. coli for freshwaters (1972)
 - Enterococci for marine waters (1972)

52

Coliform Bacteria

- MPN of coliform bacteria are estimated to indicate the presence of bacteria originating from the intestines of warm-blooded animals
- Coliform bacteria are generally considered harmless
 - But their presence may indicate the presence of pathogenic organisms

53

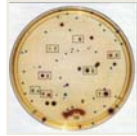
Coliform Bacteria

- Comprises all the aerobic and facultative anaerobic gram negative, nonspore-forming, rod-shaped bacteria that ferment lactose within 48 hours at 35 °C
- Coliform bacteria can be split into fecal and nonfecal groups
- The fecal group can grow at higher temperatures (44.5 °C) than the non-fecal coliforms

54

Fecal Coliform

- Indicator microorganism
 - Cultured in standard tests to indicate contamination (laboratory)
 - Membrane filter technique
 - Direct count of colonies trapped and cultured
 - Multiple tube fermentation method
 - Provides an estimate of the MPN per 100 mL
 - Measured as colonies/100 mL



55

Coliform Indicator Organisms

Total coliform	Some from fecal sources
Fecal coliform	Subset of total coliform Human and non-human fecal sources
Escherichia coli (E. coli)	Subset of fecal coliform Likely human source in wastewater
Enterococci	Human-specific strains of fecal streptococci, survive in marine waters

56

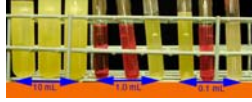
Coliform Bacteria – Approved Methods

- Number per 100 mL
- Coliform (fecal)
 - Membrane filtration
- E. coli
 - Multiple tube (Colilert®)
 - Membrane filtration
 - ✓ m-ColiBlue24®
 - ✓ Modified mTEC agar

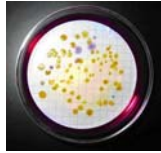
57

Enumerating Indicator Bacteria

- Multiple Tube Fermentation
 - Statistical estimate
 - MPN /100 mL
 - MPN - Most Probable Number



- Membrane Filtration
 - Direct count
 - CFU /100 mL
 - CFU - Colony Forming Units



58

Water Quality Regulations

- 1972 Clean Water Act required secondary treatment
- Setting allowable disinfection criteria was delegated to the states
- EPA originally recommended using fecal coliform as the indicator organism for wastewater disinfection, based on Public Health Service studies in the 1960's
- Later EPA recommended E coli and Enterococci as indicator organisms - better correlated to actual gastroenteritis in humans after swimming in affected waters
- Many states still use fecal coliform...!

59

Water Quality Regulations

- Disinfection fecal coliform/E coli limits are usually expressed as geometric means, instead of arithmetic means
- Why? Microbes grow exponentially...high values not uncommon in disinfection
- Using geometric means reduces the impact on the mean of a single high value per week, or a few high values per month

60

Water Quality Regulations

- Arithmetic mean = Average of 'n' numbers
= (Sum of Values) / (Number of Values)
= (10 + 10 + 10 + 10 + 10,000) / 5 = **2008**
- Geometric mean = the 'n'th root product of 'n' numbers
= (Product of Values)^(1 / Number of Values)
= (A x B x C x D x E)^(1/5)
= (10 x 10 x 10 x 10 x 10,000)^(1/5) = **40**

61

Geometric Mean Calculation

- A small wastewater plant collected 7 samples during the month for determining a geometric mean of E. Coli CFUs. The 9 individual results were 4, 10, 7, 2, 5, 3, and 9 CFUs/100 ml. Determine the geometric mean of the results.

