Introduction to Water Treatment

Grades 3 & 4

Week 2

Course # 3101

1796

TENNESSEE DEPARTMENT OF ENVIRONMENT AND CONSERVATION

Fleming Training Center
February 11 - 15, 2013

http://www.tn.gov/environment/fleming/

State of Tennessee
Fleming Training Center

Fleming Training Center
Your Partner in Clean Water
http://tn.gov/environment/fleming

Water Treatment

Grade 3&4 Week 2
Course#3101
February 11 - 15, 2013

Monday, February 11

8:30	Welcome back, Week 1 test review	Amanda
9:30	Water Corrosion Control	Amanda
10:45	Iron & Manganese removal	Amanda
12:00	Lunch	
1:15	Tour - Consolidated Utility District WTP	

Tuesday, February 12

8:30	Fluoride Control	Amanda
10:30	Membrane Filtration	Amanda
11:45	Lunch	
1:00	Adsorption	Amanda
2:00	Aeration	Amanda

Wednesday, February 13

8:30	Water Softening	Amanda
10:00	Ion Exchange	Amanda
11:45	Lunch	
1:00	Tour—Murfreesboro WTP	

Thursday, February 14

8:30	Cross Connection	Dennis Conger
9:45	Records Keeping & Design Criteria	Amanda
11:30	Lunch	
12:45	Water Loss & Audit	Amanda
2:00	Class Review	Amanda

Friday, February 15

8:30	Lab (Hands-On Review)	Amanda
11:45	Lunch	
1:00	Class Exam and Evaluations	Amanda

State of Tennessee

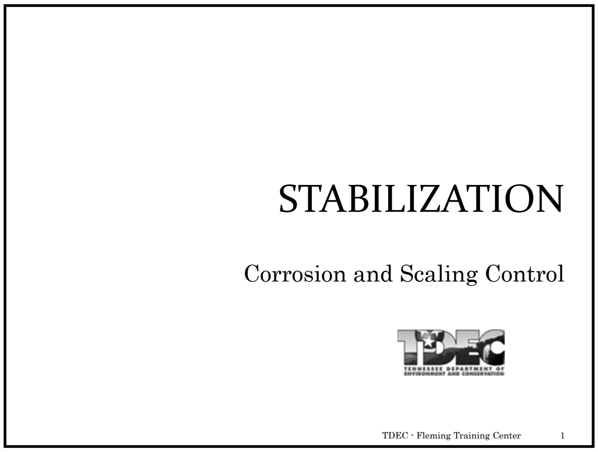
Fleming Training Center
2022 Blanton Dr.
Murfreesboro, TN 37129

Amanda Carter
Phone: 615-898-6507
Fax: 615-898-8064
Amanda.Carter@tn.gov

CONTENTS

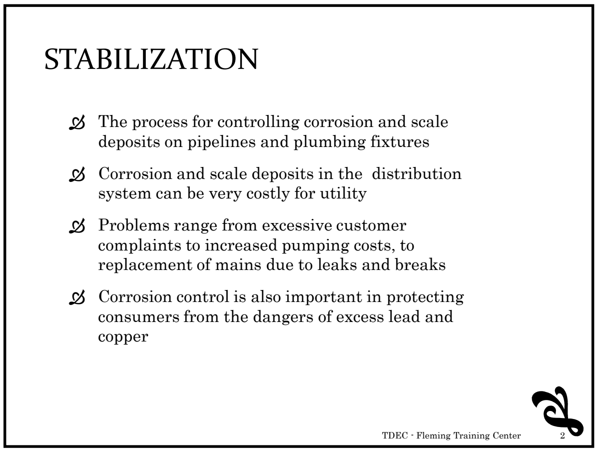
Section 1

Corrosion



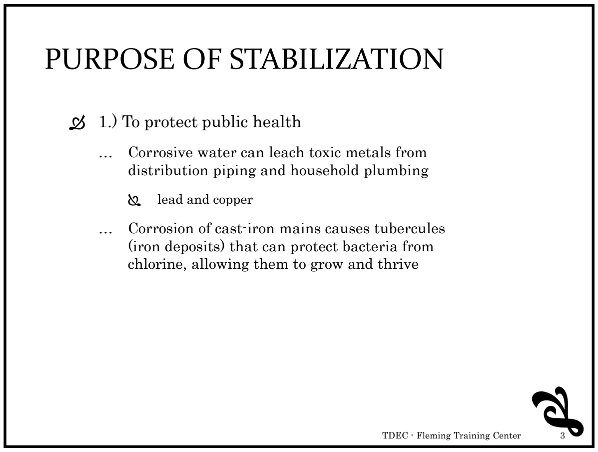
STABILIZATION

Corrosion and Scaling Control



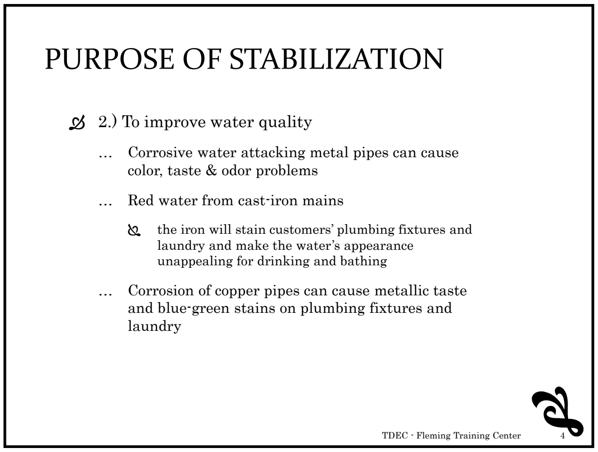
STABILIZATION

- The process for controlling corrosion and scale deposits on pipelines and plumbing fixtures
- Corrosion and scale deposits in the distribution system can be very costly for utility
- Problems range from excessive customer complaints to increased pumping costs, to replacement of mains due to leaks and breaks
- Corrosion control is also important in protecting consumers from the dangers of excess lead and copper



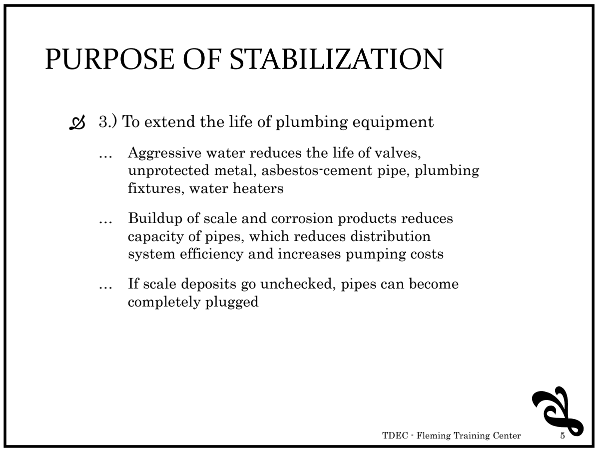
PURPOSE OF STABILIZATION

- 1.) To protect public health
  - Corrosive water can leach toxic metals from distribution piping and household plumbing
    - lead and copper
  - Corrosion of cast-iron mains causes tubercules (iron deposits) that can protect bacteria from chlorine, allowing them to grow and thrive



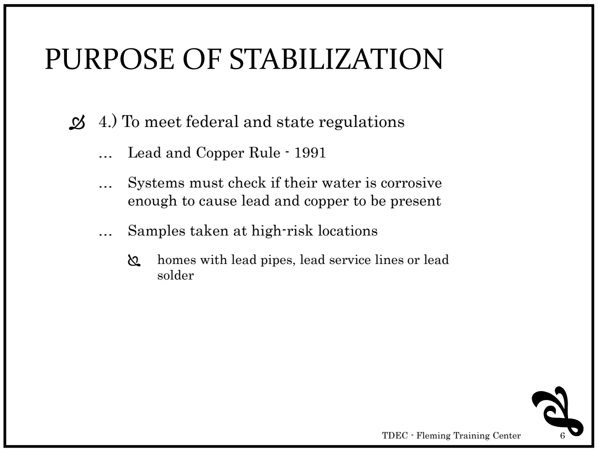
PURPOSE OF STABILIZATION

- 2.) To improve water quality
  - Corrosive water attacking metal pipes can cause color, taste & odor problems
  - Red water from cast-iron mains
    - the iron will stain customers' plumbing fixtures and laundry and make the water's appearance unappealing for drinking and bathing
  - Corrosion of copper pipes can cause metallic taste and blue-green stains on plumbing fixtures and laundry



PURPOSE OF STABILIZATION

- 3.) To extend the life of plumbing equipment
  - Aggressive water reduces the life of valves, unprotected metal, asbestos-cement pipe, plumbing fixtures, water heaters
  - Buildup of scale and corrosion products reduces capacity of pipes, which reduces distribution system efficiency and increases pumping costs
  - If scale deposits go unchecked, pipes can become completely plugged



PURPOSE OF STABILIZATION

- 4.) To meet federal and state regulations
  - Lead and Copper Rule - 1991
  - Systems must check if their water is corrosive enough to cause lead and copper to be present
  - Samples taken at high-risk locations
    - homes with lead pipes, lead service lines or lead solder

LEAD AND COPPER RULE

- Samples are to be collected after water has sat in lines for at least 6 hours - first draw
- 1 liter take from cold water tap in kitchen or bathroom
- Action levels
  - Lead is 0.015 mg/L
  - Copper is 1.3 mg/L
- If a system exceeds action level in more than 10% of samples, steps must be taken to control corrosion

CORROSION

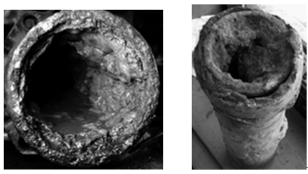
Definition of Corrosion

Factors Affecting Corrosion

Types of Corrosion

CORROSION

- The gradual deterioration or destruction of a substance or material by chemical reaction with the water
- Water that promotes corrosion is called *corrosive* or *aggressive water*



CORROSIVE WATER

Factors Affecting Corrosion

- Dissolved Oxygen
  - as dissolved oxygen increases, the rate of corrosion increases
- Total Dissolved Solids
  - increases electrical conductivity of water
- Alkalinity
  - buffers a change in pH - decreases corrosion
- pH
  - low pH promotes corrosion
  - high pH can be scale-forming

CORROSIVE WATER

- Hardness
  - a small amount can form a protective layer of scale on pipes to prevent corrosion
- Temperature
  - corrosion occurs faster in warmer water
- Flow Velocity
  - increased velocity can increase rate of corrosion if water is corrosive
  - increase velocity can decrease rate of corrosion **if** adding corrosion inhibitor

CORROSIVE WATER

- Type of Water
  - galvanic corrosion is corrosion of dissimilar metals
- Electrical Current
  - improperly grounded household electrical systems can accelerate corrosion
- Sulfate Reducing Bacteria
  - H_2S gas released - causes rotten egg odor
  - can react with water to form H_2SO_4 which is highly corrosive
  - produces black sulfide deposits

CORROSIVE WATER

- Iron Bacteria
  - converts dissolved iron into precipitate causing red-water complaints
  - produces slime which protects against chlorine and prevents accumulation of $CaCO_3$
  - bacteria can slough off causing taste and odor
  - bacteria can change pH and alkalinity of water as they give off gases, mainly CO_2

CORROSION

Types of Corrosion

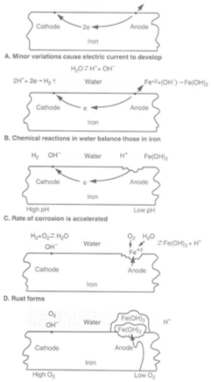
- Localized
  - Most common, most serious
  - Attacks surface unevenly, leads to rapid failure of metal
  - Two types:
    - <u>galvanic</u> - caused by the connection of dissimilar metals in an electrolyte such as water
    - <u>concentration cell</u> - forms deep pits or tubercules
- Uniform
  - Occurs evenly over all surface
  - Due to low pH and alkalinity

LOCALIZED CORROSION

LOCALIZED CORROSION

Sink hole caused by 8-in main break

GALVANIC CORROSION



GALVANIC CORROSION

Corroded End (anode)	**Most Active**
Magnesium	+
Magnesium alloys	↑
Zinc	
Aluminum	
Mild Steel	
Wrought (black) Iron	
Cast Iron	Corrosion
Potential	
Lead-tin Solders	
Lead	
Tin	
Brass	↓
Copper	−
Stainless Steel	
Protected End (cathode)	**Least Active**

SCALE FORMATION

Definition of Scale Formation

Factors Affecting Scale Formation

Types of Scale Formation

SCALE FORMATION

- The precipitation of certain hardness-causing ions with other minerals to form a coating on pipe walls
- The formation of a small amount of scale can help protect the pipe from corrosion
- Uncontrolled deposits reduce the carrying capacity of the pipe
- Can also decrease the efficiency of boilers, water heaters, etc

SCALE FORMATION

Scale-Forming Compounds

- $CaCO_3$ - calcium carbonate
- $MgCO_3$ - magnesium carbonate
- $CaSO_4$ - calcium sulfate
- $MgCl_2$ - magnesium chloride

SCALE FORMATION

- Scale is formed when magnesium and calcium combine with other minerals dissolved in the water
  - … Ca and Mg are then precipitated out coat the pipe walls
- Saturation Point - the point at which a solution can no longer dissolve any more of a particular chemical
  - … Precipitation will occur past this point

SCALE FORMATION

- Solubility varies with temp, pH, TDS, etc
- The saturation point of $CaCO_3$ depends primarily on the water's pH
  - … As pH increases, scale formation increases
- Solubility of $CaCO_3$ in water decreases as temp increases
  - … The higher temps in water heaters causes $CaCO_3$ to precipitate out and build up on pipes, tank walls, and heating elements

SCALE FORMATION

Control Methods

- 1.) pH and alkalinity adjustment
- 2.) Formation of $CaCO_3$ coating
- 3.) Use of corrosion inhibitors and sequestering agents

CONTROL METHODS

pH and Alkalinity Adjustment

- Soft waters with pH less than 7 and poorly buffered (low alkalinity) will be corrosive to lead and copper
- Water with too much alkalinity can also be corrosive
- A moderate increase in pH and alkalinity can reduce corrosion
- A moderate decrease in pH and alkalinity can prevent scale formation

CONTROL METHODS

Stability Scale

Corrosive Water ← Stable Water → Scale-Forming

CONTROL METHODS

pH and Alkalinity Adjustment

- Lime is most commonly used
  - Lime alone or in combination with other chemicals forms a scale on the pipe that protects the pipe from corrosion
    - too much reduces capacity
  - Less expensive than other chemicals
  - Works well
  - Removes CO_2 from water
  - Each mg/L of hydrated lime adds 1.35 mg/L alkalinity

CONTROL METHODS

pH and Alkalinity Adjustment

- Slaked lime (*hydrated*) - $Ca(OH)_2$
  - For small plants, more cost effective
  - Powder
  - In bags or bulk
  - Should be kept dry and well ventilated
    - moisture will start the slaking process
  - Dry feeder
    - water added, forms slurry

CONTROL METHODS

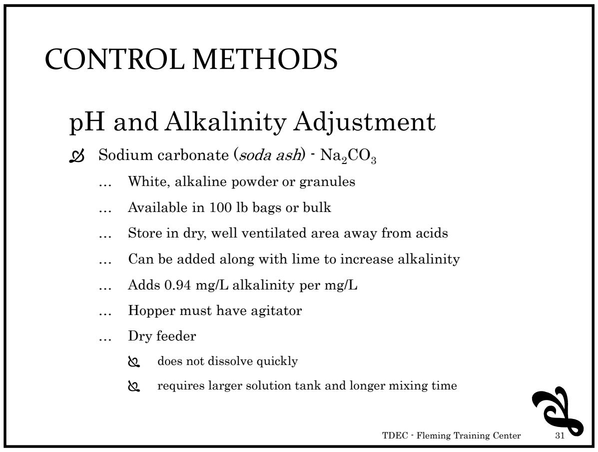
pH and Alkalinity Adjustment

- Unslaked lime (*quicklime*) - CaO
  - For plants using a lot of lime
  - Powder to pebble size
  - Usually handled in bulk
  - Should be kept dry and well ventilated
  - Dry feeder
    - adds lime to a slaker where water is added to form a slurry

CONTROL METHODS

pH and Alkalinity Adjustment

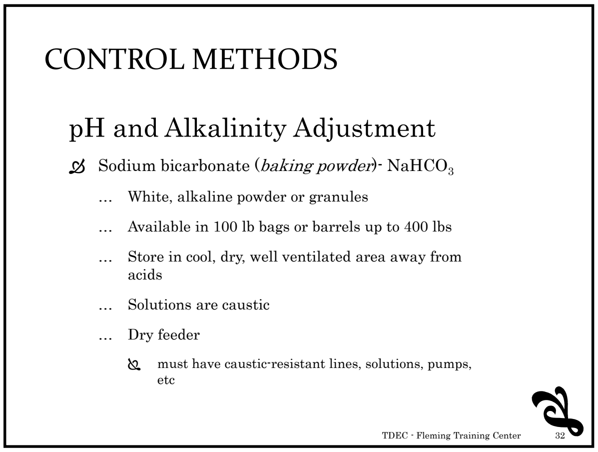
- Note:
  - Quicklime and alum should never be stored together
  - When mixed, a large amount of heat is given off
    - Hydrogen gas can be released



CONTROL METHODS

pH and Alkalinity Adjustment

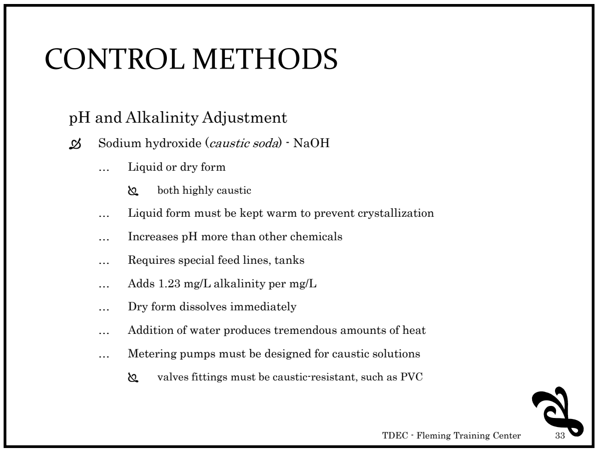
- Sodium carbonate (*soda ash*) - Na_2CO_3
  - White, alkaline powder or granules
  - Available in 100 lb bags or bulk
  - Store in dry, well ventilated area away from acids
  - Can be added along with lime to increase alkalinity
  - Adds 0.94 mg/L alkalinity per mg/L
  - Hopper must have agitator
  - Dry feeder
    - does not dissolve quickly
    - requires larger solution tank and longer mixing time



CONTROL METHODS

pH and Alkalinity Adjustment

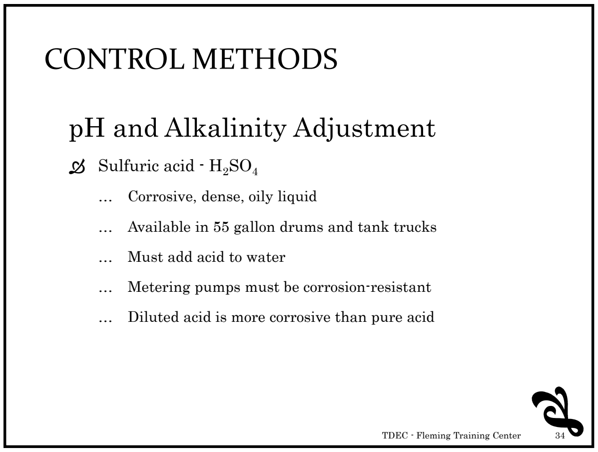
- Sodium bicarbonate (*baking powder*)- $NaHCO_3$
  - White, alkaline powder or granules
  - Available in 100 lb bags or barrels up to 400 lbs
  - Store in cool, dry, well ventilated area away from acids
  - Solutions are caustic
  - Dry feeder
    - must have caustic-resistant lines, solutions, pumps, etc



CONTROL METHODS

pH and Alkalinity Adjustment

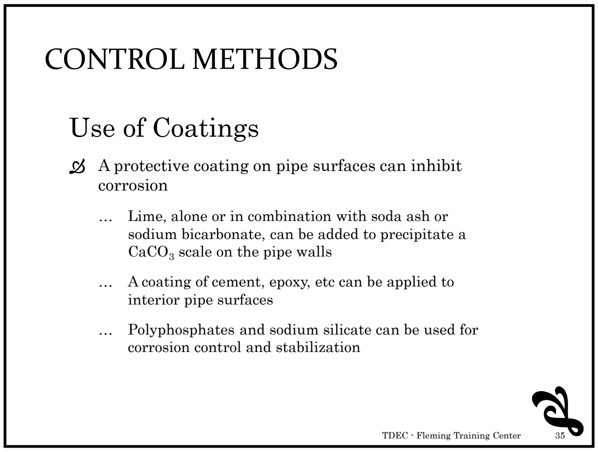
- Sodium hydroxide (*caustic soda*) - NaOH
  - Liquid or dry form
    - both highly caustic
  - Liquid form must be kept warm to prevent crystallization
  - Increases pH more than other chemicals
  - Requires special feed lines, tanks
  - Adds 1.23 mg/L alkalinity per mg/L
  - Dry form dissolves immediately
  - Addition of water produces tremendous amounts of heat
  - Metering pumps must be designed for caustic solutions
    - valves fittings must be caustic-resistant, such as PVC



CONTROL METHODS

pH and Alkalinity Adjustment

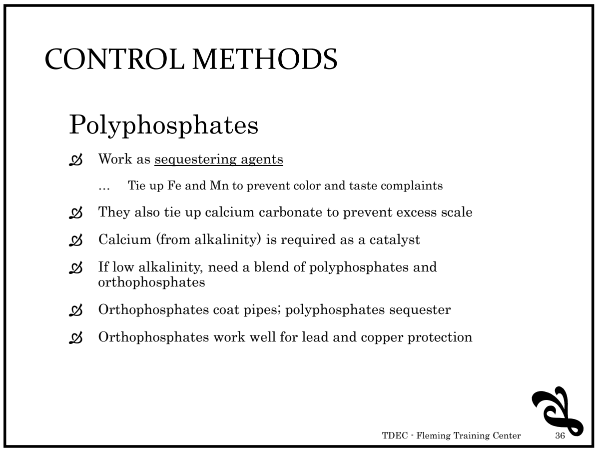
- Sulfuric acid - H_2SO_4
  - Corrosive, dense, oily liquid
  - Available in 55 gallon drums and tank trucks
  - Must add acid to water
  - Metering pumps must be corrosion-resistant
  - Diluted acid is more corrosive than pure acid



CONTROL METHODS

Use of Coatings

- A protective coating on pipe surfaces can inhibit corrosion
  - Lime, alone or in combination with soda ash or sodium bicarbonate, can be added to precipitate a $CaCO_3$ scale on the pipe walls
  - A coating of cement, epoxy, etc can be applied to interior pipe surfaces
  - Polyphosphates and sodium silicate can be used for corrosion control and stabilization

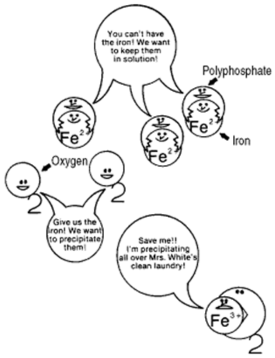


CONTROL METHODS

Polyphosphates

- Work as sequestering agents
  - Tie up Fe and Mn to prevent color and taste complaints
- They also tie up calcium carbonate to prevent excess scale
- Calcium (from alkalinity) is required as a catalyst
- If low alkalinity, need a blend of polyphosphates and orthophosphates
- Orthophosphates coat pipes; polyphosphates sequester
- Orthophosphates work well for lead and copper protection

CONTROL METHODS



CONTROL METHODS

- Phosphates
  - Sodium hexametaphosphate
  - Zinc orthophosphate
  - Available in solid or liquid form
  - Can be fed from shipping container

CONTROL METHODS

- Sodium silicate
  - Combines with calcium to form a hard, dense coating on interior of pipe
  - Works well in waters with low hardness & alkalinity and relatively high flow velocities
  - Must be approved by NSF (National Sanitation Foundation)
  - Thick, opaque alkaline liquid
  - Available in barrels and bulk
  - Non-corrosive

CONTROL METHODS

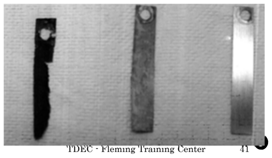
Safety

- Protective clothing, equipment must be worn
- Proper storage
  - keep dry chemicals dry
  - store caustic liquids in proper container
- Clean up spills immediately
- Have a shower and eye wash available

CONTROL METHODS

Coupon Testing

- Measures the effects of the water on a small section of metal (the coupon) inserted in a water line
- After a minimum of 120 days, the inserts are removed, cleaned, weighed and examined
- The weight loss or gain of the coupon can provide an indication of the corrosion or scaling rate



STABILITY

- Water is considered stable when it is just saturated with calcium carbonate
- It will neither deposit nor dissolve calcium carbonate

STABILITY

Langlier Index

- Used to indicate how close the water is to the equilibrium point
- Langlier Index = pH - pH_S
  - pH = actual pH of water
  - pH_S = determined by calcium carbonate saturation point
    - pH_S = A + B - log (Ca^{2+}) - log (alkalinity)
      - A = determined from temperature
      - B = determined from TDS

STABILITY

Langlier Index

- If the Langlier Index is **zero**, the water is **stable**
- If the Langlier Index is **positive**, the water will be **scale-forming**
- If the Langlier Index is **negative**, the water will be **corrosive**

STABILITY

Langlier Index

- Calculate the Langlier Index of a water with the following characteristics

Water temp = 15°C

TDS = 200 mg/L

Ca hardness = 50 mg/L as $CaCO_3$

Alkalinity = 100 mg/L as $CaCO_3$

pH = 7.6

STABILITY

Langlier Index

pH_S = A + B - log (Ca^{2+}) - log (alkalinity)
= 2.12 + 9.80 - 1.70 - 2.00
= 8.22

Langlier Index = pH - pH_S
= 7.6 - 8.22
= - 0.62

This water is moderately aggressive.