Answer: Geo. Mean = (Product of Values)^(1 / # values)
Geo. Mean = (4 x 10 x 7 x 2 x 5 x 3 x 9)^{1/7}
Geo. Mean = (75,600)^{1/7} = 5

62

Removal Efficiency is Dependent on Microbial Type

- *Giardia* and *Cryptosporidium*
 - Filtration is best
 - ✓ Large size
 - ✓ Resistant cyst and oocyst
- Bacteria and Enteric Viruses
 - Disinfection is ultimate barrier
 - Filtration and coagulation also help via adsorption to particles
 - ✓ Dependent on surface charge of virus

63

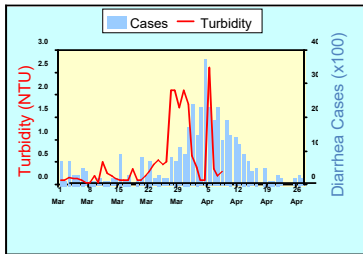
Waterborne Disease Outbreaks Cause Irreparable Damage to Public and PWSs

Year	State/Territory	Cause of Disease	No. of People Affected
1985	Massachusetts	<i>Giardia lamblia</i> (protozoan)	703 illnesses
1987	Georgia	<i>Cryptosporidium parvum</i> (protozoan)	13,000 illnesses
1987	Puerto Rico	<i>Shigella sonnei</i> (bacterium)	1,800 illnesses
1989	Missouri	<i>E. coli</i> 0157 (bacterium)	243 illnesses / 4 deaths
1991	Puerto Rico	Unknown	9,847 illnesses
1993	Missouri	<i>Salmonella typhimurium</i> (bacterium)	650 illnesses / 7 deaths
1993	Wisconsin	<i>Cryptosporidium parvum</i> (protozoan)	400,000 illnesses 50+ deaths
1998	Texas	<i>Cryptosporidium parvum</i> (protozoan)	1,400 illnesses
1999	New York	<i>E. coli</i> 0157 (bacterium)	150 illnesses / 1 death
2000	Ontario	<i>E. coli</i> 0157 (bacterium)	1,000 illnesses / 7 deaths

Source: HDR's Handbook of Public Water Systems

64

Milwaukee Disease Outbreak - 1993



403,000 illnesses (out of 1.6 million population)

Ineffective coagulation, flocculation, and filtration



Chlorination/Dechlorination

Overview

66

Chlorination

- Process of adding a chlorine product to water or wastewater for disinfection, e.g., inactivation of pathogens
- Chlorine chemicals (i.e., oxidizing agents):
 - Compressed elemental (Cl_2) gas
 - Hypochlorites:
 - Aqueous sodium hypochlorite solution (Bleach): NaOCl
 - Anhydrous (solid) calcium hypochlorite: Ca(OCl)_2

67

Properties of Chlorine

- Very reactive
- Characteristic odor
- Corrosive
- Establishes a chlorine residual after disinfection
- Escapes from water if exposed to air

68


Properties of Chlorine

- Reacts with:
 - Iron, Manganese, hydrogen sulfide and nitrites
 - Ammonia to form chloramines:
 - ✓ Monochloramine
 - ✓ Dichloramine
 - ✓ Trichloramine
 - Natural organic materials (NOM) to form disinfectant by-products (DBPs)


69

Properties of Chlorine


Chlorine may be found in three forms



Powder



Liquid



Gas

70

Chlorination/Dechlorination Chemicals

- Chemicals used for chlorination and dechlorination are a function of:
 - Availability
 - Cost perspective: Economies of scale
 - Operator training and expertise: chemical storage and handling
 - Operator and community safety concerns
 - Contaminant concerns:
 - D/DBPs
 - Perchlorate (New...!)

71

Chlorination/Dechlorination Chemicals

- When using chlorine gas:
 - Low concentration of dissolved chlorine
 - D/DPBs can form
 - Perchlorate, chlorate and chlorite are not expected to form

72

Chlorination/Dechlorination

- Sodium hypochlorite is an “aqueous solution” of NaOCl in which water (H₂O) is the solvent



73

Sodium hypochlorite, NaOCl

- Manufactured by the reaction of chlorine with sodium hydroxide and water
- To minimize decomposition, excess sodium hydroxide is required to maintain a pH between 11 and 13
- Household bleaches: 3% to 8% NaOCl
- Water/wastewater disinfection applications: typically 10% – 15% active NaOCl