STABILITY

Langlier Index

- Calculate the Langlier Index of a water with the following characteristics

Water temp = 20°C

TDS = 200 mg/L

Ca hardness = 125 mg/L as $CaCO_3$

Alkalinity = 140 mg/L as $CaCO_3$

pH = 7.6

STABILITY

Langlier Index

pH_S = A + B - log (Ca^{2+}) - log (alkalinity)
= 2.04 + 9.80 - 2.10 - 2.15
= 7.59

Langlier Index = pH - pH_S
= 7.6 - 7.59
= 0.01

This water is non-aggressive.

STABILITY

- In the distribution system
  - Evaluate effects of corrosion and scaling
  - Records of main breaks and leaks due to corrosion
  - Info on how well older valves operate
    - if difficult to operate, may be coated with scale
  - Info on reduced flow rates in mains
    - build up of scale
  - When possible, pieces or sections of pipe removed should be tagged and evaluated

STABILITY

- In customer's plumbing
  - Customer complaints
    - red water, brown water, loss of pressure
    - location of where problems occur
    - time of year
- For meeting regulation requirements
  - Lead and Copper Rule
    - must take steps to reduce corrosion if action levels are exceeded

STABILITY

- Water quality data
  - Determine if there is an increase in metals in the distribution system
    - i.e. copper, zinc, cadmium
  - Before initiating a corrosion control program, check with others in the field who can give sound advice
  - Using the wrong stabilization method can increase problems

STABILITY

Records

- Amount of chemicals used
  - State report
- Lab tests, Langlier Index calculations
- Maintenance records
- Results of coupon tests and other tests
- Customer complaints related to corrosion or scaling

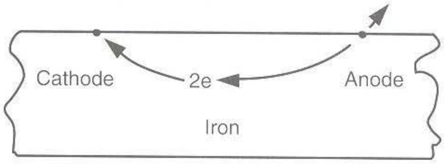
Stabilization Vocabulary

______1. Aggressive
______2. Anode
______3. Cathode
______4. Concentration Cell Corrosion
______5. Corrosion
______6. Corrosive
______7. Coupon Test
______8. Galvanic Corrosion
______9. Galvanic Series
______10. Iron Bacteria
______11. Langelier Index
______12. Localized Corrosion
______13. Milk of Lime
______14. Red Water
______15. Saturation Point
______16. Sequestering Agent
______17. Slaker
______18. Stabilization
______19. Tubercules
______20. Uniform Corrosion
______21. Unstable

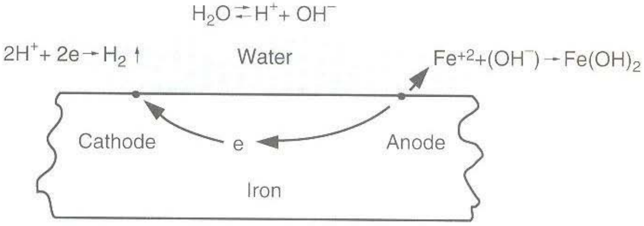
A. A chemical compound such as EDTA or certain polymers chemically tie up other compounds or ions so they can't be involved in chemical reactions.
B. To deteriorate material, such as pipe, through electrochemical processes.
C. Bacteria that use dissolved iron as an energy source.
D. The lime slurry formed when water is mixed with calcium hydroxide.
E. Knobs of rust formed on the interior of cast iron pipes due to corrosion.
F. Corrosive.
G. A term used to describe rust-colored water due to the formation of ferric hydroxide from iron naturally dissolved in the water or as a result of the action of iron bacteria.
H. A listing of metals and alloys according to their corrosion potential.
I. To be corrosive or scale-forming.
J. Positive end (pole) of an electrolytic system.
K. The point at which a solution can dissolve no more of a particular material.
L. A numerical index that indicates whether calcium carbonate will be deposited or dissolved in a distribution system.
M. The water treatment process intended to reduce the corrosive or scale-forming tendencies of water.
N. Negative end (pole) of an electrolytic system.
O. A form of localized corrosion that can form deep pits or tubercules.
P. A form of corrosion that attacks a small area.
Q. The part of the quicklime feeder that mixes the quicklime with water to form hydrated lime.
R. A form of localized corrosion caused by the connection of dissimilar metals in an electrolyte such as water.
S. The gradual deterioration or destruction of a substance or material by chemical reaction. The action proceeds inward from the surface.
T. A form of corrosion that attacks material at the same rate over the entire area of its surface.
U. A method of determining the rate of corrosion or scale formation by placing metal strips of a known weight in the pipe.

Answers to Stabilization Vocabulary

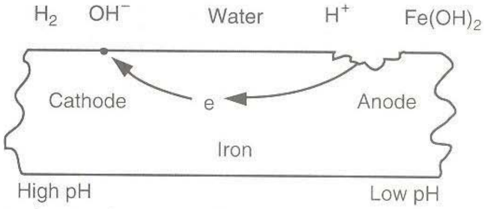
1. F
2. J
3. N
4. O
5. S
6. B
7. U
8. R
9. H
10. C
11. L
12. P
13. D
14. G
15. K
16. A
17. Q
18. M
19. E
20. T
21. I



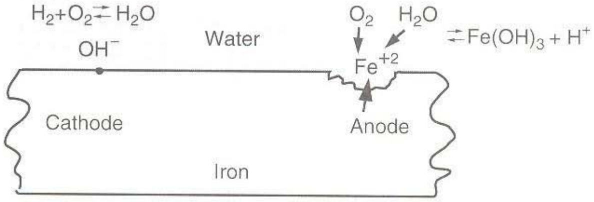
A. Minor variations cause electric current to develop



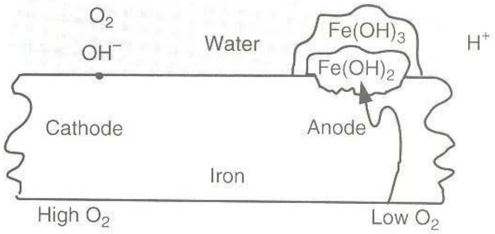
B. Chemical reactions in water balance those in iron



C. Rate of corrosion is accelerated



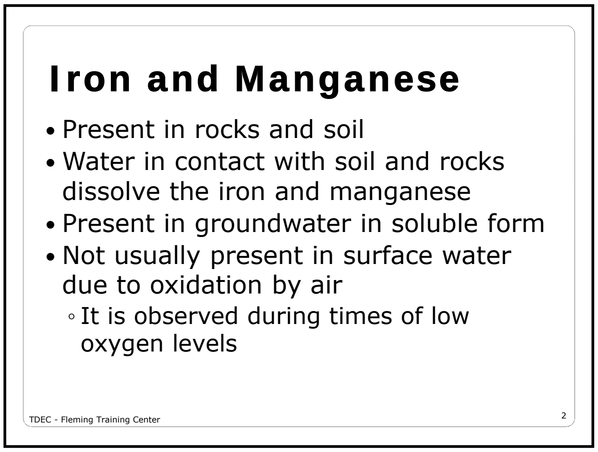
D. Rust forms



Section 2

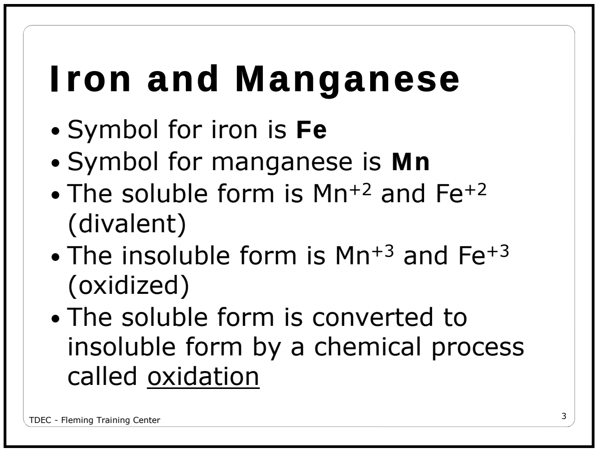
Iron & Manganese

Iron and Manganese Control



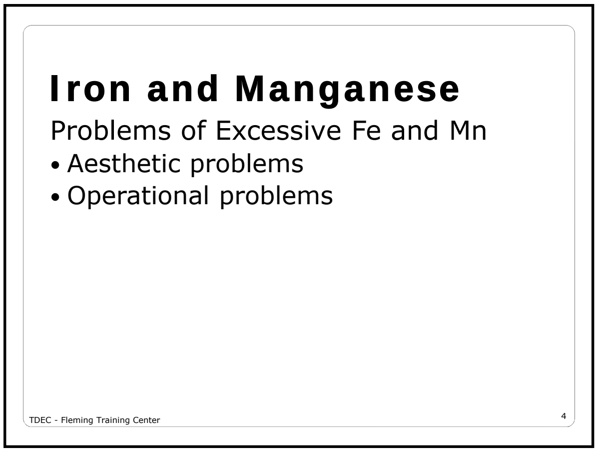
Iron and Manganese

- Present in rocks and soil
- Water in contact with soil and rocks dissolve the iron and manganese
- Present in groundwater in soluble form
- Not usually present in surface water due to oxidation by air
  - It is observed during times of low oxygen levels



Iron and Manganese

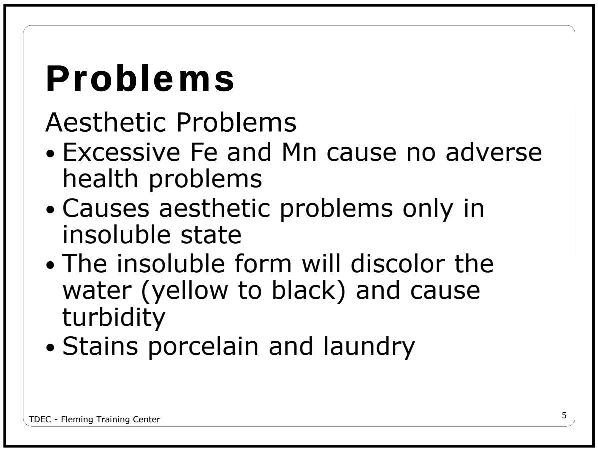
- Symbol for iron is **Fe**
- Symbol for manganese is **Mn**
- The soluble form is Mn^{+2} and Fe^{+2} (divalent)
- The insoluble form is Mn^{+3} and Fe^{+3} (oxidized)
- The soluble form is converted to insoluble form by a chemical process called oxidation



Iron and Manganese

Problems of Excessive Fe and Mn

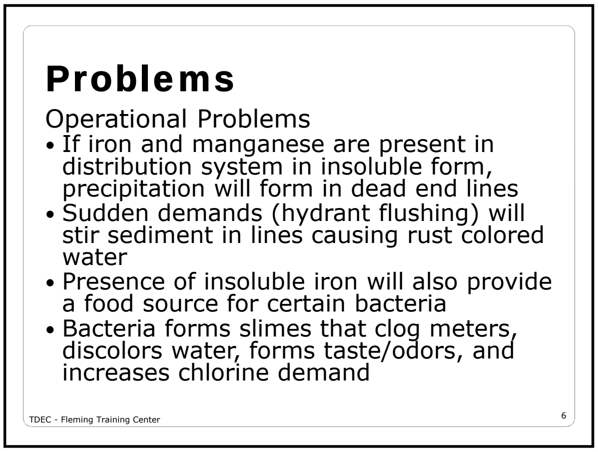
- Aesthetic problems
- Operational problems



Problems

Aesthetic Problems

- Excessive Fe and Mn cause no adverse health problems
- Causes aesthetic problems only in insoluble state
- The insoluble form will discolor the water (yellow to black) and cause turbidity
- Stains porcelain and laundry



Problems

Operational Problems

- If iron and manganese are present in distribution system in insoluble form, precipitation will form in dead end lines
- Sudden demands (hydrant flushing) will stir sediment in lines causing rust colored water
- Presence of insoluble iron will also provide a food source for certain bacteria
- Bacteria forms slimes that clog meters, discolors water, forms taste/odors, and increases chlorine demand

Iron and Manganese

Regulations

- No MCL
- Only sMCL
  - Fe = 0.3 mg/L in finished water
  - Mn = 0.05 mg/L in finished water
- Aesthetics only, no health hazard
- Difficult to explain to customer complaints

Iron

- Elevated levels of iron may cause staining of plumbing fixtures and laundry and may give an objectionable taste or color

Iron

Red Water

- Iron concentrations above 0.3 mg/L can cause "red water" complaints
- Iron can provide a nutrient source for bacteria that grow in distribution pipes

Iron

Analysis

- Analyze samples as soon as possible to prevent air oxidation of ferrous iron to ferric iron
- Hach's method has a detection range of 0.02 - 3.0 mg/L
- Three minute reaction period needs to take place before reading

Manganese

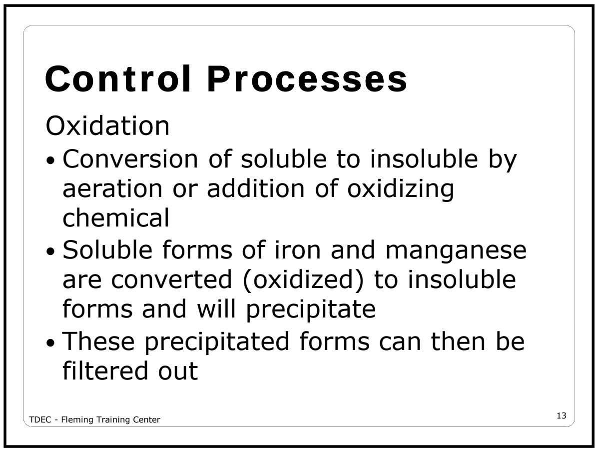
Analysis

- Hach has 2 methods
  - High range
    - 0.2 - 20.0 mg/L
  - Low range
    - PAN method
    - 0.007 - 0.700 mg/L
- Iron can be an interference if it is in excess of 5 mg/L
  - Allow 10 minute reaction period

Make sure to use low range; this sees down to sMCL (0.05 mg/L)

Control Processes

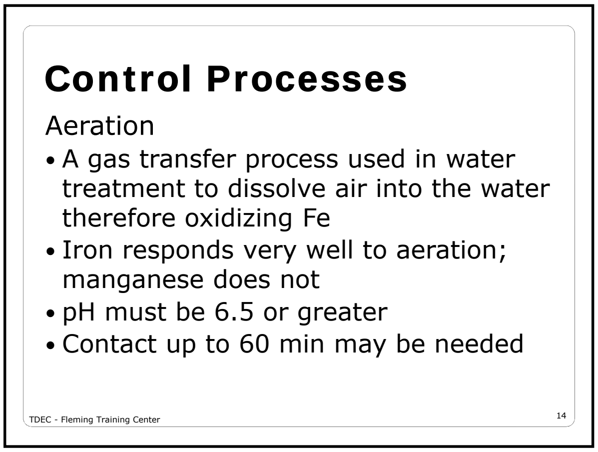
- If iron and manganese levels are mild, regular flushing in the distribution system at dead ends is acceptable
- For increased control, other methods may be needed
- These methods include:
  - Oxidation and filtration
  - Ion exchange
  - Sequestration



Control Processes

Oxidation

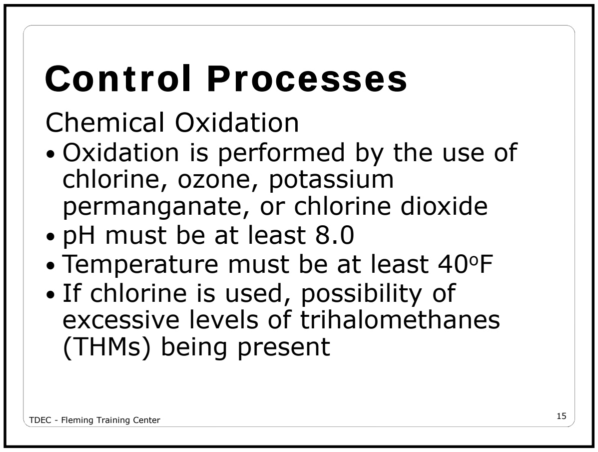
- Conversion of soluble to insoluble by aeration or addition of oxidizing chemical
- Soluble forms of iron and manganese are converted (oxidized) to insoluble forms and will precipitate
- These precipitated forms can then be filtered out



Control Processes

Aeration

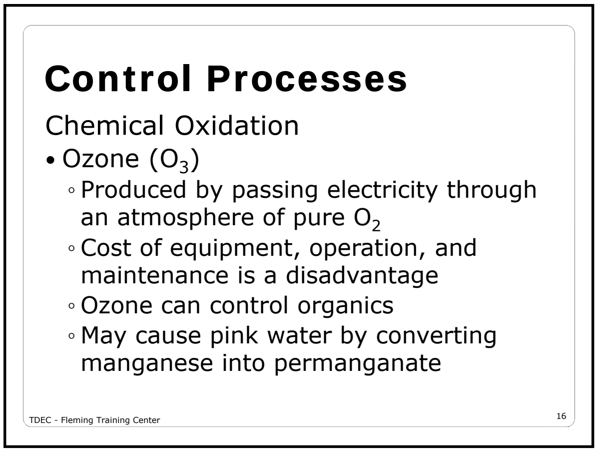
- A gas transfer process used in water treatment to dissolve air into the water therefore oxidizing Fe
- Iron responds very well to aeration; manganese does not
- pH must be 6.5 or greater
- Contact up to 60 min may be needed



Control Processes

Chemical Oxidation

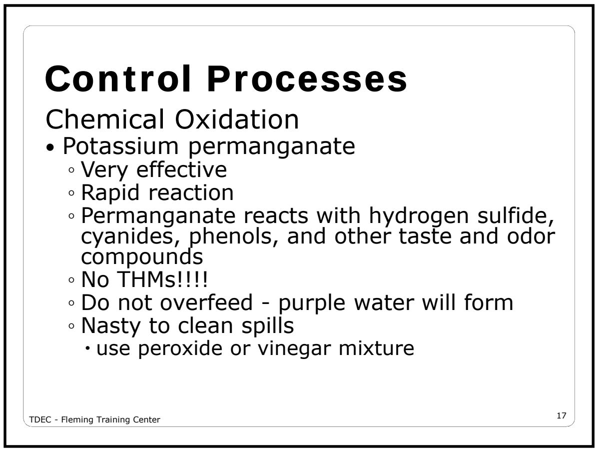
- Oxidation is performed by the use of chlorine, ozone, potassium permanganate, or chlorine dioxide
- pH must be at least 8.0
- Temperature must be at least 40°F
- If chlorine is used, possibility of excessive levels of trihalomethanes (THMs) being present



Control Processes

Chemical Oxidation

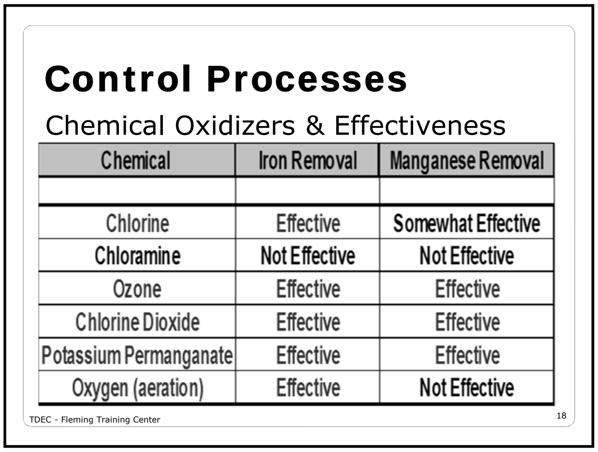
- Ozone (O_3)
  - Produced by passing electricity through an atmosphere of pure O_2
  - Cost of equipment, operation, and maintenance is a disadvantage
  - Ozone can control organics
  - May cause pink water by converting manganese into permanganate



Control Processes

Chemical Oxidation

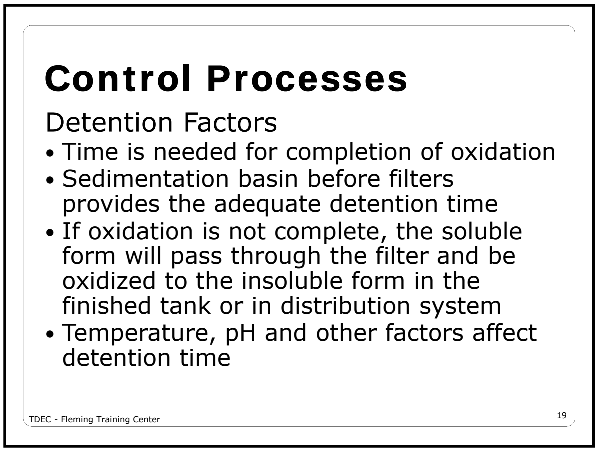
- Potassium permanganate
  - Very effective
  - Rapid reaction
  - Permanganate reacts with hydrogen sulfide, cyanides, phenols, and other taste and odor compounds
  - No THMs!!!!
  - Do not overfeed - purple water will form
  - Nasty to clean spills
    - use peroxide or vinegar mixture



Control Processes

Chemical Oxidizers & Effectiveness

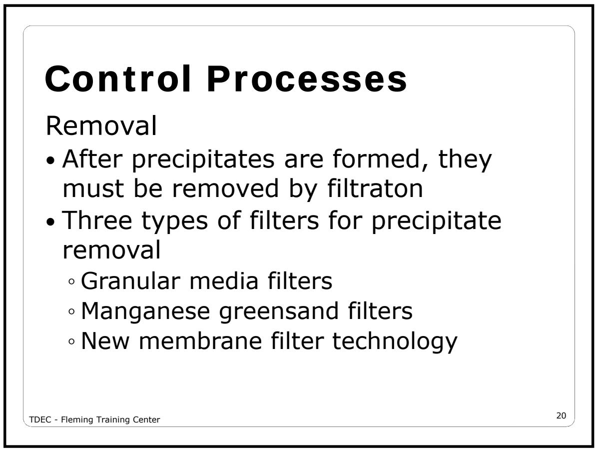
Chemical	Iron Removal	Manganese Removal
Chlorine	Effective	**Somewhat Effective**
Chloramine	**Not Effective**	**Not Effective**
Ozone	Effective	Effective
Chlorine Dioxide	Effective	Effective
Potassium Permanganate	Effective	Effective
Oxygen (aeration)	Effective	**Not Effective**



Control Processes

Detention Factors

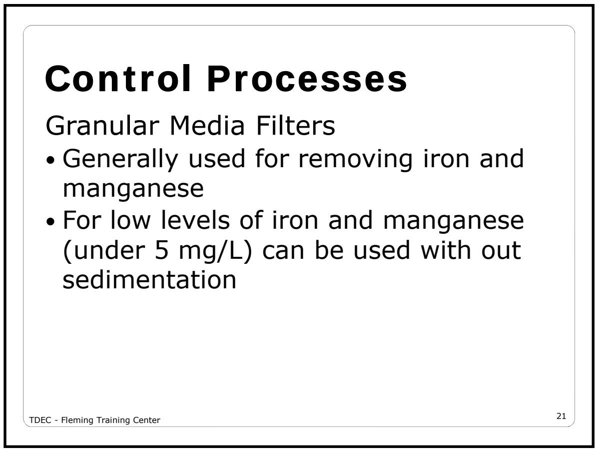
- Time is needed for completion of oxidation
- Sedimentation basin before filters provides the adequate detention time
- If oxidation is not complete, the soluble form will pass through the filter and be oxidized to the insoluble form in the finished tank or in distribution system
- Temperature, pH and other factors affect detention time



Control Processes

Removal

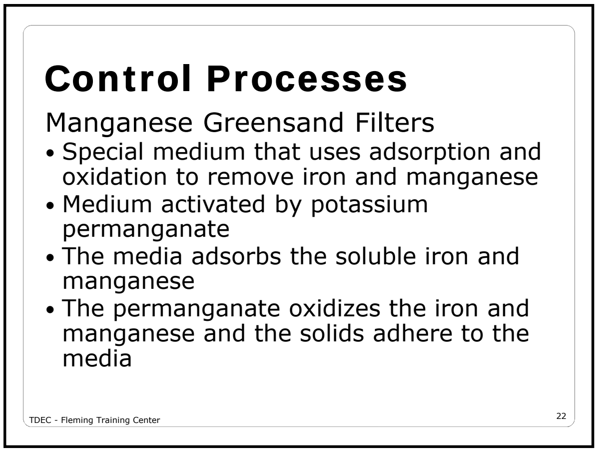
- After precipitates are formed, they must be removed by filtraton
- Three types of filters for precipitate removal
  - Granular media filters
  - Manganese greensand filters
  - New membrane filter technology



Control Processes

Granular Media Filters

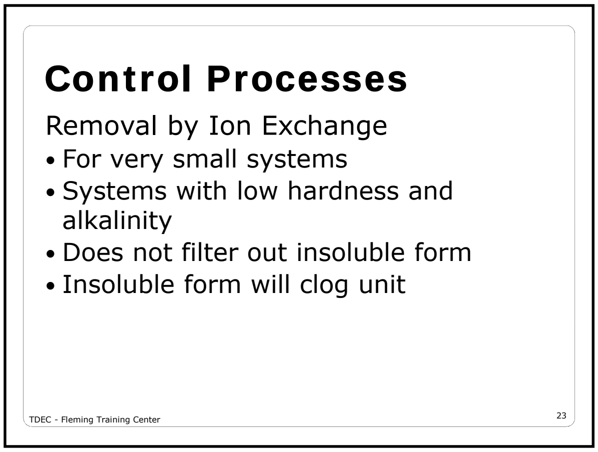
- Generally used for removing iron and manganese
- For low levels of iron and manganese (under 5 mg/L) can be used with out sedimentation



Control Processes

Manganese Greensand Filters

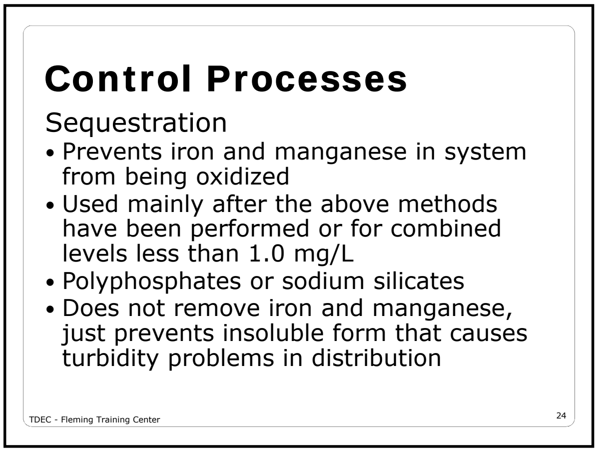
- Special medium that uses adsorption and oxidation to remove iron and manganese
- Medium activated by potassium permanganate
- The media adsorbs the soluble iron and manganese
- The permanganate oxidizes the iron and manganese and the solids adhere to the media



Control Processes

Removal by Ion Exchange

- For very small systems
- Systems with low hardness and alkalinity
- Does not filter out insoluble form
- Insoluble form will clog unit



Control Processes

Sequestration

- Prevents iron and manganese in system from being oxidized
- Used mainly after the above methods have been performed or for combined levels less than 1.0 mg/L
- Polyphosphates or sodium silicates
- Does not remove iron and manganese, just prevents insoluble form that causes turbidity problems in distribution

Iron and Manganese Control Review Questions

1. What form are iron and manganese normally in when present in raw water?

2. How do iron and manganese become objectionable in a water system?

3. What are some of the principal aesthetic problems caused by excessive iron or manganese in water distributed to customers?

4. What are some of the consequences (other than customer complaints) when iron and manganese are oxidized at the treatment plant but not removed?

5. What are the maximum desirable levels of iron and manganese in drinking water furnished to customers?

6. What are the three principal methods of iron and manganese control?

7. What chemicals are principally used for oxidation of iron and manganese?

8. Explain the four steps used in removing of high concentrations of iron and manganese in water?

9. How does sequestration work?

Iron and Manganese Control Answers

1. Iron and manganese are normally in the dissolved form in raw water, where they are colorless and odorless.

2. When iron and manganese are oxidized, they change to a precipitate that will, in most cases, color the water yellow. Under some circumstances, the water may be turned brown or even black.

3. *Color in drinking water is generally disagreeable to customers, and they will refuse to drink it, even though it is microbiologically safe.

   *Brown stains will form on plumbing fixtures.

   *Brown stains will form in laundered clothes.

   *The presence of iron may turn tea and coffee dark black.

4. *Much of the precipitate will settle out in the water mains, then it will later be put back into suspension whenever there is a change in water flow.

   *The accumulation of sediment in mains can result in a reduction of flow capacity.

   *The sediment may clog meters and valves.

   *Bacteria that feed on the iron could increase discoloration.

   *Objectionable tastes and odors could be formed.

   *There will be an increase in chlorine demand in the system.

5. *Fe=0.3 mg/L
   *Mn= 0.05 mg/L

6. *oxidation, precipitation, and filtration
   *ion exchange
   *sequestering

7. *Chlorine
   *Chlorine dioxide
   *Ozone
   *Potassium permanganate

8. *Oxidation-the iron and/or manganese is oxidized by aerating the water or by adding an oxidizing chemical.

   *Detention-the water is held in a contact basin for a period of time to allow the reaction to be completed.

   *Sedimentation-most of the precipitate that has been formed is allowed to settle out in settling tanks.

   *Filtration-the material that remains in the water after sedimentation is removed with sand or multimedia filters.

9. In the sequestration process, polyphosphates or sodium silicates are added to the water before the water is exposed to air or another oxidant. The iron and manganese are not are moved but are kept in the finished water.

Section 3

Fluoride

F Flourine
Atomic Number: 9
Atomic Mass: 19

Fluoridation

Fluoride adjustment for the reduction of tooth decay in children

Who, What, Where, Why, How

- Fluoridation is the adjustment of water fluoride
- Used for optimum oral health benefits
- One of ten great public health achievements of the 20th century (CDC)
- Water fluoridation has a 60 year history of success
- Tooth decay is the most prevalent chronic disease among humans, especially children
- Water fluoridation is the most economical and effective method of reducing tooth decay

Who

- Dr. Frederick S. McKay initiated a study in 1908 of “Colorado Brown Stain” in Colorado Springs
- Important conclusions
  - Mottled teeth more resistant to dental decay
  - Life-long residents had stained teeth, more recent residents did not
  - High fluoride content of water identified in 1931

Who

- In 1930’s, Dr. H. Trendley Dean conducted the “21 Cities Study”
- Important conclusions
  - Optimum levels of fluoride for enhancing oral health (natural breakpoint at 1 mg/L)
  - 1.0 mg/L provided best combination of reduction in tooth decay (*caries*) and low risk of fluorosis
  - Established community fluorosis index (increased incidence at 2 mg/L)

Optimal Fluoride Dose

- Varies depending on climate and how much water people drink in a day
- Too little fluoride doesn’t protect against cavities
- Too much fluoride can cause fluorosis

Fluorosis

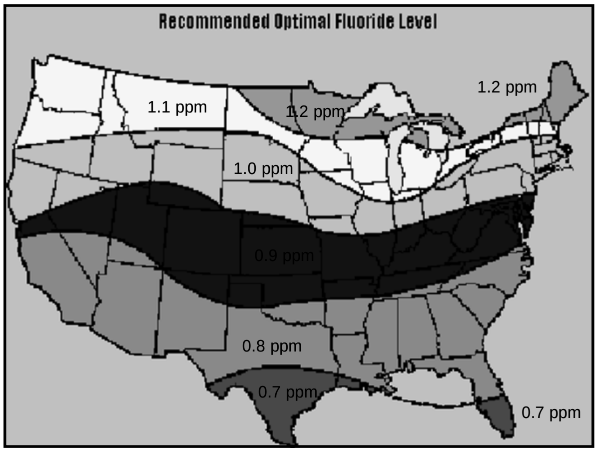
- Dental fluorosis
  - Mottling of the teeth
  - Pitting of teeth, greater chance of tooth decay
  - Can occur at twice the optimal dosage
- Skeletal fluorosis
  - Crippling disease with rheumatic attacks, pain, and stiffness in the joints
  - Can occur at 20 mg/day for many years

Mild Dental Fluorosis
White mottling of the teeth

Severe Dental Fluorosis
Dark brown stains on teeth

Fluoride Consumption

- If a person drinks 1 liter of water containing 1 mg/L of fluoride, that person has consumed 1 mg of fluoride
- If a person drinks 2 liters of water containing 1 mg/L of fluoride, that person has consumed 2 mg of fluoride



General Practices

- There are no state regulations requiring water systems to fluoridate
- USEPA sets MCLs on fluoride, but there is no minimum level
  - Primary MCL = 4.0 mg/L
  - Secondary MCL = 2.0 mg/L
- The minimum fatal dose of fluoride for a 150 lb person is 2 grams

Sampling Requirements

- Daily sampling and analysis
- One quarterly sample required by state

Fluoride Chemicals

- Fluoride is not pure in form when purchased
- It is combined with other elements for stability and ease of handling
  - Sodium fluoride (NaF) 98% pure
  - Sodium fluorosilicate (Na_2SiF_6) 98.5% pure
  - Fluorosilicic acid (H_2SiF_6) 23% pure

Fluoride Chemicals

Sodium Fluoride (NaF)

- First compound used for fluoridation
- White, odorless crystals or powder
- Solubility is constant at 4 grams per 100 mL
- Solutions have pH near neutral
- 98% pure
- Principle hazard is dust

Fluoride Chemicals

Sodium Fluorosilicate (Na_2SiF_6)

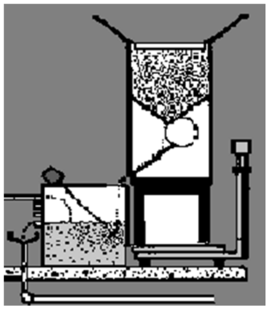
- Salt of fluorosilicic acid
- General by-product of fertilizer
- White, odorless crystalline powder
- Solubility varies with temperature
- 98% or higher purity
- Principle hazard is dust
- Most expensive

Fluoride Chemicals

Fluorosilicic Acid (H_2SiF_6)

- Once referred to as “silly acid”
  - aka hydrofluorosilicic acid
- Clear, colorless to slightly yellow liquid
- Pungent odor, fuming, will etch glass
- Corrosive, pH 1.0-1.5
- 18-23% pure
- Can cause burns, respiratory irritation
- More costly; easier to handle than dry chemicals

Fluoridation Systems



TDEC TENNESSEE DEPARTMENT OF ENVIRONMENT AND CONSERVATION

Dry Feeders

- Measure a given amount of dry chemical into a mixing tank where it forms a solution
- Requires a stirrer to provide good mixing
- Solution pumped or gravity-fed to clearwell

Dry Feeders

Types of Feeders

Volumetric Feeders	Gravimetric Feeders
Easy to operate	Very accurate
Less expensive	More expensive
Less accurate	Feed by weight, not volume
Feeds measured volume per revolution (unit time)	Belt-type
	Loss-of-weight type

Solution Feeders

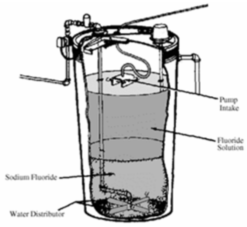
- Small pumps feed solution from tank
  - Diaphragm pumps
    - cam speed or stroke is adjusted
  - Piston pumps
    - adjusting stroke length
    - can pump at very low rates
- Both are accurate & can pump against pressure
- Positive displacement

Solution Feeders

- Must ensure that chemical is completely dissolved to avoid clogging of feed lines and inconsistent dosages
  - 5 minute mixing time
- Must have vacuum breaker between tank and inlet valve as backflow preventer
  - No cross-connections

Saturators

- Used for ***sodium fluoride***
- Saturated solution will result if water trickles through a bed of NaF crystals
- Fluoride solution will stabilize at 4% at normal temps
- Pumped by metering pump



Saturators

Two Types

- Upflow saturators
  - Water introduced at bottom
  - Bed of undissolved NaF on bottom of tank
- Downflow saturators
  - Water flows from top to bottom
  - Bed of granular NaF sits on layer of sand and gravel
  - **Not approved for use in Tennessee**

Acid Feed Systems

- Can be fed from shipping container
- Container set on scale to record usage
- Small systems may have to dilute
- Large systems can purchase tank truck and feed from day tank

Auxiliary Equipment

Safety Equipment

- Shower and eye wash facilities
- Chemical aprons
- Gauntlets
- Goggles
- Respirator or dust masks

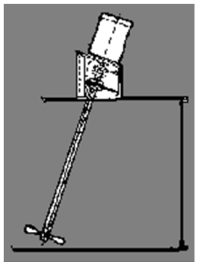
Scales

- Required for all systems except saturators
- Must have capacity to weigh full tank
- Measure to nearest pound
  - 1/2 pound for acid
- Connections to water lines & discharge lines must be flexible

Dissolving Tanks

- Also known as solution tanks
- Dry chemicals from a feeder must be dissolved in a tank
- Minimum of 35 gallon tank
- Chemicals must be completely dissolved to avoid clogging or inconsistent feed rates

Mixers



- Mechanical mixer with stainless steel shaft and propeller
- In-line mixers also available

Day Tanks (Acid)

- Hold enough chemical for 1 day or 1 shift
- Required to be set on a scale for weight measurement
- Polyethylene tanks most common
- Should be vented to outdoors
- All connection sealed to prevent corrosion

Hoppers

- On dry feeders, hoppers hold chemicals over feeder
- Should hold at least one bag of chemical to avoid spillage and excess dust
- May be installed with agitator to promote smooth and even flow

Bag Loaders

- Helps operator lift chemical to fill hopper
- Holds one bag of chemical
- Door swings down, bag is attached by a rod through bottom of bag
- Bag is cut open and swung into position
- Requires operator to wear dust mask

Operation of Fluoridation Systems

Operation of Feeders
Injection Point
Chemical Storage

Dry Feeders

- Inspect and clean regularly to prevent breakdowns
- Inspect feed mechanism for signs of wear
- Inspect solution tank for precipitate buildup
- Calibrate feeder occasionally

Saturators

- Maintain at least 6 inches of chemical at all times
- Saturators treating over 1,000 gpm need 10 inches of chemical
- Use crystalline NaF
  - less dust, does not compact
- Metering pumps should be periodically cleaned and worn parts replaced

Fluoride Injection Point

- Apply fluoride after all treatment is complete
  - After filtration, before clearwell
- Should be as far as possible from lime or calcium hypochlorite application
- Injectors should be cleaned periodically to prevent precipitate buildup
- If injected into a pipe, inject into lower part

Chemical Storage

- Chemical storage areas must be kept clean and orderly
- Improper storage can cause chemical loss and safety hazards

Dry Chemical Storage

- Dry chemicals must be kept dry
- Bags should be stored as close to feeder as possible to minimize handling and dust
- Whole bags should be emptied into hopper to minimize spillage and dust
- Cut the top of the bag; do not tear
- Pour contents gently; do not toss the bags
- Good ventilation is required even if dust isn’t bad

Fluorosilicic Acid Storage

- Containers should be kept tightly closed or vented to the outdoors due to corrosive vapors
- Should be stored away from switches, contacts and control panels

Storage

- Never re-use empty fluoride containers. They may still contain high levels of fluoride even after repeated rinsing.

Analysis of Fluorides in Drinking Water

- Ion Selective Electrode method
  - preferred because of fewer interferences
- SPADNS
  - interferences from phosphates

When Running Fluoride Tests

- Make sure glassware is clean and rinsed with distilled water
- The use of phosphate-based detergents can interfere with test results (if using SPADNS)

Operating Problems

Varying Concentrations

Dangers of Improper Concentrations

Varying Concentrations

- Takes time for fluoride concentration in distribution system to stabilize
- Variations caused by inaccurate calibration, improper functioning of feeders and equipment
- Unfluoridated water introduced into the system

Low Concentrations

- Interferes with lab tests
- Inadequate chemical depth in a saturator
- Improper mixing in a solution tank
- Improper injection point

High Concentrations

- Phosphates cause high readings with SPADNS
- Naturally occurring fluoride levels can vary

Fluoride Poisoning

- Can occur from malfunctioning equipment or failure to turn off feed system when flow is stopped
- Illnesses and at least one death blamed on high fluoride levels in public water supply

Control Tests

- Check raw fluoride level
- Check finished fluoride level
- Automatic monitors continuously record level
  - Have alarm in case maximum concentration is exceeded

Symptoms of Overexposure

- Chronic Toxic Exposure
  - Results from prolonged exposure to 2-8 times recommended level
  - Mottled teeth
  - Calcified ligaments and tendons
  - Vertebrae consolidation

Symptoms of Overexposure

- Acute Toxic Exposure
  - Results from a single, massive dose
  - Inhalation causes sharp pains in nose, nosebleed, respiratory distress
  - Ingestion causes vomiting, abdominal pain
  - Acid spilled on skin can cause burns
    - splashed in eyes can cause severe irritation

Fluoride Math

Dosage and Feed Rates for Fluoride

Determining Feed Rate

- Fluoride is not in pure form when purchased. It is combined with other elements for stability and ease of handling.
- To calculate the correct dosage, you must know the following:
  - Ion concentration
  - Percent purity

Fluoride Chemicals Purity

- Sodium Fluoride (NaF) = 98% purity
- Sodium Fluorosilicate (Na_2SiF_6)= 98.5% purity
- Fluorosilicic Acid (H_2SiF_6) = 18-23% purity

Fluoride Chemicals

Ion Concentration Percent (AFI)

- Sodium Fluoride = 45.2%
- Sodium Fluorosilicate = 60.7%
- Fluorosilicic Acid = 79.2%

Optimal Dosage

- The optimal dosage for fluoride in drinking water in Tennessee is 0.7 mg/L
- To determine fluoride dosage, subtract the naturally occurring fluoride concentration from the desired concentration

Fluoride Dose

A water plant wants a fluoride concentration of 1.00 mg/L in the finished water. If the raw fluoride content is 0.25 mg/L, how much fluoride needs to be added?

Fluoride dose = Total fluoride, mg/L - raw fluoride, mg/L

= 1.00 mg/L - 0.25 mg/L

= 0.75 mg/L

Calculating Feed Rate

A water plant treats 750,000 gpd and wants to add 0.9 mg/L of fluoride to the water using sodium fluoride. How many pounds per day will be used?

$$\textbf{lbs/day} = \frac{\textbf{(dosage, mg/L)(flow, MGD)(8.34 lbs/gal)}}{\textbf{(AFI, as decimal)(purity, as decimal)}}$$

$$= \frac{(0.9\text{ mg/L})(0.75\text{ MGD})(8.34\text{ lbs/gal})}{(0.452)(.98)}$$

$$= 12.7\text{ lbs/day}$$

Calculating Feed Rate

A water plant treats 200,000 gpd and wants to add 0.82 mg/L of fluoride to the water using sodium fluorosilicate. How many pounds per day will they use?

$$\textbf{lbs/day} = \frac{\textbf{(dosage, mg/L)(flow, MGD)(8.34 lbs/gal)}}{\textbf{(AFI, as decimal)(purity, as decimal)}}$$

$$= \frac{(0.82\text{ mg/L})(0.20\text{ MGD})(8.34\text{ lbs/gal})}{(0.607)(.985)}$$

$$= 2.29\text{ lbs/day}$$

Calculating Feed Rate

A water plant treats 12.0 MGD and wants to add 0.75 mg/L of fluoride using fluorosilicic acid to the water. How many pounds per day will be used?

$$\textbf{lbs/day} = \frac{\textbf{(dosage, mg/L)(flow, MGD)(8.34 lbs/gal)}}{\textbf{(AFI, as decimal)(purity, as decimal)}}$$

$$= \frac{(0.75\text{mg/L})(12\text{ MGD})(8.34\text{ lbs/gal})}{(0.792)(.230)}$$

$$= 412\text{ lbs/day}$$

Feed Rate for Saturator

A water plant produces 250 gpm. Determine the feed rate for a saturator in gal/day if the dosage is 1.0 mg/L?

$$\textbf{gal/min} = \frac{\textbf{(capacity, gpm)(dosage, mg/L)}}{\textbf{(18,000 mg/L)}}$$

$$= \frac{(250\text{ gpm})(1.0\text{ mg/L})}{18{,}000\text{ mg/L}}$$

$$\text{gal/day} = (0.014\text{ gal/min})\ (1440\text{ min/day})$$

$$= 20.16\text{ gallons a day}$$

Dosages

A total of 25 lbs of sodium fluorosilicate is used to treat 1.75 MGD. What is the concentration of fluoride in the water in mg/L?

$$\textbf{mg/L} = \frac{\textbf{(fluoride fed, lbs)(AFI, as decimal)(purity, as deci.)}}{\textbf{(MGD)(8.34 lbs/gal)}}$$

$$= \frac{(25\text{ lbs})(0.607)(0.985)}{(1.75\text{ MGD})(8.34\text{ lbs/gal})}$$

$$= 1.02\text{ mg/L}$$

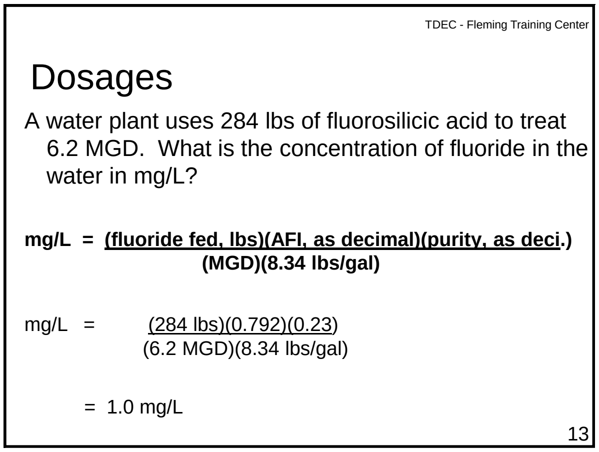
Dosages

A total of 5 lbs of sodium fluoride is used to treat 0.2 MGD. What is the concentration of fluoride in the water in mg/L?

$$\textbf{mg/L} = \frac{\textbf{(fluoride fed, lbs)(AFI, as decimal)(purity, as deci.)}}{\textbf{(MGD)(8.34 lbs/gal)}}$$

$$\text{mg/L} = \frac{(5\text{ lbs})(0.452)(0.98)}{(0.2\text{ MGD})(8.34\text{ lbs/gal})}$$

$$= 1.33\text{ mg/L}$$



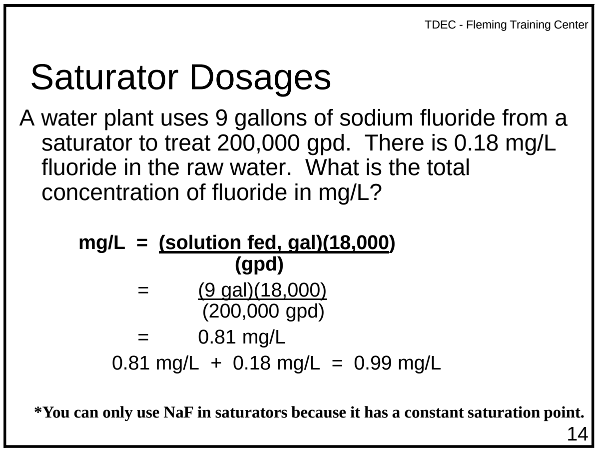
Dosages

A water plant uses 284 lbs of fluorosilicic acid to treat 6.2 MGD. What is the concentration of fluoride in the water in mg/L?

$$\textbf{mg/L} = \frac{\textbf{(fluoride fed, lbs)(AFI, as decimal)(purity, as deci.)}}{\textbf{(MGD)(8.34 lbs/gal)}}$$

$$\text{mg/L} = \frac{(284\text{ lbs})(0.792)(0.23)}{(6.2\text{ MGD})(8.34\text{ lbs/gal})}$$

$$= 1.0\text{ mg/L}$$



Saturator Dosages

A water plant uses 9 gallons of sodium fluoride from a saturator to treat 200,000 gpd. There is 0.18 mg/L fluoride in the raw water. What is the total concentration of fluoride in mg/L?

$$\textbf{mg/L} = \frac{\textbf{(solution fed, gal)(18,000)}}{\textbf{(gpd)}}$$

$$= \frac{(9\text{ gal})(18{,}000)}{(200{,}000\text{ gpd})}$$

$$= 0.81\text{ mg/L}$$

0.81 mg/L + 0.18 mg/L = 0.99 mg/L

***You can only use NaF in saturators because it has a constant saturation point.**

Fluoride Vocabulary

______1. Anti-siphon device
______2. Backflow
______3. Colorimetric Method
______4. Day Tank
______5. Dental Carries
______6. Diaphragm Pump
______7. Electrode Method (Ion Specific)
______8. Fluorosis
______9. Fluoridation
______10. Fluorosilicic Acid
______11. Gravimetric Dry Feeder
______12. Ion
______13. Ion-Exchange Water Softener
______14. Mottling
______15. Piston Pump
______16. Positive-Displacement Pump
______17. SPADNS Method
______18. Saturator
______19. Sodium Fluoride
______20. Sodium Silicofluoride
______21. Vacuum Breaker
______22. Volumetric Dry Feeder

A. A mechanical device that prevents backflow due to a siphoning action created by a partial vacuum that allows air into the piping system, breaking the vacuum.
B. A piece of equipment that feeds a sodium fluoride solution into water for fluoridation. A layer of sodium fluoride is placed in a plastic tank and water is allowed to trickle through the layer forming a constant solution, which is fed to the water system.
C. The staining of teeth due to excessive amounts of fluoride in the water.
D. Chemical feeder that adds specific weights of dry chemical.
E. A tank used to store a chemical solution of known concentration for feed to a chemical feeder. The tank usually stores sufficient chemical solution to properly treat the system's water for a least one day.
F. Chemical feeder that adds specific volumes of dry chemical.
G. A dry chemical used in the fluoridation of drinking water. It is derived from fluorosilic acid. It is also called Sodium Fluorosilicate.
H. A colorimetric procedure used to determine the concentration of fluoride ion in the water. This is also the name given to he chemical reagent used in the test.
I. The addition of a chemical to increase the concentration of fluoride ion in drinking water to a predetermined optimum level to reduce the incidence of dental caries in children.
J. A dry chemical used in fluoridation of drinking water. It is commonly used in saturators.
K. A type of piston, diaphragm, gear or screw pump that delivers a constant volume with each stroke. These pumps are used as chemical solution feeders.
L. A treatment unit used to remove calcium and magnesium from water using ion-exchange resins.
M. Staining or pitting of the teeth due to excessive amounts of fluoride in the water.
N. A positive displacement pump that uses a piston moving back and forth in a cylinder to deliver a specific volume of liquid.
O. An atom that is electrically unstable because it has more or less electrons than protons.
P. A strongly acidic liquid used to fluoridate drinking water. This chemical was called Hydrofluosilic Acid or "Silly Acid".
Q. A pump in which a flexible rubber, plastic or metal diaphragm is fastened at the edges in a vertical cylinder. As the diaphragm is pulled back, suction is exerted and the liquid is drawn into the pump. When it is pushed forward, the liquid is discharged.
R. Another term for vacuum breaker.