74

Hypochlorite Solutions

- Sodium hypochlorite solutions are clear, greenish to yellow liquids with a chlorine odor
- Calcium hypochlorite is a white solid that readily decomposes in water releasing chlorine
- Sodium and calcium hypochlorites are used primarily as bleaching agents or disinfectants

75

Calcium Hypochlorite Solutions

- Calcium hypochlorite:
 - White solid that readily decomposes in water releasing chlorine
 - Tablets or granules
 - 65 to 70% chlorine



76

Chlorination

- **Chlorination w/Sodium Hypochlorite (NaOCl)**
 1. $\text{NaOCl} + \text{H}_2\text{O} \rightarrow \text{HOCl} + \text{NaOH}$
 - **HOCl** - Hypochlorous acid
 - NaOH - Sodium hydroxide
 2. $\text{HOCl} \leftrightarrow \text{H}^+ + \text{OCl}^-$ (in equilibrium)
 - **HOCl** – most effective form of dissolved chlorine
 - H^+ - Hydrogen ion
 - OCl^- - hypochlorite ion (less active form of dissolved chlorine)

77

Dechlorination

- WWTPs have been chlorinating effluent discharges for more than 100 years
- Residual chlorine can have a negative impact on aquatic life in receiving waters
- Chlorine hazardous to both plant life and fish
- Need dechlorination



78

Dechlorination

- Process of removing chlorine from water (e.g., disinfected wastewater) before discharging it into the environment
- Dechlorination chemicals (i.e., reducing agents):
 - Compressed sulfur dioxide (SO₂) gas
 - Sulfites, metabisulfites and thiosulfates:
 - **Aqueous bisulfite solutions:**
 - ✓ **Sodium bisulfite: NaHSO₃**
 - Anhydrous (solid) forms:
 - ✓ Sodium sulfite: Na₂SO₃
 - ✓ Sodium metabisulfite: Na₂S₂O₅
 - ✓ Calcium thiosulfate: CaS₂O₃

79

Chlorination/Dechlorination

- Sodium bisulfite is an “aqueous solution” of NaHSO₃
- Sodium bisulfite is a yellowish-white solution with a strong pungent SO₂
- Sodium bisulfite is added following chlorine disinfection prior to discharging chlorinated effluent to receiving water



80

Dechlorination

- **Dechlorination w/Sodium Bisulfite (NaHSO₃):**
 1. $\text{NaHSO}_3 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_3 + \text{NaOH}$
 - H₂SO₃ – Sulfurous acid
 - NaOH – Sodium hydroxide
 2. $\text{H}_2\text{SO}_3 + \text{HOCl} \rightarrow 3\text{H}^+ + \text{Cl}^- + \text{SO}_4^{-2} \rightarrow \text{HCl} + \text{H}_2\text{SO}_4$
 - **HOCl - Hypochlorous acid**
 - H: Hydrogen ion; Cl: Chloride ion; SO₄⁻² sulfate ion
 - H₂SO₄ – Sulfuric acid
 - HCl - Hydrochloric acid

81

Chlorination/Dechlorination

- All sulfur chemicals are explosive if mixed with acids or oxidizers like bleach
- Refer to chemical Safety Data Sheets (SDS) when handling bleach and bisulfites
- PPE for handling bleach and bisulfites include:
 - Respirators
 - Face shields
 - Goggles
 - Chemical gloves
 - Aprons

82

Chlorination/Dechlorination

History and Evolution

83

Prior to 1900

- 1846 – Vienna, Austria: Hospital began chlorinated water to reduce patient infections
- 1854 – London, England: Dr. John Snow used chlorine to disinfect the Broad Street Pump water supply (i.e., cause of a cholera outbreak due to sewage contamination)

84

1850s – Cholera Epidemic in London

- British epidemiologist, Dr. John Snow, proved that cholera was a waterborne disease by linking the illness to sewage contamination of a public well
- Dr. Snow applied chlorine to purify the water, which paved the way for water disinfection
- This led to first government regulation of public water