S. The medical term for tooth decay.
T. A hydraulic condition, caused by a difference in pressures that causes nonpotable water or other fluid to flow into a potable water system.
U. A laboratory procedure for determining the fluoride concentration in water. This method has less interference and is generally more accurate than other methods.
V. Based on a reaction in which a dye lake is formed with zirconium and a dye. The colors produced by different concentrations of fluoride ions are all shades of red. A photometer is used to measure the difference in color.

Fluoride Review Questions

1. Name two types of Fluorosis and a description of each.
   -
   -

2. What are the maximum contaminant levels for fluoride as set by the USEPA?

   Primary MCL –

   Secondary MCL –

3. List the two factors that determine the total amount of fluoride a person consumes in a day.
   -
   -

4. List the three fluoride chemicals used in the US and describe each.
   -
   -
   -

5. Of the two types of dry feeders (volumetric and gravimetric) which is more accurate?

6. List five types of safety equipment recommended when handling fluoride chemicals.
   -
   -
   -
   -
   -

7. Why should fluoride be injected as far as possible from the addition of lime or calcium hypochlorite?

8. What is the minimum mixing time recommended for fluoride solutions?

9. Which of the following can cause erroneously high fluoride readings?
   (a) Aluminum
   (b) Chlorine
   (c) Polyphosphates
   (d) Sodium

10. How often should a fluoride test be run on finished water?

11. Which of the following are characteristics of acute toxic exposure to fluoride?
    (a) Mottled teeth
    (b) Sharp, biting pains in the nose
    (c) Vomiting
    (d) b and c
    (e) All of the above

Fluoride Math

1. A water plant produces 2000 gallons per minute and wants to add 1.1 mg/L of fluoride to the water using sodium fluorosilicate. What will the fluoride feed rate be in lbs/day?

2. What is the fluoride feed rate in lbs/day using fluorosilicic acid if the plant rate is 1.0 MGD, the natural fluoride in the water is 0.2 mg/L, and the desired fluoride level is 1.2 mg/L?

3. A water plant produces 1.0 MGD. What will the sodium fluoride feed rate be from a saturator (in gpd) to obtain a 1.0 mg/L fluoride dose in the finished water?

4. A plant uses 65 lbs of sodium fluorosilicate in treating 5,540,000 gallons of water in one day. What is the calculated dosage in mg/L?

Answers to Fluoride Questions

Vocabulary

1. R
2. T
3. V
4. E
5. S
6. Q
7. U
8. M
9. I
10. P
11. D
12. O
13. L
14. C
15. N
16. K
17. H
18. B
19. J
20. G
21. A
22. F

Answers to Fluoride Review Questions

1. Dental Fluorosis – mottling of the teeth due to mild overexposure to fluoride
   Skeletal Fluorosis – crippling disease characterized by rheumatic attacks, pain and stiffness; caused by chronic overexposure to fluoride
2. The primary MCL for fluoride is 4 mg/L to prevent skeletal Fluorosis. The secondary MCL is 2 mg/L to prevent dental Fluorosis.
3. The total amount of water a person consumes in a day and the amount of fluoride in the water determine the total amount of fluoride a person consumes in a day.
4. Sodium Fluoride (NaF) – white, odorless, crystalline solid; solubility is a constant 4% which allows it to be used in a saturator
   Sodium Fluorosilicate (Na_2SiF_6) – white, odorless, crystalline solid; salt of fluorosilicic acid
   Fluorosilicic Acid (H_2SiF_6) – pH of 1-1.5, clear, colorless to slightly yellow liquid
5. A gravimetric feeder is more accurate, but also more expensive.
6. Safety equipment needed when handling fluoride are: shower and eye wash, goggles or face shield, gauntlets, chemical apron, respirator or dust mask
7. Fluoride will form an insoluble precipitate with chemicals containing calcium.
8. A 5 minute mixing time is recommended for fluoride solutions.
9. Polyphosphates can cause erroneously high fluoride readings.
10. Daily fluoride tests are required.
11. Sharp, biting pains in the nose and vomiting may indicate acute toxic fluoride exposure.

Answers to Math

1. 44.19 lbs/day
2. 45.9 lbs/day
3. 55.6 gpd
4. 0.84 mg/L

Section 4

Membrane Filtration

MEMBRANE FILTER

MEMBRANE FILTRATION

- This technology reduces disinfectant demand and by-product formation while at the same time improves disinfection
- Reduces microbial pathogens, particulate matter, organic and inorganic species
- Can also be used in water softening

MEMBRANE SYSTEMS

- Provide precision barriers to contaminants
- Allow for rapid modular capacity expansions
- Allow for treatment of lower quality source water

COMPARED TO CONVENTIONAL TREATMENT

- Provides more consistent water quality
- Requires less chemicals
- Requires smaller equipment footprint

MEMBRANE PROCESSES

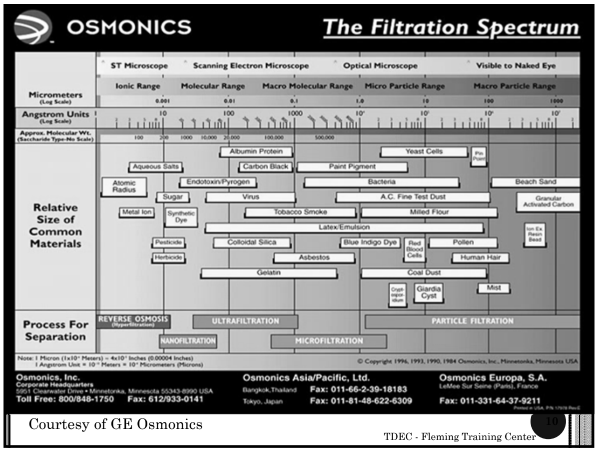
- Water is forced through a porous membrane under pressure while suspended solids, larger molecules or ions are held back or rejected
- Two types
  - Pressure driven processes
  - Electric driven processes

PRESSURE-DRIVEN PROCESSES

- Uses a semi permeable membrane to filter water
- Microfiltration (MF) or ultrafiltration (UF) acts as a fine sieve to retain particulate matter while water and soluble components pass through the membrane as filtered water
- The pore size controls the amount of the particulates removed

PRESSURE-DRIVEN PROCESSES

- Four general processes
  - Microfiltration (MF)
  - Ultrafiltration (UF)
  - Nanofiltration (NF)
  - Reverse Osmosis (RO)



Courtesy of GE Osmonics

PRESSURE-DRIVEN PROCESSES

- Microfiltration (MF)
  - pore sizes range from 0.03-1.2 micron
  - effective barrier for particles, bacteria and protozoan cysts
  - operating pressures are 5-30 psi
- Ultrafiltration (UF)
  - retains particulates, bacteria, protozoa, viruses and organic molecules
  - operating pressures are 10-50 psi

PRESSURE-DRIVEN PROCESSES

- Nanofiltration (NF)
  - retains dissolved organic compounds in the range of 200-400 D MWCO (molecular weight cut-off)
  - these membranes are used often to soften water
  - remove DBP precursors, like humic acid
  - operating pressure ranges are 50-150 psi
- Reverse Osmosis (RO)
  - removes essentially all organic and inorganic elements
  - operating pressures are 300-600 psi

REMOVAL OF CONTAMINANTS

Contaminant	MF	UF	NF	RO
Suspended solids	Yes	Yes	Yes	Yes
Dissolved solids	No	No	Some	Yes
Bacteria and cysts	Yes	Yes	Yes	Yes
Viruses	No	Yes	Yes	Yes
Dissolved organic matter	No	No	Yes	Yes
Iron and manganese	Yes, if oxidized		Yes*	Yes*
Hardness	No	No	Yes	Yes

*High levels will foul these membranes

ELECTRIC-DRIVEN PROCESSES

- There are two processes that use an electric current to move ions across a membrane
  - Electrodialysis
  - Electrodialysis reversal
- These types are normally used to treat brackish water for potable use

ELECTRIC-DRIVEN PROCESSES

- Electrodialysis (ED)
  - Ions are transferred through a membrane due to a direct current applied to the water
  - The current carries ions through the membrane from a less concentrated solution to a greater concentrated solution
- Electrodialysis Reversal (EDR)
  - Very similar to ED except the polarity of the direct current is reversed periodically
  - Provides automatic flushing of scale-forming materials from the membrane surface

---

MICROFILTRATION MEMBRANES

- Pore sizes can range from 0.03 to 1.2 micron
- Most robust are those with 0.03 to 0.2 micron pore size made from polyvinylidene fluoride (PVDF)
  - These are resistant to oxidants like chlorine, ozone, and permanganate
  - Service life ranges from 5-10 years

CLEANING OF MEMBRANE

- Chemical oxidants can be used to remove particulates from the membrane
  - Chlorine or citric acid
- Reverse flow is generated using water or water with oxidants, acids or compressed air

---

NF AND RO MEMBRANES

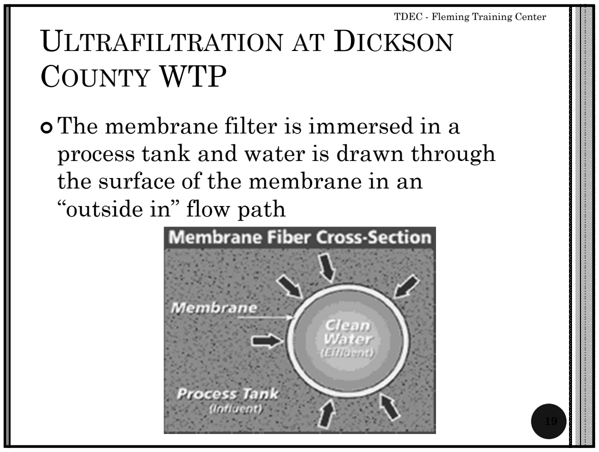
- Two membranes most commonly used
  - Cellulose acetate
  - Polyamide-composite
- Every type has its own characteristics
  - efficiency of salt rejection
  - pH operating range
  - Resistance to oxidant degradation
  - Susceptibility to biological attack
  - Resistance to hydrolysis

RO OPERATING PROBLEMS

- Premature fouling
- Flux decline
- Unit shutdown

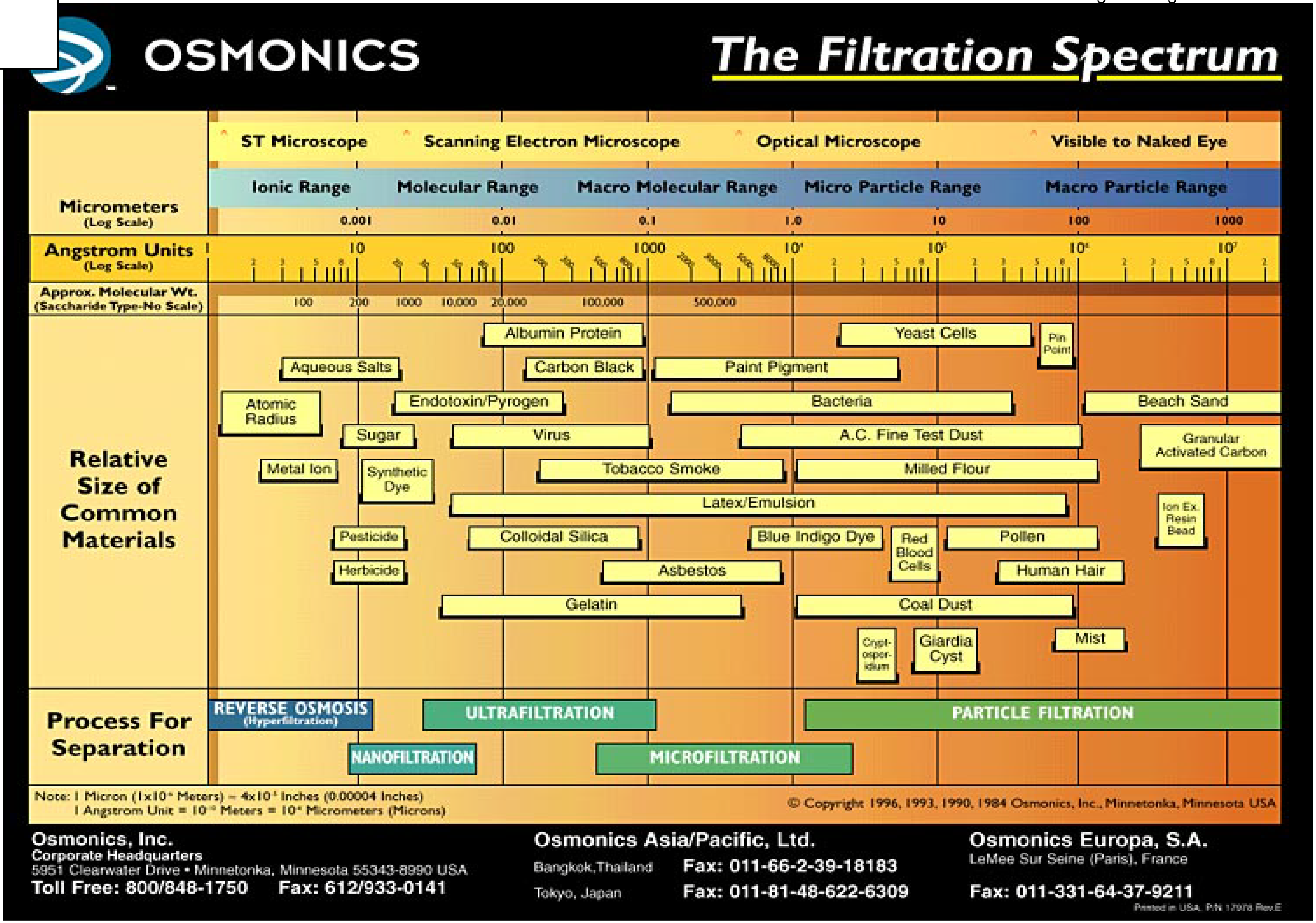
DICKSON WATER TREATMENT PLANT

- Plant was built in 2003
- Pumping water since December 2003
- First plant in Tennessee to use membrane filtration
- Raw water turbidity averages 80 NTU
- Finished water turbidity averages 0.02 NTU



ULTRAFILTRATION AT DICKSON COUNTY WTP

- The membrane filter is immersed in a process tank and water is drawn through the surface of the membrane in an “outside in” flow path


OSMONICS
The Filtration Spectrum
ST Microscope
Scanning Electron Microscope
Optical Microscope
Visible to Naked Eye
Ionic Range
Molecular Range
Macro Molecular Range
Micro Particle Range
Macro Particle Range
Micrometers (Log Scale)
0.001
0.01
0.1
1.0
10
100
1000
Angstrom Units (Log Scale)
1
10
100
1000
10⁴
10⁵
10⁶
10⁷
Approx. Molecular Wt. (Saccharide Type-No Scale)
100
200
1000
10,000
20,000
100,000
500,000
Relative Size of Common Materials
Albumin Protein
Yeast Cells
Pin Point
Aqueous Salts
Carbon Black
Paint Pigment
Atomic Radius
Endotoxin/Pyrogen
Bacteria
Beach Sand
Sugar
Virus
A.C. Fine Test Dust
Granular Activated Carbon
Metal Ion
Synthetic Dye
Tobacco Smoke
Milled Flour
Latex/Emulsion
Ion Ex. Resin Bead
Pesticide
Colloidal Silica
Blue Indigo Dye
Red Blood Cells
Pollen
Herbicide
Asbestos
Human Hair
Gelatin
Coal Dust
Crypt-ospor-idium
Giardia Cyst
Mist
Process For Separation
REVERSE OSMOSIS (Hyperfiltration)
ULTRAFILTRATION
PARTICLE FILTRATION
NANOFILTRATION
MICROFILTRATION
Note: 1 Micron (1x10⁻⁶ Meters) ≈ 4x10⁻⁵ Inches (0.00004 Inches)
1 Angstrom Unit = 10⁻¹⁰ Meters = 10⁻⁴ Micrometers (Microns)
© Copyright 1996, 1993, 1990, 1984 Osmonics, Inc., Minnetonka, Minnesota USA
Osmonics, Inc.
Corporate Headquarters
5951 Clearwater Drive • Minnetonka, Minnesota 55343-8990 USA
Toll Free: 800/848-1750 Fax: 612/933-0141
Osmonics Asia/Pacific, Ltd.
Bangkok,Thailand Fax: 011-66-2-39-18183
Tokyo, Japan Fax: 011-81-48-622-6309
Osmonics Europa, S.A.
LeMee Sur Seine (Paris), France
Fax: 011-331-64-37-9211
Printed in USA. P/N 17978 Rev.E

Section 5

Softening

Softening

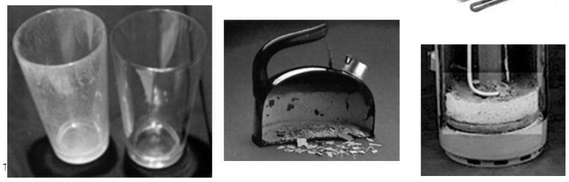
Hardness
Lime-softening
Ion Exchange

Objectives

- Effects of hard water
- Minerals causing hard water
- Various types of hardness
- Equipment used for softening
- Operating problems and considerations
- Operational control tests in softening
- Handling and safety of chemicals

Water Hardness

- Most common customer complaints
  - Scale formation on cooking utensils, water heaters, and water fixtures
  - Increases amount of soap needed



Water Hardness

- Hardness is picked up as water passes over geological formations of limestone, dolomite, and other magnesium-bearing minerals
- Groundwater usually has more hardness than surface water because of the extended period of time it is exposed to the geological formation

Water Hardness

- Main hardness causing compounds:
  - Calcium bicarbonate - $Ca(HCO_3)_2$
  - Magnesium bicarbonate - $Mg(HCO_3)_2$
  - Calcium sulfate - $CaSO_4$
    - gypsum
  - Magnesium sulfate - $MgSO_4$

Water Hardness

Expressing Hardness Concentration

- Hardness is expressed as mg/L as $CaCO_3$
- Also expressed as grains per gallon
  - 17.12 mg/L = 1 grain per gallon
  - More important when doing ion exchange

Types of Water Hardness

Calcium vs. Magnesium Hardness

- Calcium hardness caused by calcium
- Magnesium hardness caused by magnesium
- Total hardness = Ca hardness + Mg hardness

Types of Water Hardness

Carbonate vs. Noncarbonate Hardness

- Carbonate hardness includes carbonate and bicarbonate species of Mg
  - Sometimes called temporary hardness because it can be settled out by heat
- Noncarbonate hardness includes all other Ca and Mg salts
  - Also called permanent hardness because it cannot be removed or precipitated by heat
- Total hardness = Ca hardness + bicarbonate hardness

Objections to Hard Water

- Scale formation
  - Decreases flow through pipes
  - Leaves scale on dishes
  - Magnesium hydroxide precipitates at 140-150°F, which increases heating costs for water heaters
- Effect on Soap
  - Causes "soap scum"
  - Reduces soap efficiency
  - Synthetic detergents have sequestering agents that tie up the hardness ions

Objections to Soft Water

- Leaves slippery feeling on skin
- Usually very corrosive, even moderately soft water can be corrosive to plumbing and pipes
- Steps should be taken to reduce corrosion and ensure compliance with the Lead & Copper Rule

Deciding to Soften

- Chemical precipitation method will also remove iron and manganese, radionuclides, etc
- Cost may be too great to justify to customers
- Lime-softening occurs in pH range of 10-11
  - Same pH for Fe & Mn removal

Softening Process

Chemical Precipitation

- Convert from soluble to insoluble for removal by sedimentation or filtration
- Methods:
  - Lime softening
  - Lime-soda ash softening
  - Excess lime treatment
  - Caustic-soda treatment

Softening Process

Lime Softening

- Used if there is little or no noncarbonate hardness
- Noncarbonate magnesium hardness is precipitated by lime, but it creates calcium noncarbonate hardness as a by product that requires soda ash for precipitation

Softening Process

Lime-Soda Ash Softening

- Most commonly used process
- The minerals are precipitated and removed by conventional processes
- Does not remove all hardness
  - 50 to 85 mg/L remains
- Removes noncarbonate calcium hardness

Softening Process

Excess Lime Treatment

- If magnesium hardness exceeds 40 mg/L, more lime must be added to reduce it
- pH must be higher than 10.6 to remove magnesium hydroxide

Softening Process

Split Treatment

- Only a portion of the water is treated, saving chemical costs
- Water combined after bypass
- Must bypass all processes including coagulation

Softening Process

Caustic Soda Treatment

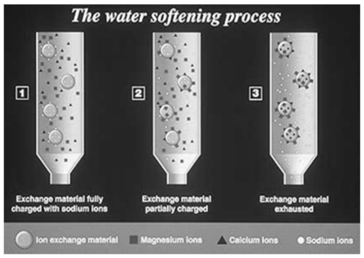
- Removes carbonate and noncarbonate hardness
- More expensive than other methods
- Increases TDS in finished water
- Produces less sludge
- Chemical is easier to store, feed, and handle

Softening Process

Ion Exchange

- Requires an ion exchange medium, called a <u>resin</u>
  - Releases the nonhardness-causing ion attached to it in favor of the hardness causing ion present in the raw water
- All hardness is removed
- Very corrosive water must be combined with some unsoftened water to stabilize it

Softening Process



Ion Exchange

Advantages

- Much lower initial cost and space
- Easy to operate
- Salt is only chemical needed
- Removes all types of hardness

Disadvantages

- Must be preceded by coag/floc/sed
- Water will be very corrosive
- Adds sodium to water

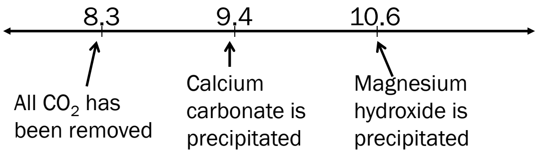
Softening Process

Chemical Reactions

- CO_2 will remove lime
  - Aerate to remove CO_2
  - Add excess lime

Softening Process

pH Scale



Softening Process

Recarbonation

- Softened water has a pH near 11
  - Saturated with $CaCO_3$
- Recarbonation is the process of adding CO_2 to stabilize water
- pH drops to 8.6
  - Small amount of hardness formed
- Detention time of 15-30 minutes

Softening Process

Operation of Softening

- Add softening chemicals
- Conventional treatment or upflow clarifiers can be used
- Precipitates from softening can clog filters
  - May have to backwash more frequently
- Calculate proper dosage of chemicals for type of hardness present by jar test

Softening Process

Regulations

- Increased pH from softening increases THM formation potential
- Softened water may affect stabilization
  - Lead and Copper compliance

Softening Process

Operating Problems

- Suspended $CaCO_3$ can pass through to filters
  - Scale formation
  - Clogging
- Must properly stabilize water

Softening Process

Interferences

- Disinfection is less effective at higher pH
  - Requires longer detention time

Softening Process

Record Keeping

- Pounds of chemical used
- Amount of water treated
- Lab test results at various stages
- Sludge protection

Softening Vocabulary

______1. After-precipitation
______2. Calcium Carbonate
______3. Calcium Hardness
______4. Carbonate Hardness
______5. Cation Exchange
______6. Centrate
______7. Decant
______8. Excess-Lime Treatment
______9. Hardness
______10. Ion-Exchange Process
______11. Lime-Soda Ash Method
______12. Loading Rate
______13. Magnesium Hardness
______14. Milk of Lime
______15. Noncarbonate Hardness
______16. Permanent Hardness
______17. Polystyrene Resin
______18. Precipitate
______19. Quicklime
______20. Recarbonation
______21. Regeneration
______22. Resin
______23. Sequestering Agent
______24. Slake
______25. Sludge
______26. Sludge Blowdown
______27. Stabilization
______28. Temporary Hardness
______29. Trihalomethanes

A. Another term for noncarbonate hardness, it does not precipitate when water is boiled.
B. The controlled withdrawal of sludge from a solids-contact basin to maintain the proper level of settled solids in the basin.
C. The addition of water to quicklime, CaO, to form calcium hydroxide, $Ca(OH)_2$, which can then be used in the softening or stabilization process.
D. A characteristic of water, caused primarily by the salts of calcium and magnesium.
E. The continued precipitation of a chemical compound, primarily $CaCO_3$, after leaving the sedimentation or solids-contact basin.
F. The portion of total hardness caused by calcium compounds such as calcium carbonate and calcium sulfate.
G. The most common resin used in the ion exchange process.
H. The reintroduction of carbon dioxide into the water, either during or after lime-soda ash softening, to lower the pH of the water.
I. A process used to remove carbonate and noncarbonate hardness from water.
J. Another term for carbonate hardness, derived from the fact that the hardness causing carbonate compounds precipitate when water is heated.
K. In water treatment, the synthetic, bead-like material used in the ion exchange process.
L. A process used to remove hardness from water that depends upon special materials known as resins. The resins trade no hardness-causing ions for the hardness-causing ions of calcium and magnesium.
M. The water that is separated from sludge and discharged from a centrifuge.
N. The principal hardness- and scale-causing compound in water. $CaCO_3$
O. To draw off the liquid from a basin or tank without stirring up the sediment in the bottom.
P. The lime slurry formed when water is mixed with calcium hydroxide.

Q. Another name for calcium oxide, which is used in water softening and stabilization.
R. A chemical compound such as EDTA or certain polymers that chemically tie up other compounds or ions so that they can't be involved in chemical reactions.
S. The water treatment process intended to reduce the corrosive or scale-forming tendencies of water.
T. (1) A substance separated from a solution or suspension by a chemical reaction. (2) To form such a substance.
U. The portion of total hardness caused by magnesium compounds such as magnesium carbonate or magnesium sulfate.
V. Hardness caused by salts of calcium and magnesium.
W. The accumulated solids separated from water during treatment.
X. Hardness caused primarily by compounds containing carbonate (CO_3), such as calcium carbonate and magnesium carbonate.
Y. A modification of the lime-soda ash method that uses additional lime to remove magnesium compounds.
Z. Ion exchange involving ions that have positive charges, such as calcium and sodium.
AA. The flow rate per unit area at which the water is passed through a filter or ion exchange unit.
BB. The process of reversing the ion exchange softening reaction of ion exchange materials. Hardness ions are removed from the used materials and replaced with nontroublesome ions, thus rendering the materials fit for reuse in the softening process.
CC. A compound formed when natural organic substances from decaying vegetation and soil (such as humic and fulvic acids) react with chlorine.

Softening Review Questions

1. Explain the most important difference in carbonate hardness and noncarbonate hardness.

2. What are the names and formulas of the two principal hardness-causing compounds that settle out during the lime-soda ash process?

3. List some characteristics of hard water.

4. List some characteristics of soft water.

5. How does ion exchange softening process work?

6. In what ways can the softening process affect other treatment plant processes?

7. What is recarbonation and why is it necessary?

Softening Answers

Matching

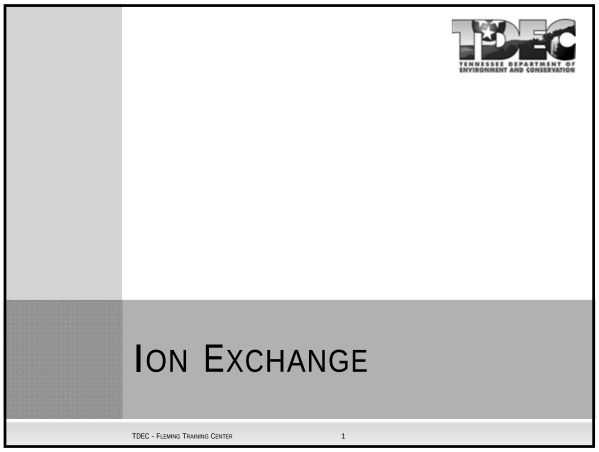
1. E
2. N
3. F
4. X
5. Z
6. M
7. O
8. Y
9. D
10. L
11. I
12. AA
13. U
14. P
15. V
16. A
17. G
18. T
19. Q
20. H
21. BB
22. K
23. R
24. C
25. W
26. B
27. S
28. J
29. CC

Review Questions

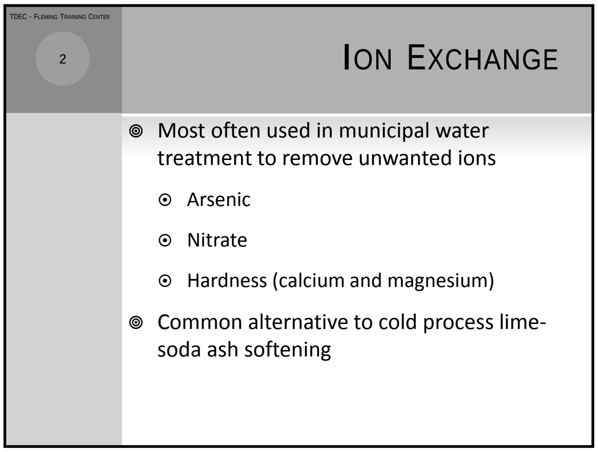
1. Carbonate hardness is caused primarily by the bicarbonate salts of calcium and magnesium, which are calcium bicarbonate and magnesium bicarbonate. Calcium and magnesium combined with carbonate also contribute to carbonate hardness. Noncarbonate hardness is a measure of calcium and magnesium slats other than carbonate and bicarbonate salts.
2. calcium carbonate – $CaCO_3$
   magnesium hydroxide – $Mg(OH)_2$
3. scale forming on cooking utensils, hot water heaters and water fixtures; increase amount of soap needed
4. leaves skin feeling slippery; very corrosive
5. replaces Ca and Mg with Na from resin
6. can increase TDS, may have to aerate to remove CO_2
7. recarbonation is the reintroduction of carbon dioxide into the water, either during or after lime-soda ash softening, to lower the pH of the water; this stabilizes water

Section 6

Ion Exchange

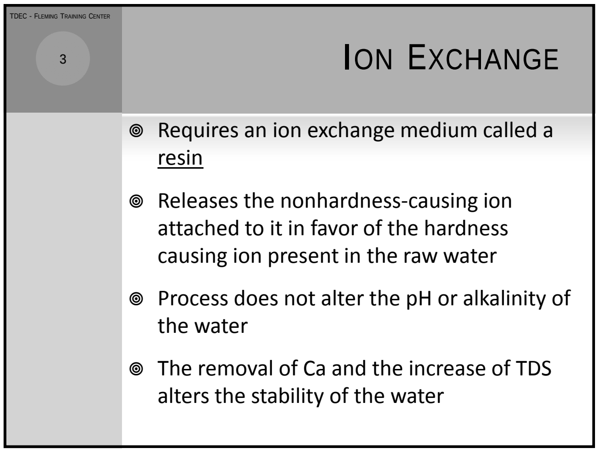


ION EXCHANGE



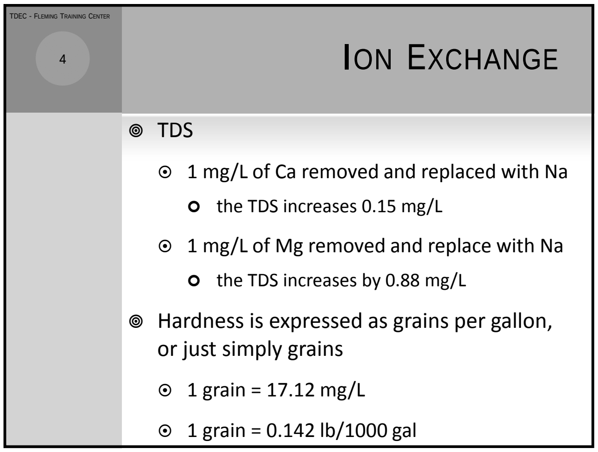
ION EXCHANGE

- Most often used in municipal water treatment to remove unwanted ions
  - Arsenic
  - Nitrate
  - Hardness (calcium and magnesium)
- Common alternative to cold process lime-soda ash softening



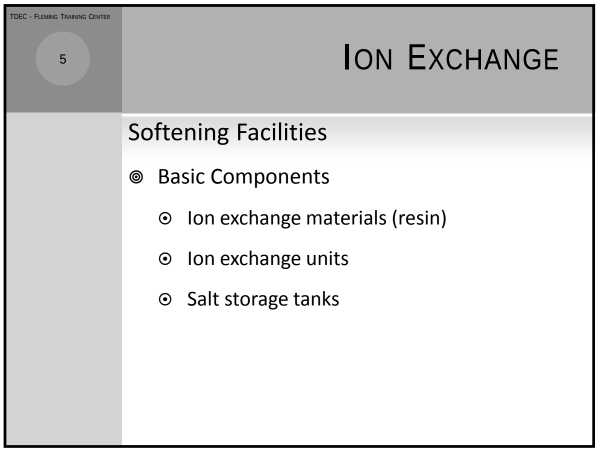
ION EXCHANGE

- Requires an ion exchange medium called a <u>resin</u>
- Releases the nonhardness-causing ion attached to it in favor of the hardness causing ion present in the raw water
- Process does not alter the pH or alkalinity of the water
- The removal of Ca and the increase of TDS alters the stability of the water



ION EXCHANGE

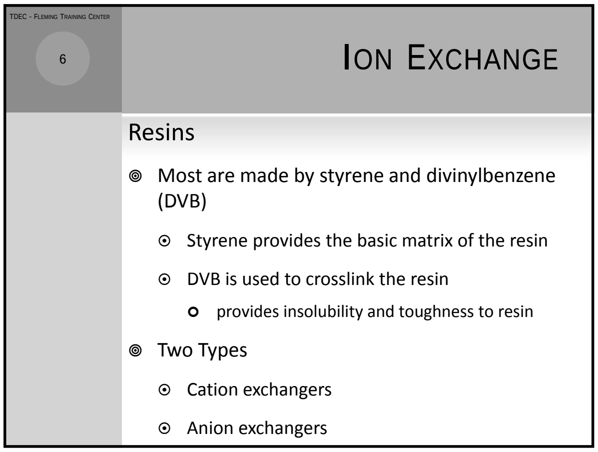
- TDS
  - 1 mg/L of Ca removed and replaced with Na
    - the TDS increases 0.15 mg/L
  - 1 mg/L of Mg removed and replace with Na
    - the TDS increases by 0.88 mg/L
- Hardness is expressed as grains per gallon, or just simply grains
  - 1 grain = 17.12 mg/L
  - 1 grain = 0.142 lb/1000 gal



ION EXCHANGE

Softening Facilities

- Basic Components
  - Ion exchange materials (resin)
  - Ion exchange units
  - Salt storage tanks



ION EXCHANGE

Resins

- Most are made by styrene and divinylbenzene (DVB)
  - Styrene provides the basic matrix of the resin
  - DVB is used to crosslink the resin
    - provides insolubility and toughness to resin
- Two Types
  - Cation exchangers
  - Anion exchangers

Ion Exchange Resins

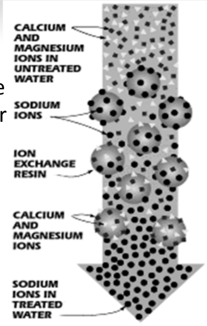
Cation Exchangers

- Positively charged ions that migrate toward the cathode (Ca^+ and Mg^+)
- Used to exchange unwanted positively charged cations with cation species
  - i.e. sodium (Na^+) or hydrogen (H^+)
- Strong-acid cation exchangers work over the entire pH range
- Weak-acid cation exchangers only operate above pH 4

Ion Exchange Resins

Cation Exchangers

- Ca and Mg ions are exchanged for Na on the resin to soften the water
  - Ca is calcium
  - Mg is magnesium
  - Na is sodium



Ion Exchange Resins

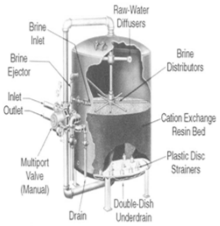
Anion Exchangers

- Negatively charged ions that migrate toward anode
  - i.e. nitrate (NO_3) and sulfate(SO_4)
- Used to exchange unwanted anions with anion species
  - i.e. chloride (CL^-) or hydroxide (OH^-)
- Strong-acid anion exchangers operate over the entire pH range
- Weak-acid anion exchangers do not remove anions above pH 6

Ion Exchange Units

- Resemble pressure filters
- Tank interior coated with a special lining to prevent corrosion caused by the brines (high salt concentration) used in regenerations
- Upflow and downflow units available

Ion Exchange Units



Courtesy of US Filter/Permutit

FIGURE 12-4 Vertical-downflow ion exchange unit

Components

- Hard-water inlet
- Soft-water outlet
- Wash-water inlet and collector
- Brine inlet and distribution system
- Brine and rinse-water outlet
- Rate-of-flow controllers
- Sampling taps
- Underdrain systems
- Graded Gravel

Ion Exchange

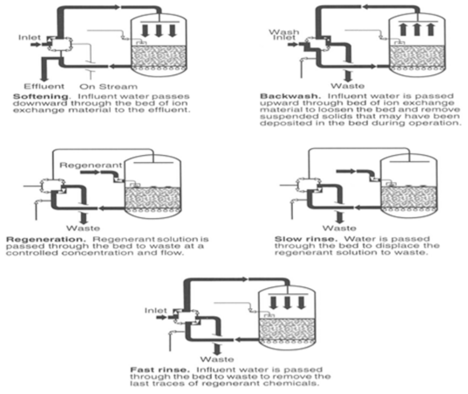
Regenerant Storage Tanks

- To form brine that is used to regenerate the resin, sodium chloride or potassium chloride are the most common salts used in water softening
- Brine is heavier than water
  - To get the highest concentration brine, you would pump from the bottom of the tank

ION EXCHANGE

Operation of Processes

- Four basic cycles in the water softening ion exchange process:
    - Softening
    - Backwash
    - Regeneration
    - Rinse



Softening. Influent water passes downward through the bed of ion exchange material to the effluent.

Backwash. Influent water is passed upward through bed of ion exchange material to loosen the bed and remove suspended solids that may have been deposited in the bed during operation.

Regeneration. Regenerant solution is passed through the bed to waste at a controlled concentration and flow.

Slow rinse. Water is passed through the bed to displace the regenerant solution to waste.

Fast rinse. Influent water is passed through the bed to waste to remove the last traces of regenerant chemicals.

Courtesy of Infilco Degremont Inc., Richmond, Va.

FIGURE 12–5 Four cycles in the ion exchange process

ION EXCHANGE CYCLES

Backwash

- Loosens the resin that has compacted
- Randomly mixes the resin
- Removes any silt, dirt, precipitated iron
- Bed is expanded 50 - 75%
- Typical flow rates are 5-8 gpm/ft^2

ION EXCHANGE CYCLES

Regeneration

- Requires 5 - 15% of the product water
- Also called *brining*
    - Displaces ions held onto the resin sites
- Follows backwash

ION EXCHANGE CYCLES

Regeneration

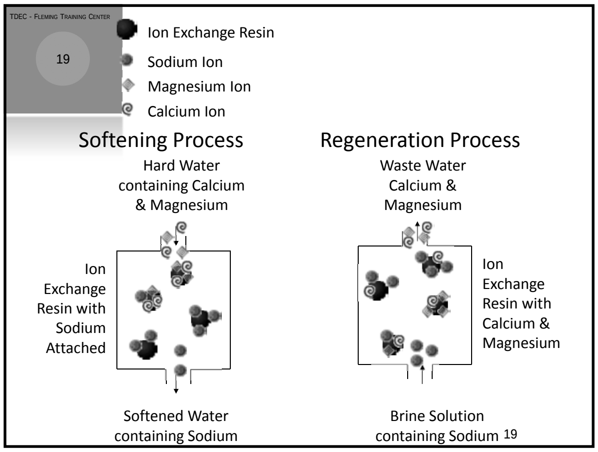
- The resin holds the unwanted ion temporarily, releases it when a regenerant solution is used to restore resin to its original form
- The process of regeneration allows the resin to be reused

ION EXCHANGE CYCLES

- Regeneration
- The regeneration process using sodium chloride , or salt, as the regenerant involves the following chemical reaction:

$$CaX + 2NaCl \longleftrightarrow CaCl_2 + Na_2X$$

$$MgX + 2NaCl \longleftrightarrow MgCl_2 + Na_2X$$



Ion Exchange Resin

Sodium Ion

Magnesium Ion

Calcium Ion

Softening Process

Hard Water containing Calcium & Magnesium

Ion Exchange Resin with Sodium Attached

Softened Water containing Sodium

Regeneration Process

Waste Water Calcium & Magnesium

Ion Exchange Resin with Calcium & Magnesium

Brine Solution containing Sodium

ION EXCHANGE CYCLES

- Rinse
  - Removes excess regenerant from the resin bed
  - Typically uses raw water
  - Softening operations usually use both a slow and a fast rinse
- Service
  - Operational cycle (softening process, demineralization process or the process of removal of unwanted contaminants)

REGENERANT DISPOSAL

- Options evaluated before process chosen
  - Cost of disposal can effect selection of softening process
- Primarily dependent on state pollution control agency
- TDS runs between 35,000 - 45,000 mg/L
  - Can cause pipe corrosion and upset biological processes in wastewater treatment plants

REGENERANT DISPOSAL

- If not properly disposed of, negative effects can occur
  - Land application
    - can make unusable for agriculture
  - Discharged to seepage bed
    - can contaminate aquifers

OPERATING PROBLEMS

- Resin deterioration
- Iron fouling
- Turbidity, organic and bacteriological slime fouling
- Removal of arsenic, barium, radium, nitrate and uranium
- Unstable water

OPERATING PROBLEMS

Resin Deterioration

- Designed to last 15-20 years
- Can come under attack by oxidizers
- Deterioration due to
  - Physical degradation to smaller particles
  - Decross-linking and subsequent swelling
  - Loss of breakthrough capacity
  - Loss of acidity of functional groups
  - Poisoning of functional groups
  - Fouling due to precipitation in or on the exchanger surface

OPERATING PROBLEMS

Iron Fouling

- Uncomplexed soluble iron is cationic in nature and is removed by cation exchangers
- Iron complexed with organic matter is anionic and is not removed by cation exchange
- Iron can form insoluble hydroxides when exposed to air and precipitate on cation exchange resins, which decreases the resins' exchange capacity
- Best solution: remove iron before ion exchange

OPERATING PROBLEMS

Turbidity, Organic Color and Bacterial-Slime Fouling

- Turbidity and bacterial slimes, measured by HPC (heterotrophic plate count), in raw water will coat the resin, decrease exchange capacity and cause excessive head loss
- Backwashing removes some (becomes tightly held onto the resins)
- Highly colored water, highly turbid water and water with an HPC concentration require pretreatment

OPERATING PROBLEMS

Removal of As, Ba, & Ra

- Arsenic (As)
  - Exists as arsenite (AsO_3) and arsenate (AsO_4)
  - Soluble forms removed with strong-base anion exchange in chloride form when waters are low in divalent anions, such as sulfate
- Barium (Ba) & Radium (Ra)
  - Found frequently in groundwater
  - Exceed MCL in many wells
  - Removed by strong-acid cation exchangers in the sodium or hydrogen cycle

OPERATING PROBLEMS

Removal of NO_3 and U

- Nitrate (NO_3)
  - Found in shallow wells in rural areas
    - agricultural contaminant
  - Present in excess of MCL, 10 mg/L
  - Strong-base anion exchange process
    - uses a single bed chloride cycle
- Uranium (U)
  - Cation and anion exchange resins used successfully
  - Strong-base anion exchange in the chloride cycle is better and more cost-effective

OPERATING PROBLEMS

Unstable Water

- Water softened by the ion exchange process is corrosive as tested by the Langelier saturation index
- To help this, there are 2 options:
  - Blending raw water and treated water
  - Adding chemicals to provide corrosion control

RECORD KEEPING

- Records kept for tracking performance of the softening process and for ordering chemicals
- Each operator should develop the records required

Section 7

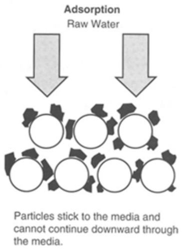
Adsorption

ADSORPTION

OBJECTIVES

- The origin of organic chemicals in groundwater and surface water
- The methods of removing organic chemicals
- The principles of adsorption
- Types of activated carbon
- Operation and safety of activated carbon

ADSORPTION



- Adsorption is the process of removing contaminants, usually organic, from water by adhering them onto the surface of an adsorbent, such as activated carbon

ORGANICS IN WATER

- Organics causing taste, odor, & color
- Synthetic organics (SOC's) that may cause adverse health effects; some have established MCL's
- Precursors to DBPs
- DBPs that have been formed

ORIGIN OF ORGANICS

- "Organic" means containing carbon
- Naturally occurring organics come from soil and vegetation
- Synthetic organics include pesticides, industrial chemicals, oils, etc.

ORGANICS IN SURFACE WATER

- Many water systems that use surface sources have bothersome tastes, odors or color in their source water at some time or another
- Precursors for the development of THM's and other DBP's are present in most surface waters

ORGANICS IN GROUNDWATER

- Groundwater does not usually contain much organic matter
- Shallow wells, on occasion, have had relatively high levels of humic substances
- Groundwater can become contaminated with SOC's (synthetic organic chemicals) such as pesticides, solvents, etc.
- In a great number of locations the concentration has been high enough that the well has been discontinued or special treatment began to remove the SOC's

ORGANIC CHEMICAL REMOVAL

- The best place to control organics in drinking water is at the source.
  - Control of watershed
  - Control of algae growth

REMOVAL BY OTHER PROCESSES

- Oxidation
  - chlorine, potassium permanganate, chlorine dioxide or ozone
- Aeration combined with coagulation, flocculation, sedimentation, filtration
- Adsorption
  - activated carbon

PRINCIPLE OF ADSORPTION

- Organic contaminants adhere to surface of adsorbent
- Adsorbent must provide very large surface area for contaminant to adhere - porous
- Activated carbon has large surface area and varying pore sizes
  - 1 lb has a surface area of 150 acres
- Carbon is activated by heating to high temp in presence of steam
- Surface area is increased
  - holes and crevices formed for particle attachment

SOURCE OF ACTIVATED CARBON

- Can be made from a variety of materials - wood, peach pits, coconut shells, coal, peat, petroleum residues; usually comes from coal
- Coal is converted to carbon by heating without oxygen
- Activated by exposure to steam-air mixture
- Crushed and screened to get proper particle size - powder or granule

POWDERED ACTIVATED CARBON

- Can be fed dry or in a slurry with water; doesn't mix well with water - hydrophobic
- Most commonly used to control tastes & odors
- Cheaper than GAC, can be fed only when needed
- Most common problem is handling
- Apply near mixing facilities - carbon must come in contact with substances to be removed

DRY FEED SYSTEMS

- If a plant uses PAC only during certain times of the year, dry feed may be best
- Feeder feeds to tank or ejector, carbon is mixed with water to form a thin slurry
- Use only feeder specifically designed for carbon
- Feeder should be capable of operating over wide range of dosages
- Feed rate doesn’t have to be precise

SLURRY FEED SYSTEMS

- Systems using PAC continuously can have slurry feed system
- High speed mixer required to form slurry
- After slurry is formed, low speed mixer maintains slurry - requires constant mixing
- Fed from day tank by volumetric feeder

APPLICATION POINT OF PAC

- Contact time should be at least 15 minutes with carbon in suspension before any chlorine is added
- PAC particles lose ability to adsorb if coated with coagulant or other chemicals
- PAC will adsorb chlorine (possibly increasing Cl_2 demand), $KMnO_4$, ozone, chlorine dioxide
- If fed too near filters, may pass through creating black water problems
- Raw intake or flash mix may be best application point if adequate mixing and detention time are available

DETERMINING PAC DOSAGES

- Jar test - for taste & odor removal, use odor test on jar samples
- Use results on plant-scale, monitor raw and finished water with odor test (TON) on each shift, or at least once daily

RECORD KEEPING - PAC

- Keep track of PAC usage for future reference
  - Time of year
  - Effective dose
  - Type of taste or odor problems
  - TON values for raw and finished water

GRANULAR ACTIVATED CARBON

- For continuous removal of organics from groundwater or surface water
- Used as filter media or in contactors
- Higher installation and operating costs
- After installation, requires little maintenance, no handling
- More efficient than PAC at removing SOCs

GAC AS FILTER MEDIA

- Can be installed in place of sand or anthracite in open filters
- Can be added over media
- Acts as adsorbent and filter media
- Life of GAC depends on type and amount of organics being removed
- Coag/floc/sediment process should be optimized to increase bed life
- Proper backwashing is crucial

GAC AS FILTER MEDIA

- Rapid growth of bacteria can occur due to adsorbed organics - increased chlorine demand
- Recommended that bed be at least 24 inches thick

GAC CONTACTORS

- Enclosed pressure tanks used after filtration
- More practical for high organic loading
- Can remove DBPs before water enters distribution system
- Can remove SOCs from contaminated groundwater
- Can be used for emergency treatment - temporary units set up
- Bacteria growth may be problem

REPLACING GAC

- When exhausted, GAC is removed and replaced, not usually recharged
- Reactivation consists of passing the spent carbon through a regeneration furnace, where it is heated to 1500-1700°F (820-930°C), which oxidizes the impurities
- Disposal can be an issue if used to remove radionuclides from groundwater - low level radioactive waste
- Must be backwashed to remove trapped air and small carbon particles (carbon fines)

APPLICATION POINT OF GAC IN FILTERS

- Contact time - also called the empty bed contact time (EBCT) - volume of GAC media divided by flow rate
- Filtration rate usually about 2 gpm/ft^2, EBCT is around 7.5 - 9 minutes
- Backwashing - try to prevent media loss

APPLICATION POINT OF GAC IN CONTACTORS

- Tank size designed for proper contact time
- Tanks can be set up in parallel so they aren’t exhausted at same time
- Tanks backwashed to remove suspended matter and carbon fines
- Finished water samples analyzed for organic chemicals , indicates when GAC needs to be replaced

TESTS OF GAC IN FILTERS

- Core samples taken every six months
- Check for carbon loss during backwashing
- Run odor test and Heterotrophic Plate Count daily

TESTS OF GAC IN CONTACTORS

- Test for organic chemicals in finished water
- Head loss monitored for backwash purposes
- Core samples taken every 3 months
- HPC before and after chlorination

RECORD KEEPING - GAC

- Keep track of amount of water processed, date GAC was replaced
  - Results of organics tests
  - Carbon level loss
  - Dates when media and GAC replaced
  - Results of periodic TON tests
  - Results of raw and finished water organic concentrations

STORAGE

- PAC and GAC should be stored on pallets in clean, dry area with circulation underneath and access aisles for inspection, not over 6 feet high
- Control dust
  - near motors can increase fire hazard
- No smoking in carbon storage area
- Storage room should be fire-proof, with self-closing doors

STORAGE

- Burns like charcoal, no smoke or flame
- Fire difficult to detect and extinguish - use carbon dioxide or foam, not stream of water
- Do not store near gasoline, oils, chlorine (HTH), potassium permanganate
- Explosion-proof light fixtures, electrical wiring
- Tanks should be vented, have dust collectors

PAC AND GAC SAFETY

- Use dust masks, gauntlets, aprons
- Wet activated carbon removes oxygen from the air
- When working with GAC tanks, requires circulation of air to prevent O_2 loss; buddy system
- Exposure to skin not dangerous, but difficult to wash off - inhalation may cause respiratory problems

Adsorption Vocabulary

______1. Activated Alumina
______2. Activated Carbon
______3. Activation
______4. Adhesion
______5. Adsorbent
______6. Adsorption
______7. Arching
______8. Bed Life
______9. Carcinogen
______10. Contactor
______11. Eductor
______12. Empty Bed Contact Time
______13. Granular Activated Carbon (GAC)
______14. Herbicide
______15. Humic Substance
______16. Insecticide
______17. Nuclei
______18. Organic Substance
______19. Pesticide
______20. Powdered Activated Carbon (PAC)
______21. Precursor Compound
______22. Reactivate
______23. Slurry
______24. Synthetic Resin
______25. Total Organic Carbon (TOC)
______26. Trihalomethane (THM)

A. A thin mixture of water and any insoluble material.
B. The center of atoms, made up of positively charged particles called protons and uncharged neutrons.
C. The time it takes for a bed of adsorbent to lose its adsorptive capacity.
D. A compound, usually synthetic organic, used to stop or retard plant growth.
E. Activated carbon in a granular form, which is used in a bed, much like a conventional filter, to adsorb organic substances from water.
F. Sticking together.
G. A chemical compound that can cause cancer in animals and humans.
H. Any of the organic substances that react with chlorine to form trihalomethanes.
I. Compound formed when natural organic substances from decaying vegetation and soil (such as humic and fulvic acids) react with chlorine.
J. Material resulting from the decay of leaves and other plant matter.
K. Any material, such as activated carbon, used to adsorb substances.
L. The water treatment process used primarily to remove organic contaminants from the water.
M. Activated carbon in a fine powder form.
N. A chemical substance of animal or vegetable origin, having carbon in its molecular structure.
O. The amount of carbon bound in organic compounds in a water sample as determined by a standard laboratory test.
P. A device used to mix a chemical with water by using a constriction to create a low pressure to draw the chemical into the stream of water.
Q. The process of producing a highly porous structure in carbon by exposing the carbon to high temperatures in the presence of steam.
R. The volume of the tank holding an activated carbon bed divided by the flow rate of water.
S. The chemical compound aluminum oxide, which is used to remove fluoride and arsenic from water by adsorption.
T. A compound, usually a synthetic organic substance, used to kill insects.