Water Pump Monument to John Snow in London, England
[http://en.wikipedia.org/wiki/John_Snow_\(physician\)](http://en.wikipedia.org/wiki/John_Snow_(physician))

85

Prior to 1900

- 1879 – England: Chlorinated lime (i.e., Calcium hypochlorite) used to treat typhoid patient wastes before disposal into the sewer
- 1893 – Hamburg, Germany: chlorine used on a plant scale basis for disinfecting drinking water
- 1897 – Kent, England: potable water distribution mains disinfected using bleach

86

After 1900

- 1903 – Middlekerke, Belgium: The first use of chlorine gas for disinfection of drinking water
– Previous chlorination was with chlorinated lime (Calcium hypochlorite)
- 1908 – Jersey City, NJ water utility became the first in the U.S. to use full scale drinking water chlorination, using sodium hypochlorite

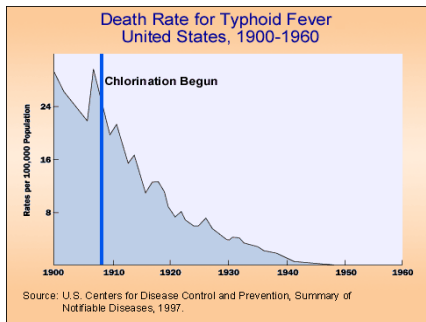
87

After 1900

- 1908 – Chicago, IL: the Bubbly Creek Filter Plant began chlorination using chlorinated lime
- 1910 – Youngstown, Ohio: First to use compressed chlorine gas from a steel cylinders for water chlorination

88

Drop of Typhoid Fever Death Rates



89

After 1900

- 1914 – The U.S. Department of the Treasury enacted standards calling for a maximum bacterial concentration of 2 coliforms per 100 ml in drinking water:
 - Required drinking water disinfection
 - Chlorination was only option at the time
 - Lead to a dramatic:
 - o Increase use of chlorination at water treatment plants
 - o Decrease in infectious diseases

90

After 1900

- 1920s – 1930s – Drinking water filtration and chlorination had virtually eliminated epidemics of waterborne diseases in the U.S.
- 1940s – 1990s – Disinfection with chlorine gas was the method of choice for most facilities
 - Cheap
 - Readily available

91

After 1900

- 1970s – Awareness of disinfection byproducts (DBPs) formed by reaction of chlorine with natural organic compounds in water
 - Possible health effects of DBPs were investigated
- 1979 – Initial DBP rule
- 1998: Stage 1 Disinfectants and Disinfection Byproducts (D/DBP) Rule issued
- 2006: Stage 2 D/DBP Rule issued

92

Disinfectant By-Products (DBPs)

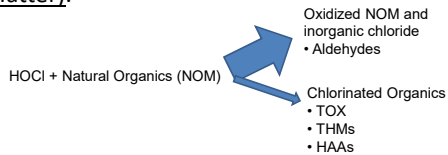
- By-products of reactions between disinfectant (chlorine, ozone, etc.) and precursors like suspended solids, natural organic matter (NOM), and/or bromide present in source water



93

Disinfection By-products (DBPs) Formation

- Disinfection by-products arise in water treatment through the reaction of a Disinfectant and background water constituents (most often Natural Organic Matter).



All chemical disinfectants form DBPs

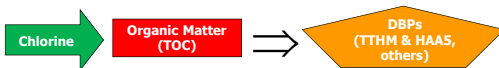
- Chlorine – THMs, HAAs, other chlorinated DBPs (haloacetonitriles, halo ketones, etc)
- Ozone – bromate, aldehydes, ketones, etc.
- Chlorine dioxide – chlorite, chlorate
- Chloramines – N-nitrosodimethylamine (NDMA), other nitrogenous DBPs

95

The Flip Side:

Disinfection Byproduct (DBP) Formation

- DBPs are formed when chlorine (or other disinfectant) reacts with organics (total organic carbon) in the water



- Formation is impacted by:
 - Reactions within the bulk water (due to increased chlorine, temperature, organics, etc.)
 - Reactions within the distribution system infrastructure (e.g., biofilm, etc.)
 - Water age (time)

96

Disinfectant By-Products (DBPs)

Disinfectant + Bacteria → Dead Bacteria
Disinfectant + Virus → Dead Virus
Disinfectant + Giardia cyst → Dead Giardia cyst

Disinfectant + Precursor → DBPs

All disinfectants form disinfection by-products!!!

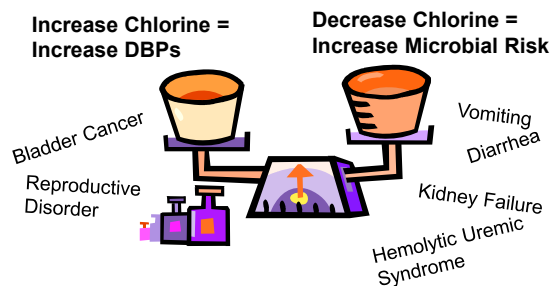
97

Disinfection By-products (DBPs)

- The **World Health Organization** has stated that:
 - "...the risks to health from disinfection by-products are extremely small in comparison with the risks associated with inadequate disinfection."

98

Risks Must be Balanced



99

Disinfectants and Disinfection Byproducts (DBPs)

- Due to the potential **carcinogenicity** of these compounds:
 - Drinking water regulations require regular monitoring of the concentration of these compounds in the distribution systems of municipal water systems

100

Disinfectants and Disinfection Byproducts (DBPs)

Regulated DBP Contaminants	MCL (mg/L)	MCLG (mg/L)	Regulated Disinfectants	MRDL* (mg/L)	MRDLG* (mg/L)
Total Trihalomethanes (TTHMs)	0.080		Chlorine	4.0 as Cl ₂	4
Chloroform		-			
Bromodichloromethane		Zero			
Dibromochloromethane		0.06			
Bromoform		zero			

101

Disinfectants and Disinfection Byproducts (DBPs)

Regulated DBP Contaminants	MCL (mg/L)	MCLG (mg/L)	Regulated Disinfectants	MRDL* (mg/L)	MRDLG* (mg/L)
Five Haloacetic Acids (HAA5)	0.060		Chloramines	4.0 as Cl ₂	4
Monochloroacetic acid		-			
Dichloroacetic acid		Zero	Chlorine dioxide	0.8	0.8
Trichloroacetic acid		0.3			
Bromoacetic acid		-			
Dibromoacetic acid		-			

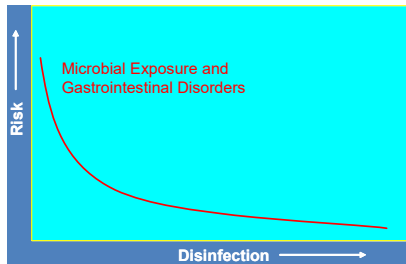
102

Disinfectants and Disinfection Byproducts (DBPs)

Regulated DBP Contaminants	MCL (mg/L)	MCLG (mg/L)	MRDL* (mg/L)	MRDLG* (mg/L)
Bromate (plants using ozone)	0.010	Zero	*Stage 1 DBPR includes maximum residual disinfectant levels (MRDLs) and goals (MRDLGs) which are similar to MCLs and MCLGs but for disinfectants	
Chlorite (plants using chlorine dioxide)	1.0	0.8		
Treatment Technique				
Enhanced coagulation/enhanced softening to improve removal of DBP precursors (See Step 1 TOC Table for systems using conventional filtration treatment)				