U. Bead-like material used in the ion exchange process.
V. A condition that occurs when dry chemicals bridge over the opening from the hopper to the dry feeder, clogging the hopper.
W. To remove the adsorbed materials from spent activated carbon and restore the carbon's porous structure so it can be used again.
X. Any substance or chemical used to kill or control troublesome organisms including insects, weeds and bacteria.
Y. A highly adsorptive material used to remove organic substances from the water.
Z. A vertical steel cylindrical pressure vessel used to hold the activated carbon bed.

Adsorption Review Questions

1. Explain the difference between adsorption and absorption.

2. Adsorption is usually used to remove what type of contaminant from drinking water?

3. If you only need to use carbon during certain times of the year, which type (PAC or GAC) would be the best choice?

4. Where in the treatment process are GAC filters generally located?

5. The best application point for powdered activated carbon is usually ____________________.

6. What test is used to analyze the odor of water?

7. List some hazards associated with the storage of activated carbon.

8. PAC is commonly used to remove _____________________________, while GAC is most commonly used to remove ____________________________.

9. Activated carbon adsorbs chemicals easily because of its large ____________________.

10. What is the process of recharging the adsorption capability of granular activated carbon called?

11. If there is a fire in the activated carbon storage area, what should you use to extinguish it?

12. What safety hazard is created by wet activated carbon?

Answers

Vocabulary

1. S
2. Y
3. Q
4. F
5. K
6. L
7. V
8. C
9. G
10. Z
11. P
12. R
13. E
14. D
15. J
16. T
17. B
18. N
19. X
20. M
21. H
22. W
23. A
24. U
25. O
26. I

Review Questions:

1. Absorption – taking in or soaking up a substance into another substance
   Adsorption – adhesion of contaminants onto the surface of an adsorbent, like activated carbon.

2. Organics

3. PAC

4. After filtration (or to replace part of the filter media)

5. Raw intake

6. Threshold Odor Test (TON)

7. Wet activated carbon removes oxygen from air; it is difficult to locate and extinguish a fire involving activated carbon.

8. Taste & odor compounds; synthetic organic chemicals

9. Surface area

10. Reactivation

11. Carbon dioxide

12. Removes O_2 from air

Section 8

Aeration

Aeration

Aeration

- The process of bringing water and air into close contact to remove or modify constituents in the water
- Aeration removes dissolved gases and oxidizes dissolved metals so they don’t interfere with other treatment processes
- The efficiency of the aeration process depends on the amount of surface contact that can be achieved between air and water
  - This is controlled primarily by the size of the water drops or air bubbles that provide the contact area

Goals of Aeration

- Removal of gases - CO_2 and H_2S
- Oxidation of metals to form precipitates - Fe and Mn
- Removal of VOCs - benzene and toluene
- Good ventilation is required for proper removal of volatile gases and to prevent buildup of dangerous gases near the aerator

Effects of Aeration

Carbon Dioxide (CO_2)

- Surface water usually contains low CO_2, but groundwater and very deep lakes may contain very high levels
  - Makes water more acidic
  - Makes iron removal more difficult
    - Increases solubility
  - Reacts with lime
    - Increases softening costs

Effects of Aeration

Hydrogen Sulfide (H_2S)

- Causes rotten-egg odor, alters taste of coffee, tea, & ice cubes
- Causes corrosion
- May cause black precipitate
- Increases chlorine demand
- Easily removed by aeration
- Requires good ventilation

Effects of Aeration

Methane (CH_4)

- Colorless, odorless, tasteless, lighter than air
- Highly flammable and explosive
- Causes garlic taste in water
- Easily removed by aeration
- Requires good ventilation

Effects of Aeration

Volatile Organic Chemicals (VOC)

- VOCs are “manufactured” chemicals found in many groundwater sypplies
- Some are suspected carcinogens
  - Regulated by EPA
- Not as easily removed by aeration

Effects of Aeration

Radon

- Radioactive, colorless, odorless gas
- Present in groundwater, not usually in surface water
- Inhalation hazard - released in homes from showers, washing machines, etc
- Easily removed by aeration
- Requires good ventilation

Effects of Aeration

Iron and Manganese (Fe & Mn)

- Present in dissolved form in groundwater & stratified reservoirs
- Stains plumbing fixtures & laundry
- Iron easily oxidized in the air above pH 7.5; manganese not easily oxidized by aeration
- Oxidation turns them into soluble form, must then be removed by filtration

---

Effects of Aeration

Tastes and Odors

- Some are easily removed by aeration
- Some require chemical oxidation or adsorption

Effects of Aeration

Dissolved Oxygen (DO)

- Added by aeration, removes “flat” taste
- Can increase corrosivity of water
- Amount of DO depends on temperature
  - Colder water holds more DO
- Algae increases level of DO

Types of Aerators

- Two types:
  - Water-into-air
    - Produce small drops of water that fall through air
  - Air-into-water
    - Mostly used in wastewater

Water-Into-Air Aerators

Types

☐ Cascade
☐ Cone
☐ Slat and coke tray
☐ Draft
☐ Spray
☐ Packed towers

Water-Into-Air Aerators

Cascade Aerators

☐ Series of steps or stacked metal rings
☐ Aeration occurs in splash areas
☐ Used to oxidize iron and reduce dissolved gases
☐ Water introduced at top and moves downward taking in oxygen

Water-Into-Air Aerators

Cascade Aerators

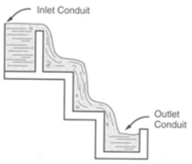
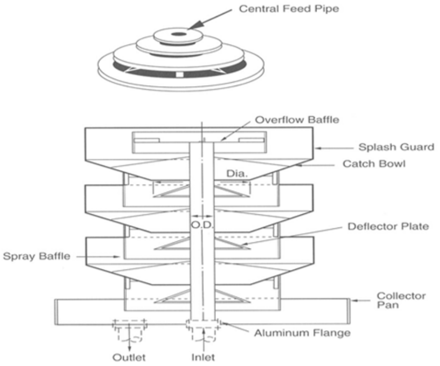


FIGURE 14-2 Stairway-type cascade aerator



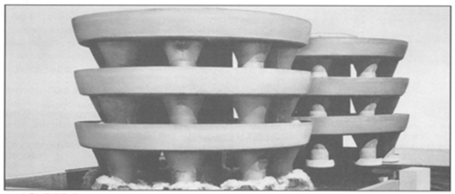
Courtesy of US Filter-General Filter Products

FIGURE 14-3 Ring-type cascade aerator

Water-Into-Air Aerators

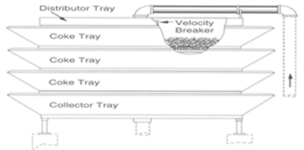
Cone Aerators

☐ Similar to ring-type cascade aerators
☐ Airs is drawn into stacked pans, mixed with falling water
☐ Water cascades downward through cones
☐ Usually used to oxidize iron
☐ Can reduce dissolved gases



Courtesy of ONDEO Degremont

FIGURE 14-4 Cone aerator



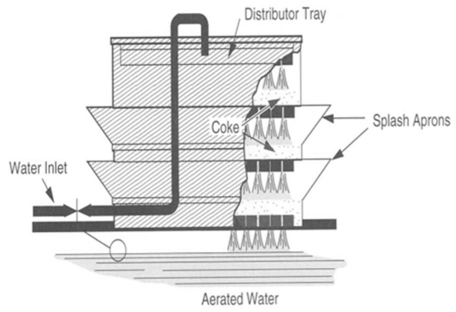
Courtesy of US Filter-General Filter Products, Ames, Iowa

FIGURE 14-5 Schematic of a cone aerator

Water-Into-Air Aerators

Slat and Coke Tray Aerators

- ☐ Consists of 3-5 stacked trays with spaced slats
- ☐ Contains media made of coke, rock, ceramic balls, and limestone



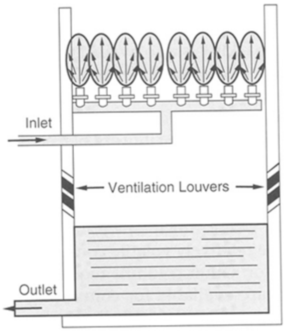
Courtesy of Power Magazine, *McGraw-Hill Inc.*

FIGURE 14-6 Slat-and-coke-tray aerator

Water-Into-Air Aerators

Spray Aerators

- ☐ One or more spray nozzles connected to a pipe manifold
- ☐ Moves through manifold under pressure
- ☐ Water leaves each nozzle in a fine spray and falls through the surrounding air, creating a fountain effect
- ☐ Very successful in oxidizing Fe & Mn
- ☐ Increases DO



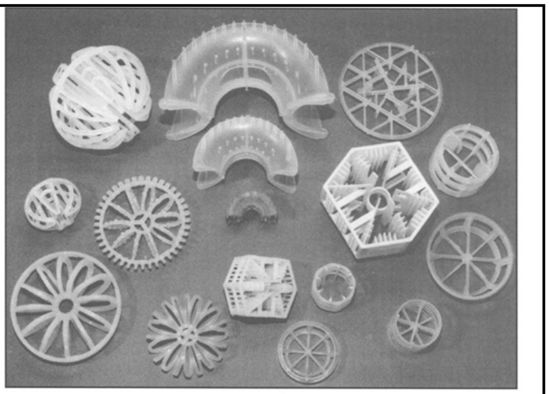
Courtesy of ONDEO Degremont Inc., Richmond, Va.

FIGURE 14–9 Spray tower

Water-Into-Air Aerators

Packed Tower Aerators

- ☐ Air stripper (new development)
- ☐ Removes volatile compounds such as VOCs
- ☐ Packed towers consist of cylindrical tanks containing a packing material
- ☐ Water distributed over the packing at the top
- ☐ Air forced in at the bottom
- ☐ Large surface area provides for more liquid-gas transfer than other aeration methods



Source: US Environmental Protection Agency.

FIGURE 14–11 Typical plastic packing pieces

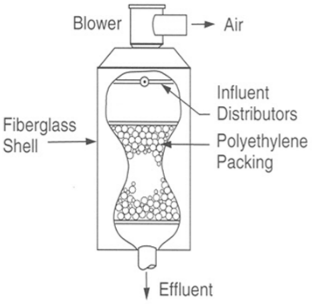


FIGURE 14–12 Cutaway view of interior of a packed tower

Air-Into-Water Aerators

- Types
  - Diffuser aerator
    - compressed air releases tiny bubbles near bottom of basin
  - Draft tube aerator
    - submersible pump equipped with a draft tube (air intake pipe)

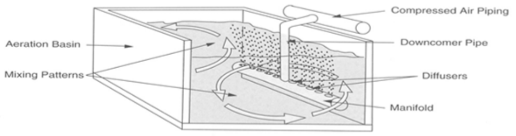


FIGURE 14–14 Diffuser aeration system

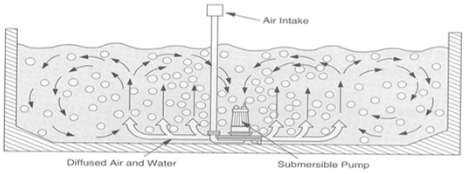


FIGURE 14–17 Draft-tube aerator

Combination Aerators

- Mechanical aerators
  - Surface aerators (water-into-air type)
  - Submerged aerators (air-into-water type)
  - Combination mechanical aerators (combo type)
  - Draft-tube surface aerators (water-into-air type)

Limitations of Aerators

- Best suited for absorption and release of gases
- Increases DO level which increases corrosivity of water
- Only treatment process that can introduce airborne contaminants into the water
- Taste & odor causing compounds are not volatile enough to respond to aeration
- Efficiency depends on type of taste and odor compound to be removed
- Best suited for treatment of groundwater and removal of CO_2 and H_2S

Aeration Vocabulary

______1. Aeration
______2. Air Binding
______3. Carbon Dioxide
______4. Cascade Aerator
______5. Cone Aerator
______6. Confined Space
______7. Corrosion
______8. Diffuser Aerator
______9. Dissolved Oxygen
______10. Draft-Tube Aerator
______11. Equilibrium
______12. Hydrogen Sulfide
______13. Induced Draft Aerator
______14. Insoluble
______15. Ionize
______16. Iron
______17. Manganese
______18. Manifold
______19. Mechanical Aerator
______20. Methane
______21. Olfactory Fatigue
______22. Oxidation
______23. Permit Required Confined Space
______24. Photosynthesis
______25. Positive Draft Aerator
______26. Pressure Aerator
______27. Respiration
______28. Slat & Coke Tray Aerator
______29. Soluble
______30. Spray Aerator
______31. Spray Tower
______32. Supersaturation
______33. Taste & Odor
______34. Turbulence
______35. Volatile

A. Aerator using a blower mounted on top of a tower to pull air through falling water.
B. The process by which plants, using the chemical chlorophyll, covert the energy of the sun into food energy.
C. Vaporizes easily.
D. Aerator that contains wooden slats and chunks of rock. Good for iron & manganese oxidation.
E. To change or be changed into ions.
F. A toxic gas produced by the anaerobic decomposition of organic matter and by sulfate-reducing bacteria. Has a rotten egg odor.
G. The process of bringing air and water into close contact in order to remove or oxidize unwanted constituents.
H. Aerator that uses perforated pipes or porous plates to inject a gas, such as CO_2 or air, under pressure into water.
I. A pipe with several branches or fittings to allow water or gas to be discharged at several points.
J. (1) The chemical reaction in which the valence of an element increases due to the loss of electrons from that element. (2) The conversion of organic substances to simpler, more stable form by either chemical or biological means.
K. Aerator with a submersible pump equipped with a draft tube. Water and air are mixed by a turbine impeller then discharged into the aeration basin.
L. An abundant element found naturally in the earth; when dissolved in water, it can cause red water problems.
M. A flow of water in which there are constant changes in flow velocity and direction resulting in agitation.

N. Aerator consisting of one or more spray nozzles connected to a pipe manifold. Water under pressure is forced into the air.
O. A colorless, odorless, flammable gas formed by the anaerobic decomposition of organic matter. Can cause a garlic-like taste in water.
P. The point at which your nose no longer can smell a certain odor.
Q. A condition under which water contains very high concentrations of dissolved gas.
R. A condition that occurs in filters when air comes out of solution as a result of pressure decreases and temperature increases. The air clogs the voids between the media grains, causing increased head loss through the filter and shorter filter run.
S. Aerator consisting of a propeller-like mixing blade mounted on the end of a vertical shaft driven by a motor.
T. Not dissolved; solid; will precipitate.
U. Aerator that channels water through cone-shaped nozzles in the bottom of each pan; primarily used to oxidize iron; can be used to partially reduce dissolved gases.
V. An abundant element found naturally in the earth; when dissolved in water, it can cause black stains to plumbing fixtures and laundry.
W. Aerator in which water is sprayed in to air in a pressurized tank, or a stream of air bubbles is diffused directly into a pressurized pipeline.
X. Aerator that uses a series of steps over which water runs.
Y. Housing for a certain aerator that protects the spray from wind-blown losses and can help reduce freezing problems.
Z. Balanced.
AA. Problems associated with dissolved metals and gases in the water usually through customer complaints.
BB. The amount of oxygen gas the water contains.
CC. Will dissolve.
DD. The gradual deterioration or destruction of a substance by chemical action.
EE. (1) Large enough and so configured that employees can bodily enter and perform assigned work and; (2) Has limited or restricted means for entry or exit, and; (3) Is not designed for continuous occupancy.
FF. Aerator using a blower mounted at the bottom of the tower to force air through the falling water.
GG. A common gas in the atmosphere that is very soluble in water. High amounts of this gas in water can cause it to be corrosive due to the acid it forms.
HH. The process by which a living organism takes in oxygen from the air or water, uses it in oxidation, and gives off the products of oxidation, especially carbon dioxide.
II. Confined Space with one or more of the following: (1) Contains or has the potential to contain a hazardous atmosphere; (2) Contains a material that has the potential for engulfing an entrant; (3) Has an internal configuration such that an entrant could be trapped or asphyxiated by inwardly converging walls or by a floor which slopes downward and tapers to a smaller cross-section; or (4) Contains any other recognized serious safety or heath hazard.

AERATION
QUIZ

1. List the two processes involved in aeration.

2. List 6 constituents affected by aeration.

   -
   -
   -
   -
   -
   -

3. List the water quality or operational problems associated with each in question #2.

4. List 2 main methods of aeration.

5. List a problem associated with excessive D.O. concentrations

6. What is the most efficient method for removing H_2S from water?

7. List at least 2 methods for minimizing energy consumption during aeration.

8. List the 3 basic control tests used in the aeration process.

9. Which type of water requires a greater frequency of testing:
Well water or Surface water

10. There are 2 gases released during aeration that present a danger. List these two gases and their dangers.

11. What are the two methods for dealing with these dangers?

Answers to Aeration Vocabulary:

1. G
2. R
3. GG
4. X
5. U
6. EE
7. DD
8. H
9. BB
10. K
11. Z
12. F
13. A
14. T
15. E
16. L
17. V
18. I
19. S
20. O
21. P
22. J
23. II
24. B
25. FF
26. W
27. HH
28. D
29. CC
30. N
31. Y
32. Q
33. AA
34. M
35. C

Answers to Review Questions:

1. Removal of gases and VOC's and oxidation of metals.
2. Carbon dioxide, hydrogen sulfide, methane, volatile organic compounds, radon, iron and manganese, tastes and odors
3. Carbon dioxide – makes water more acidic; makes iron removal more difficult; reacts with lime
   Hydrogen sulfide – causes rotten egg odor; alters taste of coffee, tea, ice cubes; causes corrosion; increases chlorine demand; may cause black precipitate
   Methane – causes garlic taste in water; highly flammable and explosive
   VOC's – suspected carcinogen
   Radon – radioactive; inhalation hazard
   Iron and manganese – stains plumbing fixtures and laundry
4. water-into-air and air-into-water (diffusers)
5. corrosive water
6. H_2S is very unstable and is easily removed from water by almost any method of aeration.
7. Operators can minimize power costs by not over aerating, keeping motors and blowers properly maintained and keeping air diffusers clean and free of debris.
8. Dissolved oxygen (DO), pH and temperature
9. Surface water – subject to more frequent change. Temperature, DO, pH, CO_2, and tastes and odors can vary daily.
10. Hydrogen sulfide is a poisonous gas and methane is highly flammable and explosive
11. Sufficient air movement in the vicinity of the aerator so that the gas is carried away.

Section 9

Cross Connections

Cross-Connection Control

TENNESSEE DEPARTMENT OF ENVIRONMENT AND CONSERVATION

Outline

- Basics of Cross-Connection Control
- Hydraulics
- Definitions
- Backflow Preventers
- Applications

Basics of Cross-Connection Control

United States Environmental Protection Agency
Cross-Connection Control Manual
www.epa.gov/ogwdw/pdfs/crossconnection/crossconnection.pdf

Tennessee Department of Environment & Conservation
Cross-Connection Control Manual & Design Criteria
www.tn.gov/environment/fleming/docs/crossconnection.pdf

Authority

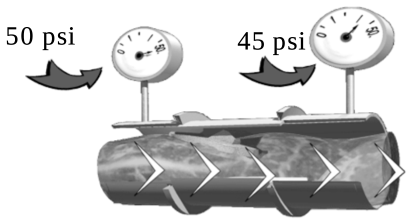
- Who has responsibility for the water served to the customer?
- Who has the responsibility to protect the water from cross-connections?
- What can happen if the water supplier does not act responsibly in the area of cross-connection control?
- Where does authority for the cross-connection control program come from?
- What can the water provider do to protect their system from contamination?

Hydraulics

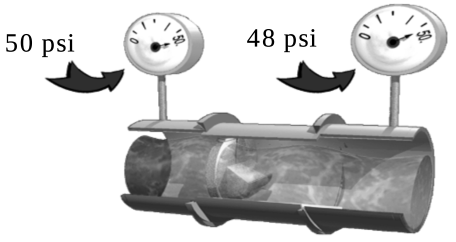
- Water pressure naturally tends to equalize

- Therefore, water flows from high pressure regions to low pressure regions

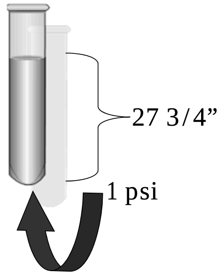
Normal Flow



No Flow

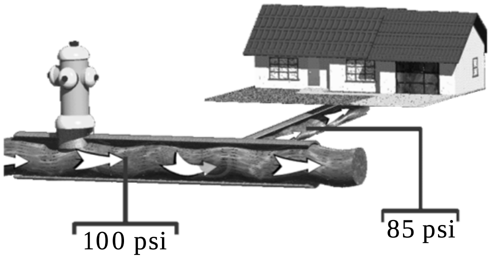


27 ¾” = 2.31 Feet of Head

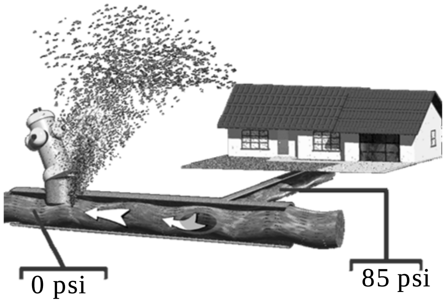


- 27 3/4” of water generates a pressure of one pound per square inch (psi)

Normal Flow



Reverse Flow

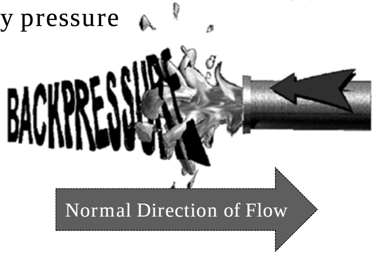


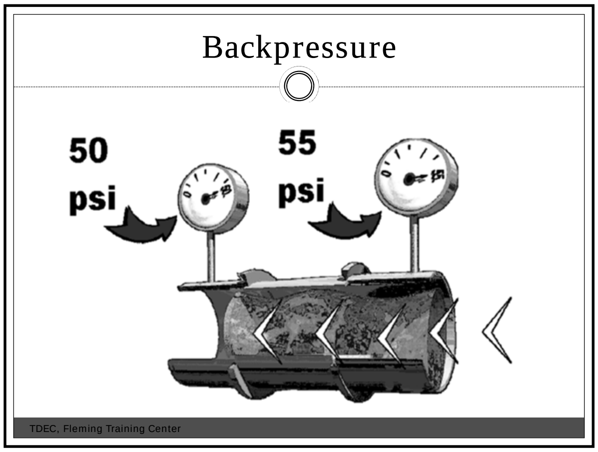
Backflow

- The undesirable reversal of flow of water or other substances into the potable water distribution supply
- Occurs due to:
  - Backpressure
  - Backsiphonage

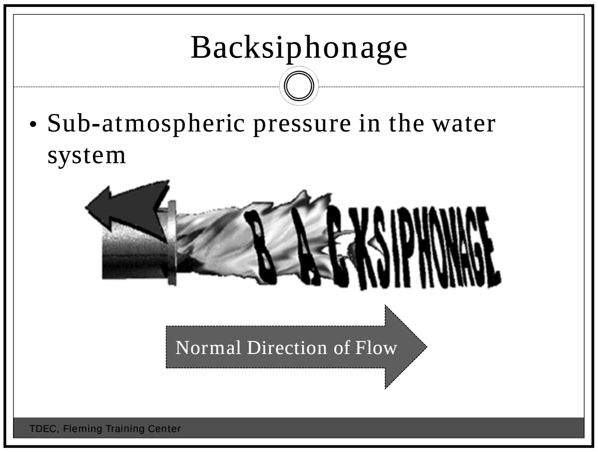
Backpressure

- Pressure in downstream piping greater than supply pressure



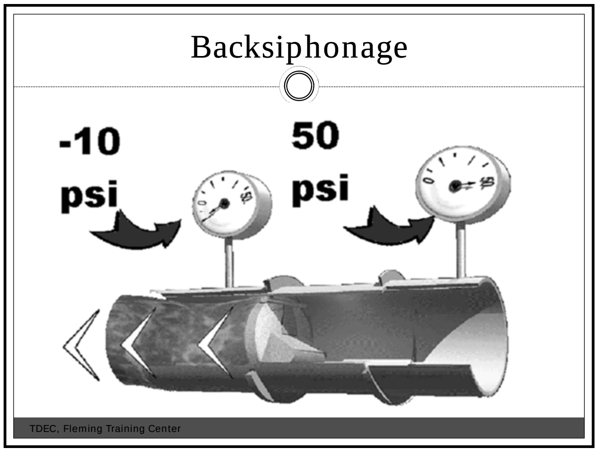


Backpressure

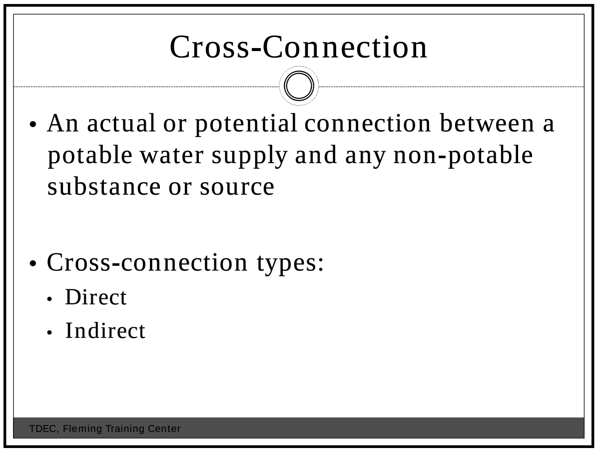


Backsiphonage

- Sub-atmospheric pressure in the water system

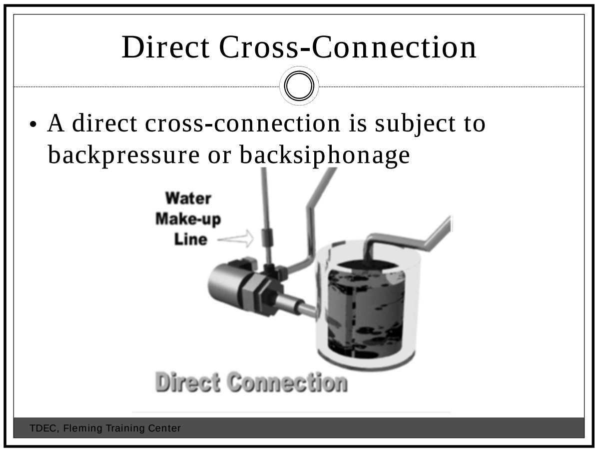


Backsiphonage



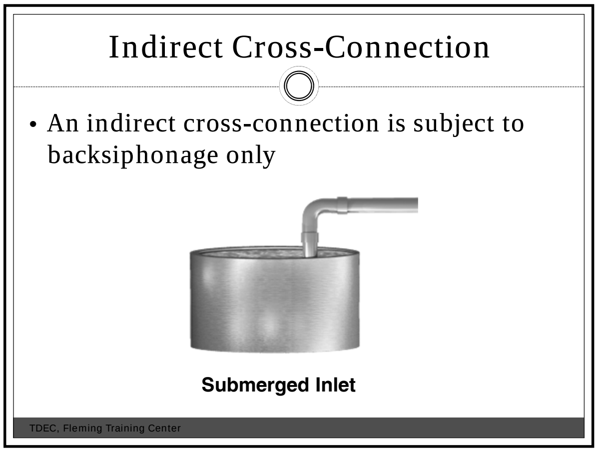
Cross-Connection

- An actual or potential connection between a potable water supply and any non-potable substance or source
- Cross-connection types:
  - Direct
  - Indirect



Direct Cross-Connection

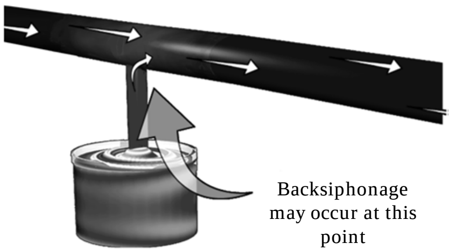
- A direct cross-connection is subject to backpressure or backsiphonage



Indirect Cross-Connection

- An indirect cross-connection is subject to backsiphonage only

Aspirator Effect



Backsiphonage
may occur at this
point

Degree of Hazard

- Non-Health Hazard
  - Low hazard
  - Will not cause illness or death
  - Pollutant
- Health Hazard
  - High hazard
  - Causes illness or death
  - Contaminant

The Backflow Incident

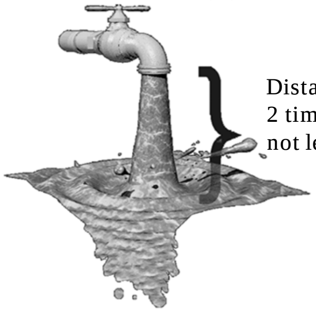
For backflow to occur three conditions must be met:

1. There must be a cross-connection. A passage must exist between the potable water system and another source.
2. A hazard must exist in this other source to which the potable water is connected.
3. The hydraulic condition of either backsiphonage or backpressure must occur.

Five Means of Preventing Backflow

- Air Gap Separation
- Reduced Pressure Principle Assembly
- Double Check Valve Assembly
- Pressure Vacuum Breaker/ Spill-Resistant Vacuum Breaker
- Atmospheric Vacuum Breaker

Air Gap



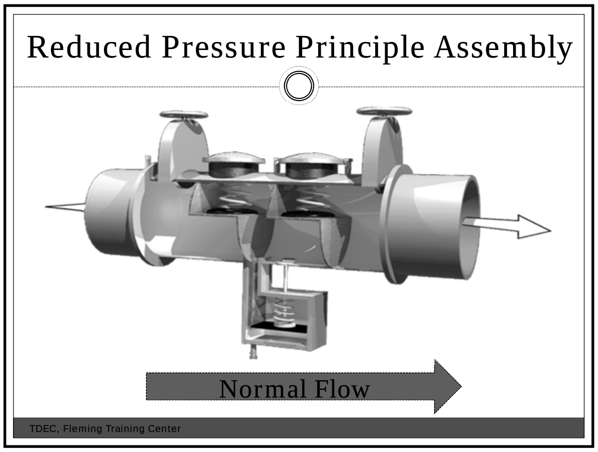
Distance:
2 times the diameter,
not less than 1 inch

Approved Air Gap Separation

- Backsiphonage
- Backpressure
- Contaminant (health hazard)
- Pollutant (non-health hazard)

	Indirect		Direct
	Backsiphonage Only		Backpressure and Backsiphonage
	Continuous Use	Non-Continuous Use	
Health Hazard	**Air Gap**	**Air Gap**	**Air Gap**
Non – Health Hazard	**Air Gap**	**Air Gap**	**Air Gap**

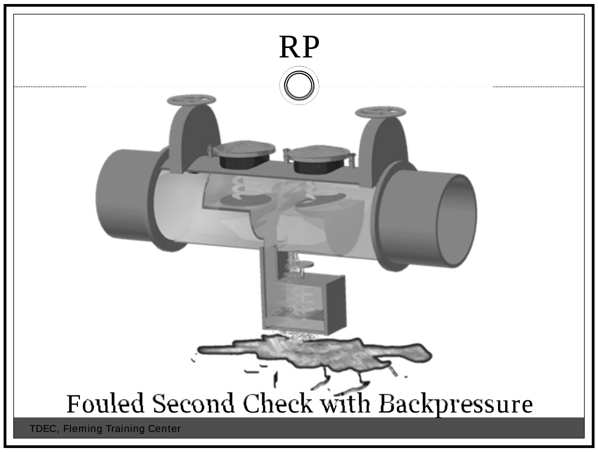
TDEC, Fleming Training Center



Reduced Pressure Principle Assembly

Normal Flow

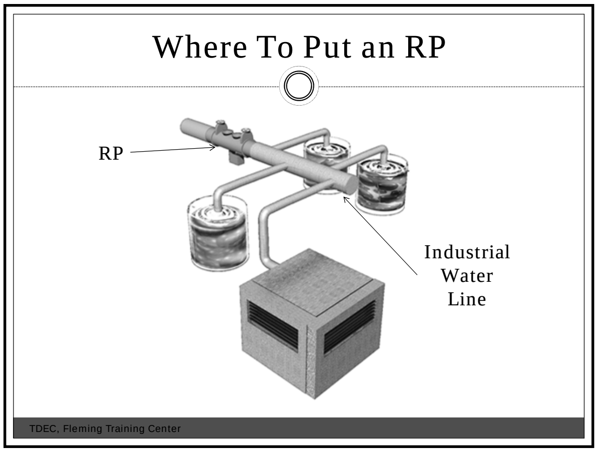
TDEC, Fleming Training Center



RP

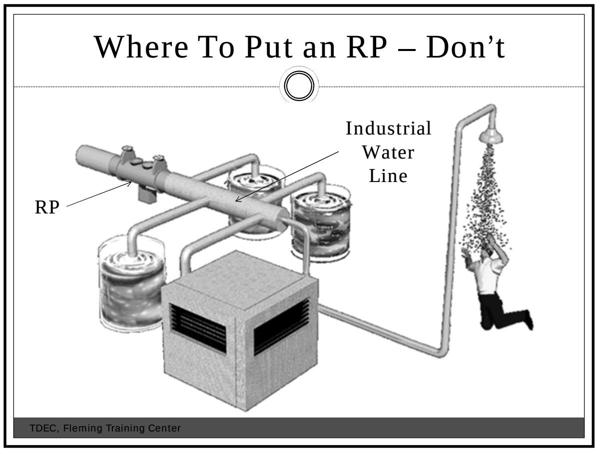
Fouled Second Check with Backpressure

TDEC, Fleming Training Center



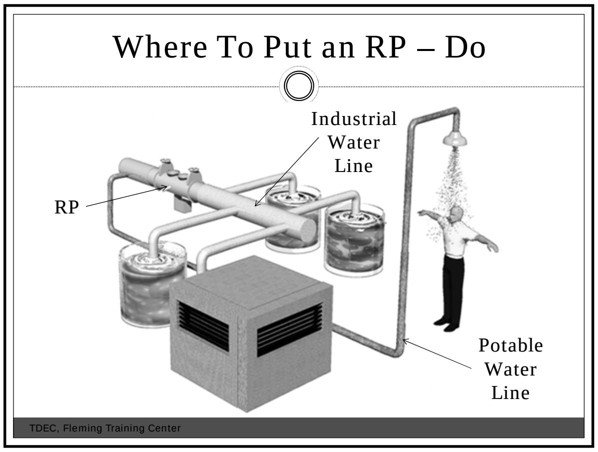
Where To Put an RP

TDEC, Fleming Training Center



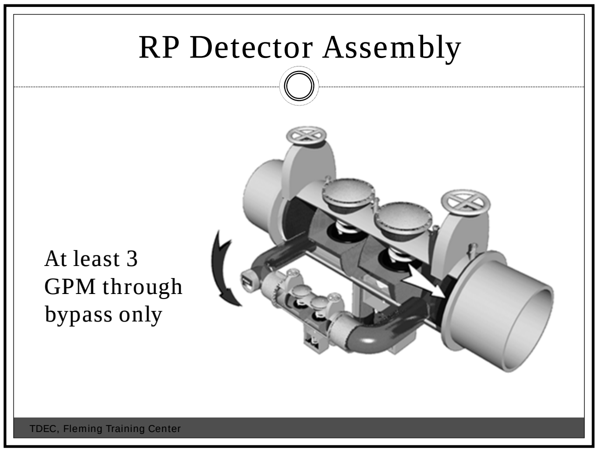
Where To Put an RP – Don’t

TDEC, Fleming Training Center



Where To Put an RP – Do

TDEC, Fleming Training Center



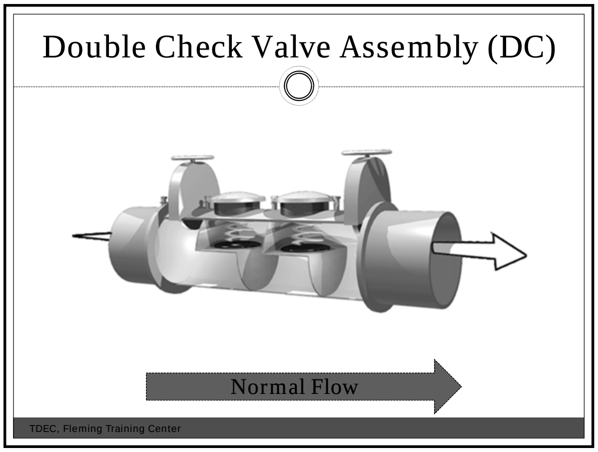
RP Detector Assembly

At least 3 GPM through bypass only

RP

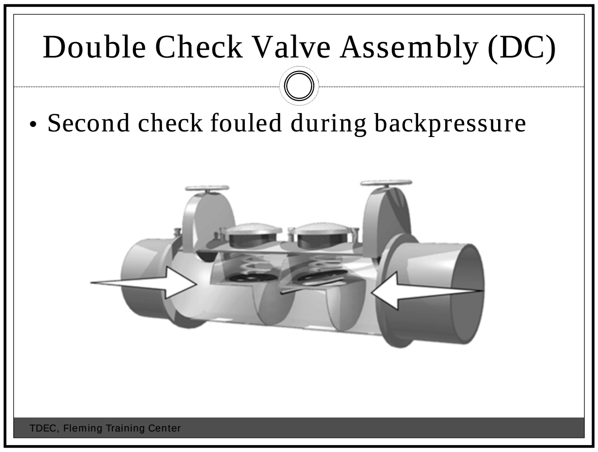
- Backsiphonage
- Backpressure
- Contaminant (health hazard)
- Pollutant (non-health hazard)

	Indirect		Direct
	Backsiphonage Only		Backpressure and Backsiphonage
	Continuous Use	Non-Continuous Use	
Health Hazard	Air Gap	Air Gap	Air Gap
	RP	**RP**	**RP**
Non – Health Hazard	Air Gap	Air Gap	Air Gap
	RP	**RP**	**RP**



Double Check Valve Assembly (DC)

Normal Flow

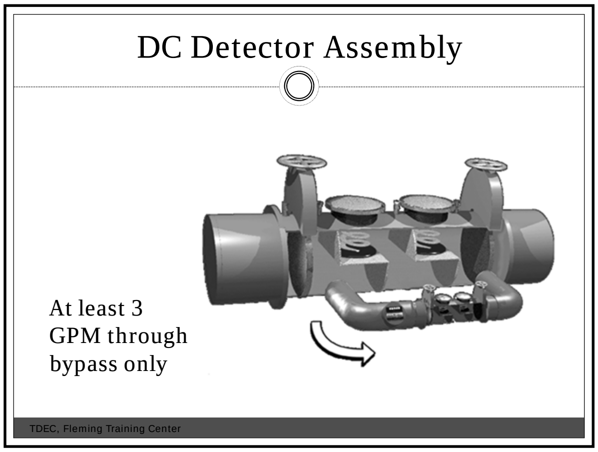


Double Check Valve Assembly (DC)

- Second check fouled during backpressure

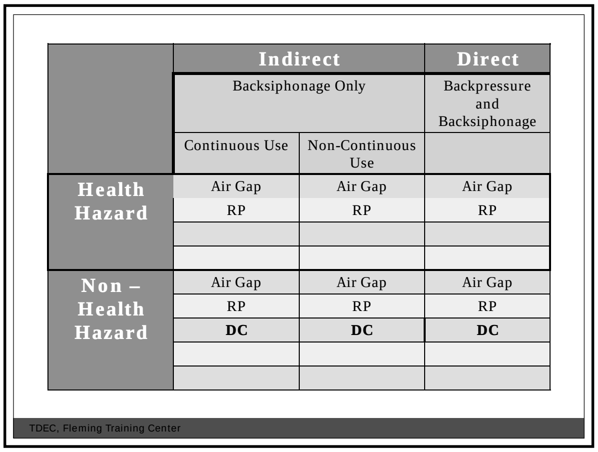
Double Check Valve Assembly (DC)

- Backsiphonage
- Backpressure
- Pollutant <u>only</u>

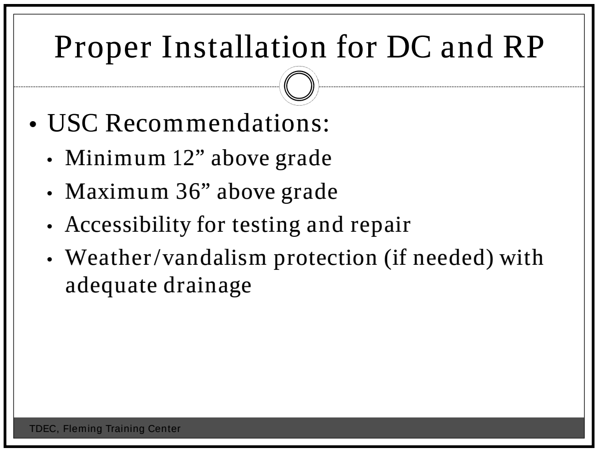


DC Detector Assembly

At least 3
GPM through
bypass only

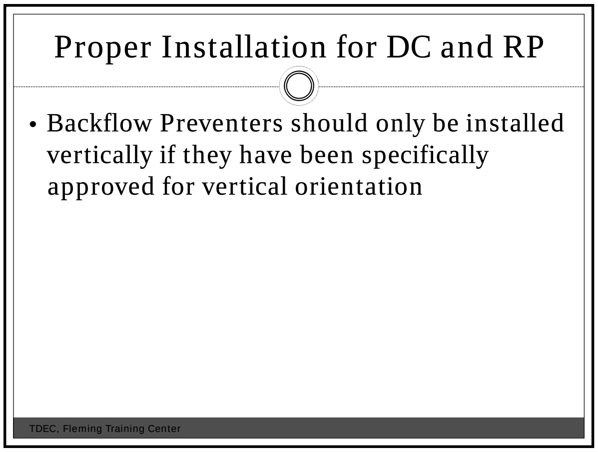


	Indirect		**Direct**
	Backsiphonage Only		Backpressure and Backsiphonage
	Continuous Use	Non-Continuous Use	
Health Hazard	Air Gap	Air Gap	Air Gap
	RP	RP	RP
Non – Health Hazard	Air Gap	Air Gap	Air Gap
	RP	RP	RP
	DC	**DC**	**DC**



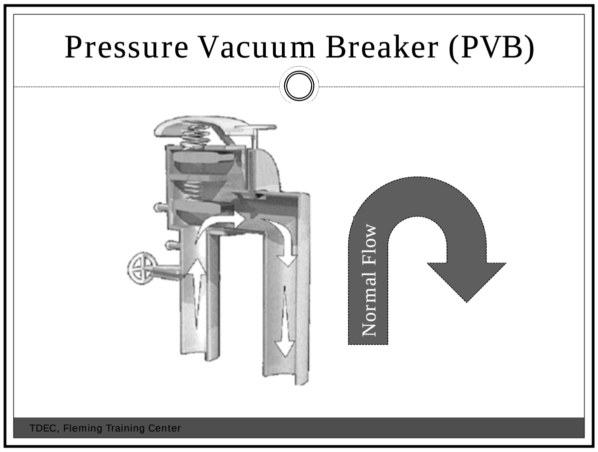
Proper Installation for DC and RP

- USC Recommendations:
  - Minimum 12” above grade
  - Maximum 36” above grade
  - Accessibility for testing and repair
  - Weather/vandalism protection (if needed) with adequate drainage

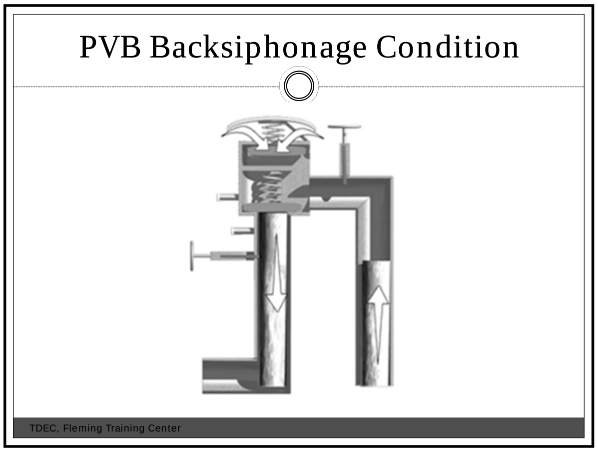


Proper Installation for DC and RP

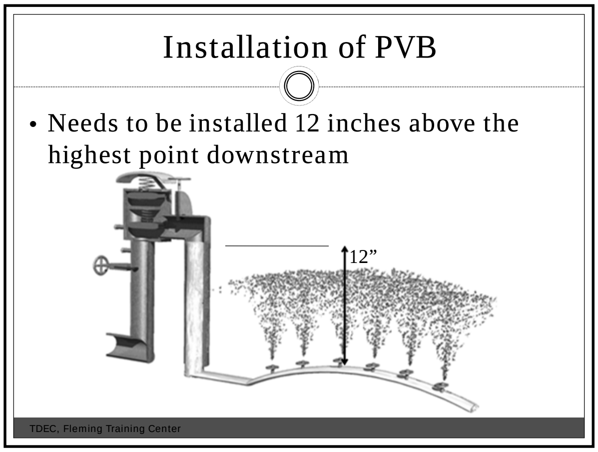
- Backflow Preventers should only be installed vertically if they have been specifically approved for vertical orientation



Pressure Vacuum Breaker (PVB)

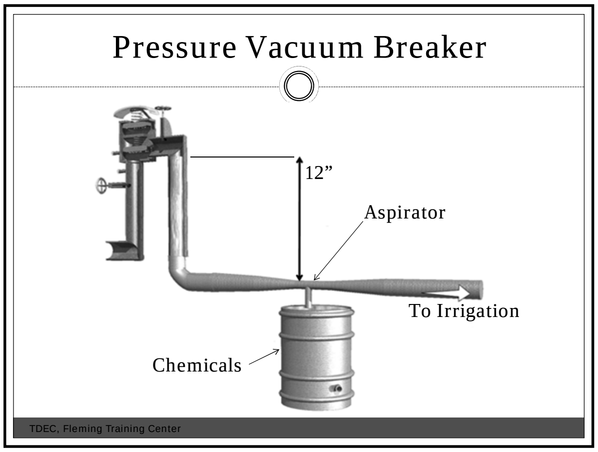


PVB Backsiphonage Condition

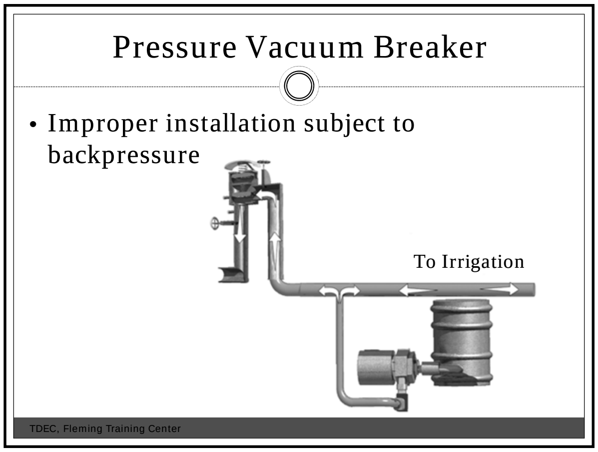


Installation of PVB

- Needs to be installed 12 inches above the highest point downstream

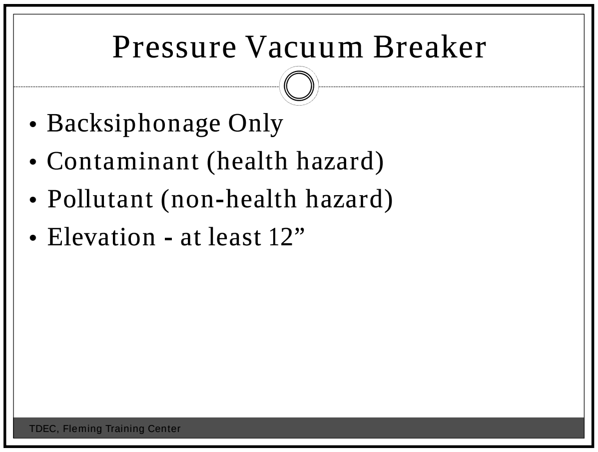


Pressure Vacuum Breaker



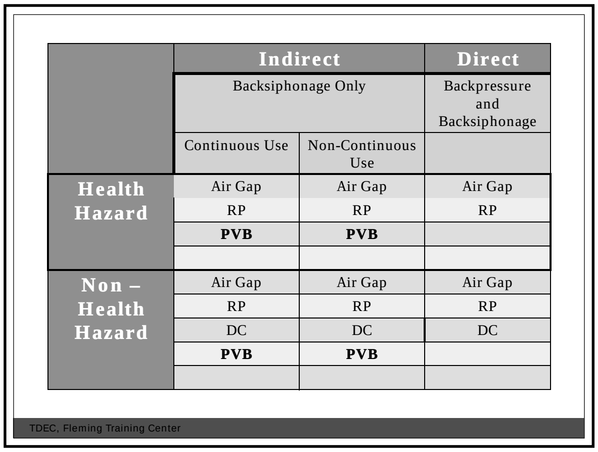
Pressure Vacuum Breaker

- Improper installation subject to backpressure

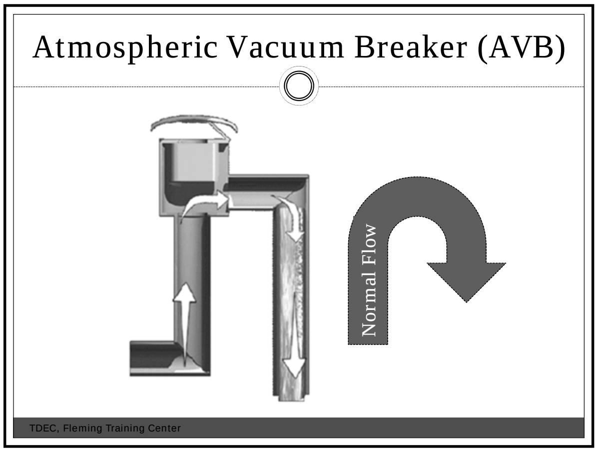


Pressure Vacuum Breaker

- Backsiphonage Only
- Contaminant (health hazard)
- Pollutant (non-health hazard)
- Elevation - at least 12”