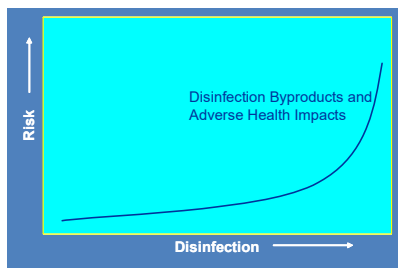
103

Microbial Risks



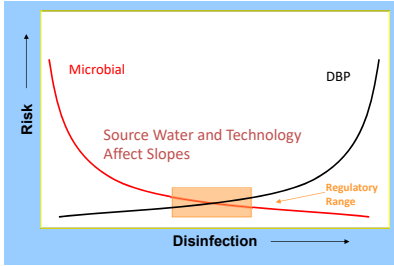
104

Disinfection Byproduct Risks



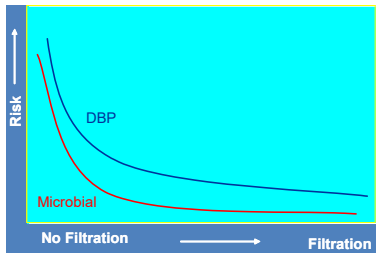
105

Microbial versus DBP Risk Trade-Offs



106

Filtration Reduces both Microbial and DBP Risks



107

After 1900

- OSHA, EPA, Fire Code, and Homeland Security regulations are making chlorine gas an increasingly expensive and undesirable disinfection alternative
- Vulnerability Assessments and Emergency Response Plans required

108

Safety and Security Regulations

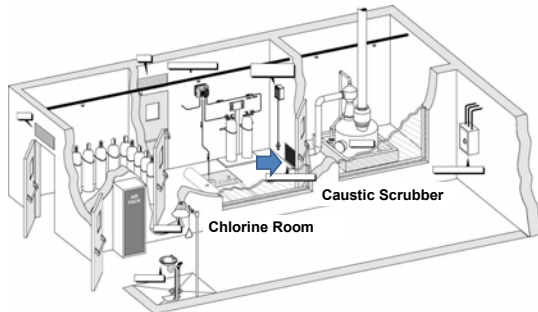
- Regulations:
 - Clean Air Act Amendment of 1990
 - OSHA's/USEPA's 1993 Risk Management Program (RMP)
 - ✓ Develop a **community** Risk Management Plan
 - ✓ Prevent/minimize consequences of accidental releases of toxic and flammable chemicals
 - ✓ Public must be notified of any release of toxic of flammable substances
 - ✓ Compliance required by 1996

109

Safety and Security Regulations

- Regulations:
 - Uniform Fire Code (UFC)
 - ✓ 1992 revisions of the UFC requires complete containment and neutralization of any catastrophic leak of chlorine gas.
 - ✓ A chlorine gas scrubber room would be needed to contain and neutralize such a leak.
 - ✓ Many states have adopted the UFC revisions

110



Chlorine room designed to meet OSHA and Fire Code requirements

111

Self-Contained Breathing Apparatus (SCBA)



112

Safety and Security Regulations

- Regulations:
 - Homeland Security Act of 2002 (P.L. 107-296) created Department of Homeland Security (DHS)
 - ✓ Responsibility for assessing and protecting the nation's critical infrastructures
 - ✓ High-risk chemical facilities
 - ✓ Apply consistent **"Inherently Safer Technologies" (IST)** approaches for all high-risk chemical facilities
 - ✓ Excludes water and wastewater systems

113

Safety and Security Regulations

- Regulations:
 - The Public Health Security and Bioterrorism Preparedness and Response Act of 2002 (P.L. 107-188) amended the Safe Drinking Water Act
 - ✓ Required some 8,400 community water systems to assess vulnerabilities and prepare emergency response plans
 - ✓ Directed EPA to review methods to prevent, detect, and respond to threats to water safety and infrastructure security

114

After 2000

- Sodium hypochlorite (bleach) becomes the second most common disinfection method
- Recent trends and concerns:
 - Bleach degrades over time, losing strength
 - More difficult for operators to control residuals
 - New drinking water regulations associated with potential contaminants such as
 - Perchlorate
 - Chlorate
 - Bromate

115