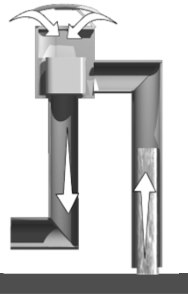
	Indirect		**Direct**
	Backsiphonage Only		Backpressure and Backsiphonage
	Continuous Use	Non-Continuous Use	
Health Hazard	Air Gap	Air Gap	Air Gap
	RP	RP	RP
	PVB	**PVB**	
Non – Health Hazard	Air Gap	Air Gap	Air Gap
	RP	RP	RP
	DC	DC	DC
	PVB	**PVB**	



Atmospheric Vacuum Breaker (AVB)

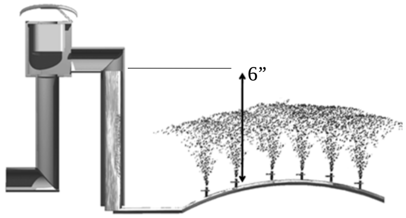
Atmospheric Vacuum Breaker (AVB)

- Backsiphonage condition

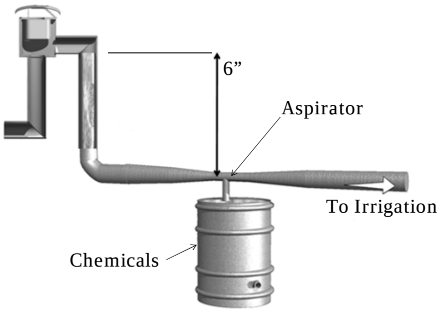


Installation of AVB

- Needs to be installed 6 inches above the highest point downstream

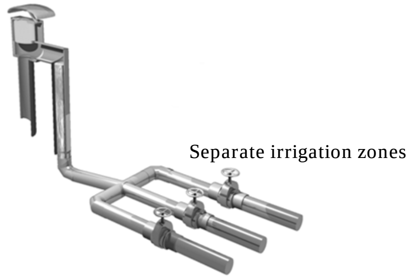


Atmospheric Vacuum Breaker



Atmospheric Vacuum Breaker

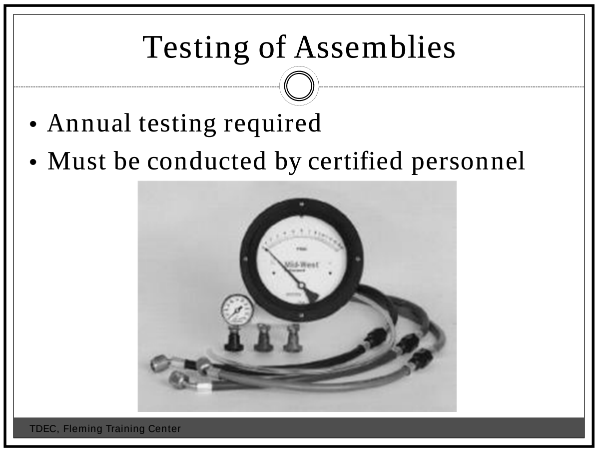
- Improper installation: downstream shutoff valves



Atmospheric Vacuum Breaker

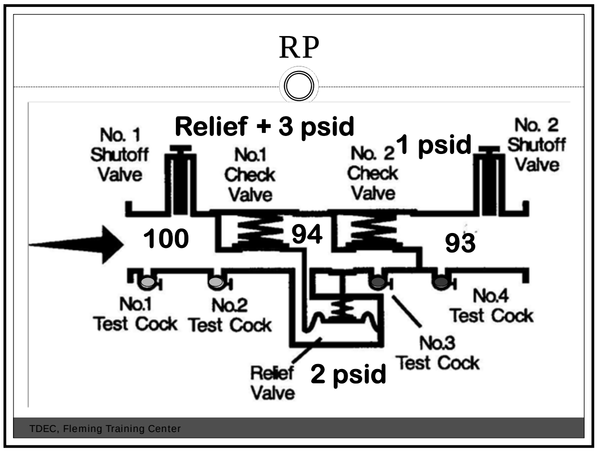
- Backsiphonage Only
- Contaminant (health hazard)
- Pollutant (non-health hazard)
- Elevation - at least 6”
- Non-Continuous Use

	Indirect		**Direct**
	Backsiphonage Only		Backpressure and Backsiphonage
	Continuous Use	Non-Continuous Use	
Health Hazard	Air Gap	Air Gap	Air Gap
	RP	RP	RP
	PVB	PVB	
		AVB	
Non – Health Hazard	Air Gap	Air Gap	Air Gap
	RP	RP	RP
	DC	DC	DC
	PVB	PVB	
		AVB	

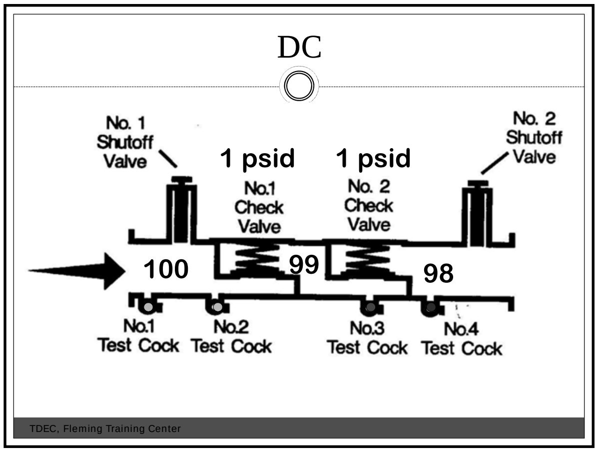


Testing of Assemblies

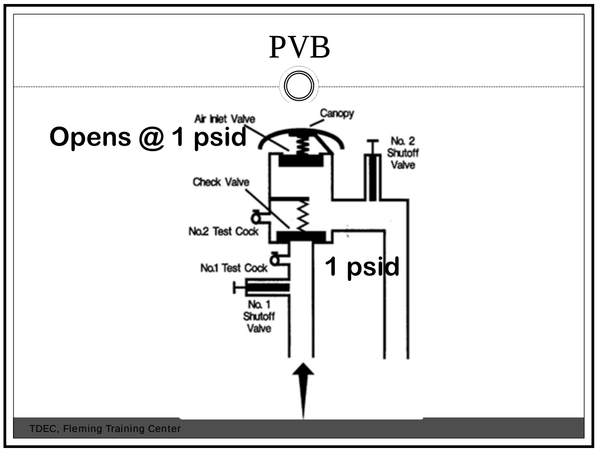
- Annual testing required
- Must be conducted by certified personnel



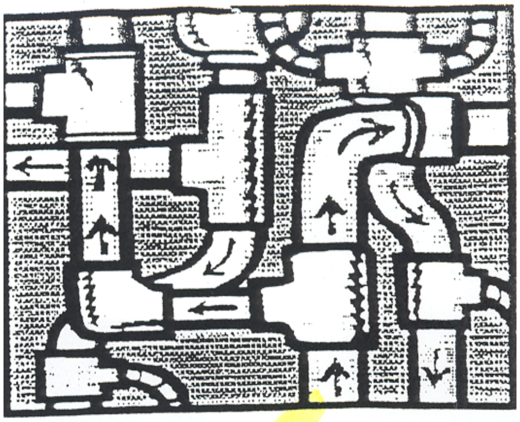
RP



DC



PVB



Vocabulary

Absolute Pressure – The total pressure; gauge pressure plus atmospheric pressure. Absolute pressure is generally measured in pounds per square inch (psi).

Air Gap – The unobstructed vertical distance through the free atmosphere between the lowest opening from any pipe or outlet supplying water to a tank, plumbing fixture or other device, and the flood-level rim of the receptacle. This is the most effective method for preventing backflow.

Atmospheric Pressure – The pressure exerted by the weight of the atmosphere (14.7 psi at sea level). As the elevation above sea increases, the atmospheric pressure decreases.

Backflow – The reversed flow of contaminated water, other liquids or gases into the distribution system of a potable water supply.

Backflow Prevention Device (Backflow Preventer) – Any device, method or construction used to prevent the backward flow of liquids into a potable distribution system.

Back Pressure (Superior Pressure) – (1) A condition in which the pressure in a nonpotable system is greater than the pressure in the potable distribution system. Superior pressure will cause nonpotable liquids to flow into the distribution system through unprotected cross connections. (2) A condition in which a substance is forced into a water systems because that substance is under higher pressure than the system pressure.

Backsiphonage – (1) Reversed flow of liquid cause by a partial vacuum in the potable distribution system. (2) A condition in which backflow occurs because the pressure in the distribution system is less than atmospheric pressure.

Bypass – Any arrangement of pipes, plumbing or hoses designed to divert the flow around an installed device through which the flow normally passes.

<u>Chemical</u> – A substance obtained by a chemical process or used for producing a chemical reaction.

<u>Containment (Policy)</u> – To confine potential contamination within the facility where it arises by installing a backflow prevention device at the meter or curbstop.

<u>Contamination</u> – The introduction into water of any substance that degrades the quality of the water, making it unfit for its intended use.

<u>Continuous Pressure</u> – A condition in which upstream pressure is applied continuously (more than 12 hours) to a device or fixture. Continuous pressure can cause mechanical parts within a device to freeze.

<u>Cross Connection</u> – (1) Any arrangement of pipes, fittings or devices that connects a nonpotable system to a potable system. (2) Any physical arrangement whereby a public water system is connected, either directly or indirectly, with any other water supply system, sewer, drain, conduit, pool, storage reservoir, plumbing fixture or other waste or liquid of unknown or unsafe quality.

<u>Cross Connection Control</u> – The use of devices, methods and procedures to prevent contamination of a potable water supply through cross connections.

<u>Degree of Hazard</u> – The danger posed by a particular substance or set of circumstances. Generally, a low degree of hazard is one that does not affect health, but may be aesthetically objectionable. A high degree of hazard is one that could cause serious illness or death.

<u>Direct Connection</u> – Any arrangement of pipes, fixtures or devices connecting a potable water supply directly to a nonpotable source; for example, a boiler feed line.

<u>Distribution System</u> – All pipes, fitting and fixtures used to convey liquid from one point to another.

<u>Double Check-Valve System Assembly</u> – A device consisting of two check valves, test cocks and shutoff valves designed to prevent backflow.

<u>Gauge Pressure</u> – Pounds per square inch (psi) that are registered on a gauge. Gauge pressure measures only the amount of pressure above (or below) atmospheric pressure.

<u>Indirect Connection</u> – Any arrangement of pipes, fixtures or devices that indirectly connects a potable water supply to a nonpotable source; for example, submerged inlet to a tank.

Isolation (policy) – To confine a potential source of contamination to the nonpotable system being served; for example, to install a backflow prevention device on a laboratory faucet.

Liability – Obligated by law.

Negative Pressure – Pressure that is less than atmospheric; negative pressure in a pipe can induce a partial vacuum that can siphon nonpotable liquids into the potable distribution system.

Nonpotable – Any liquid that is not considered safe for human consumption.

Nontoxic – Not poisonous; a substance that will not cause illness or discomfort if consumed.

Physical Disconnection (Separation) – Removal of pipes, fittings or fixtures that connect a potable water supply to a nonpotable system or one of questionable quality.

Plumbing – Any arrangement of pipes, fittings, fixtures or other devices for the purpose of moving liquids from one point to another, generally within a single structure.

Poison – A substance that can kill, injure or impair a living organism.

Pollution – Contamination, generally with man-made waste.

Potable – Water (or other liquids) that are safe for human consumption.

Pressure – The weight (of air, water, etc.) exerted on a surface, generally expressed as pounds per square inch (psi).

Pressure Vacuum Breaker – A device consisting of one or two independently operating, spring-loaded check valves and an independently operating, spring-loaded air-inlet valve designed to prevent backsiphonage.

Reduced-Pressure-Principle or Reduced-Pressure-Zone Device (RP or RPZ) – A mechanical device consisting of two independently operating, spring-loaded check valves with a reduced pressure zone between the checks designed to protect against both backpressure and backsiphonage.

Refusal of Service (Shutoff Policy) – A formal policy adopted by a governing board to enable a utility to refuse or discontinue service where a known hazard exists and corrective measures are not undertaken.

Regulating Agency – Any local, state or federal authority given the power to issue rules or regulations having the force of law for the purpose of providing uniformity in details and procedures.

Relief Valve – A device designed to release air from a pipeline, or introduce air into a line if the internal pressure drops below atmospheric pressure.

Submerged Inlet – An arrangement of pipes, fittings or devices that introduces water into a nonpotable system below the flood-level rim of a receptacle.

Superior Pressure – See backpressure.

Test Cock – An appurtenance on a device or valve used for testing the device.

Toxic – Poisonous; a substance capable of causing injury or death.

Vacuum (Partial Vacuum) – A condition induced by negative (subatmospheric) pressure that causes backsiphonage to occur.

Venturi Principle – As the velocity of water increases, the pressure decreases. The Venturi principle can induce a vacuum in a distribution system.

Waterborne Disease – Any disease that is capable of being transmitted through water.

Water Supplier (Purveyor) – An organization that is engaged in producing and/or distributing potable water for domestic use.

Cross Connection Vocabulary

______1. Air Gap
______2. Atmospheric Vacuum Breaker
______3. Auxiliary Supply
______4. Backflow
______5. Back Pressure
______6. Backsiphonage
______7. Check Valve
______8. Cross Connection
______9. Feed Water
______10. Hose Bibb
______11. Overflow Rim
______12. Pressure Vacuum Breaker
______13. Reduced Pressure Zone Backflow Preventer
______14. RPBP

A. A valve designed to open in the direction of normal flow and close with the reversal of flow.
B. A hydraulic condition, caused by a difference in pressures, in which non-potable water or other fluids flow into a potable water system.
C. Reduced pressure backflow preventer.
D. In plumbing, the unobstructed vertical distance through the free atmosphere between the lowest opening from any pipe or outlet supplying water to a tank, plumbing fixture or other container, and the overflow rim of that container.
E. A backflow condition in which the pressure in the distribution system is less than atmospheric pressure.
F. A faucet to which a hose may be attached.
G. A mechanical device consisting of two independently operating, spring-loaded check valves with a reduced pressure zone between the check valves.
H. Any water source or system, other than potable water supply, that may be available in the building or premises.
I. Water that is added to a commercial or industrial system and subsequently used by the system, such as water that is fed to a boiler to produce steam.
J. A device designed to prevent backsiphonage, consisting of one or two independently operating spring-loaded check valves and an independently operating spring –loaded air-inlet valve.
K. A backflow condition in which a pump, elevated tank, boiler or other means results in a pressure greater than the supply pressure.
L. Any arrangement of pipes, fittings, fixtures or devices that connects a nonpotable water system.
M. The top edge of an open receptacle over which water will flow.
N. A mechanical device consisting of a float check valve and an air-inlet port designed to prevent backsiphonage.

Answers:

1. D
2. N
3. H
4. B
5. K
6. E
7. A
8. L
9. I
10. F
11. M
12. J
13. G
14. C

Section 10

Records Keeping and Design Criteria

The Design Criteria document can be found in its entirety at:

http://www.state.tn.us/environment/dws/pdf/design.pdf

Record Category		Time frame required to keep records		Source
Microbiological Records				1200-5-1-.20(1)(a)
Routine distribution		5 years		
Line repair records		5 years		1200-5-1-.17(8)(a)
New line records		5 years		
Bacteriological sampling plan		Keep updated, at least every 3 years		
Chemical Analysis				1200-5-1-.20(1)(a)
Inorganics/ secondaries		10 years		
SOC's		10 years		
VOC's		10 years		
THM's and HAA5's		10 years		
Radionuclides		10 years		
Lead and copper		12 years		1200-5-1-.33(12)
Miscellaneous				
Action regarding violations		3 years		1200-5-1-.20(1)(b)
Certified Letters to Fire Departments regarding Class C hydrants		5 years		1200-5-1-.17(18)
Complaint file		5 years		1200-5-1-.20(1)(h)
Consumer Confidence Reports		3 years		1200-5-1-.35(h)
Cross connection plans and inspection records		5 years		1200-5-1-.20(1)(h)
Daily worksheets, strip charts, shift logs		5 years		1200-5-1-.20(1)(g)
Disinfection Profile		10 years		
Disinfection SOP		Keep updated		
Distribution map		Keep updated, submit copy to DWS every 5 years		1200-5-1-.17(15)
Distribution SOP		Keep updated		
Emergency Operation Plan		Keep updated		1200-1-5-.34(4)(a)
Facility Maintenance Records		5 years		1200-5-1-.20(1)(h)
Flushing records		Survey to survey or 3 years		1200-5-1-.17(10)
MOR's		5 years		
MSDS		At least 30 years		29 CFR 1910.1020
New tap records		Survey to survey or 3 years		1200-5-1-.17(32)
Notice of Construction		Survey to survey or 3 years		
Plant SOP		Keep updated		
Public Notices		3 years		1200-5-1-.20(i)
Sanitary surveys		10 years		
Storage Tank Inspection Records		5 years		1200-1-5-.17(33), 1200-5-1-.20(1)(h)
Tank maintenance records		Life of tank		1200-1-5-.17(33)
Turbidity analysis: daily worksheets, calibration data and strip charts		5 years		1200-5-1-.20(1)(f)
Variances or Exemptions		5 years		1200-5-1-.20(1)(d)

COMMUNITY PUBLIC WATER SYSTEMS DESIGN CRITERIA

Division of Water Supply Tennessee Department of Environment and Conservation
2008

Part 4 - TREATMENT

4.0 GENERAL - The design of treatment processes and devices depends on evaluation of the nature and quality of the particular water to be treated and the desired quality of the finished water. Surface water treatment plants must provide treatment for cryptosporidium, giardia, bacteria and viruses in accordance with the requirements of Division of Water Supply surface water treatment rules. Surface water treatment plants must provide for taste and odor control if there is any history or potential of taste and odor problems/complaints. Surface water treatment plants must be designed for control and reduction of disinfection by-products and their precursors.

4.1 CLARIFICATION - Plants designed for processing surface waters should:

a. Provide duplicate units for flocculation and sedimentation,

b. Be constructed to permit units to be taken out of service without disrupting operation.

4.1.1 Pre-sedimentation - Waters containing high turbidity or silica particles may require pretreatment, usually sedimentation either with or without the addition of coagulation chemicals.

a. Basin Design - Pre-sedimentation basins should be designed to hold maximum 3-day usage.

b. Inlet - Incoming water shall be dispersed across the full width of the line of travel as quickly as possible; short circuiting must be prevented.

c. Bypass - Provisions for bypassing pre-sedimentation basins shall be included.

4.1.2 Mixing (Flash or Quick):

a. Equipment - Basins should be equipped with mechanical mixing devices; other arrangements, such as baffling, and in-line mixers may be acceptable.

b. Mixing - The detention period shall not exceed 30 seconds. Concrete blocks may be placed in the flash mix temporarily to maintain this detention period if the plant is expected to be expanded in the near future.

c. Velocity gradient - The minimum shall be 300 (ft/sec)/ft.

4.1.3 Flocculation (Slow Mixing):

a. Basin Design - Inlet and outlet design shall prevent short circuiting and destruction of floc. A drain shall be provided.

b. Detention - The detention time for floc formation must be at least 30 minutes, with a detention time of 45 minutes being recommended.

c. Equipment - Agitators shall be driven by variable speed drives with the peripheral speed of paddles ranging from 0.5 to 2.0 ft/sec. The speed of each successive agitator should be less than the previous one.

d. Piping - Flocculation and sedimentation basins shall be as close together as possible. The velocity of flocculated water through pipes or conduits to settling basins shall be not less than 0.5 nor greater than 1.5 ft./sec. Allowances must be made to minimize turbulence at bends and changes in direction.

e. Other designs - Baffling may be used to provide for flocculation in small plants only after consultation with the Department. Minimum flow-through velocity shall be not less than 0.5 nor greater than 1.5 ft./sec. with a detention as noted above.

4.1.4 Sedimentation - Sedimentation shall follow flocculation. The detention time for effective clarification is dependent upon a number of factors related to basin design and the nature of the raw water. The number of basins required is dependent upon the turbidity, color and colloidal matter and taste and odor causing compounds to be removed.

a. Detention Time - Plants with conventional sedimentation shall provide a minimum of 4 hours of settling time, except for iron removal plants which shall have a minimum of 3 hours.

b. Depth - Should be based on an average depth of 8 ft. However, calculations using surface area, overflow rate and detention time should be used.

c. Rectangular tanks - A length to width ratio of 4:1 should be used.

d. Tube Settlers - Detention time required for sedimentation basins may be reduced to a minimum of 1 hour if tube settlers are installed. The maximum loading rate on the tube settlers shall be no greater than 2.5 gpm/ft^2. Provisions shall be made for more frequent removal of sludge from the basins than is required for conventional sedimentation.

e. Plate Settlers – Shall be designed, installed and loaded per the manufacturer's recommendations.

f. Inlet Devices - Inlets shall be designed to distribute the water equally and at uniform velocities. Open ports, submerged ports, or similar entrance arrangements are required. A baffle should be constructed across the basin close to the inlet end and should project several feet below the water surface to dissipate inlet velocities and provide uniform flows across the basin. Velocity is not to exceed 0.25 ft/sec.

g. Surface overflow Rate - Shall be between 0.25 - 0.38 gpm/ft^2. for conventional sedimentation. When tube settlers are used design of effluent weirs or pipes shall minimize carryover of floc from the tubes.

h. Velocity - The velocity through settling basins shall not exceed 0. 5 feet/minute. The basins must be designed to minimize short circuiting. Baffles must be provided as necessary. Not applicable if tube settlers are used.

i. Drainage - Basins must be provided with a means for dewatering. Basin bottoms should slope toward the drain not less than 1 foot in 12 feet where mechanical sludge collection equipment is not required. Drain lines shall be designed to empty the basin in 4 hours or less.

j. Weir Overflow Rate - An overflow weir should be installed which will establish the maximum water level desired on top of the filters. Adjustable V-notch weirs are preferred. Weir overflow rates shall be between 8 - 10 gpm/ft. for raw water with low turbidity and 10 - 15 gpm/ft. for raw water with high turbidity. It shall discharge with a free fall at a location where the discharge can be observed. Other methods will be considered when presented.

k. Safety - Permanent ladders or handholds should be provided for safety on the inside walls of basins above water level. Guard rails shall be included. Flushing lines or hydrants must not include interconnection of the potable water with non-potable water.

l. Sludge Collection - Mechanical sludge collection equipment should be provided.

m. Sludge Disposal - Facilities are required by the Department for disposal of sludge. See Section 4.11. Provision shall be made for operator to observe or sample sludge being withdrawn from unit.

4.1.5 Solids Contact Unit - Solids contact units are acceptable for clarification and/or softening. Clarifiers should be designed for the maximum uniform rate and should be adjustable to changes in flow which are less than the design rate and for changes in water characteristics. A minimum of 2 units is required. The following are design criteria for consideration, but any design shall be submitted in detail to be reviewed on a case-by-case basis.

a. Installation of equipment - Supervision by a representative of the manufacturer should be provided with regard to all mechanical equipment at the time of:

1. installation, and
2. initial operation.

b. Operating equipment - The following should be provided for plant operation:

1. a complete outfit of tools and accessories,

2. necessary laboratory equipment,

3. adequate piping with suitable sampling taps so located as to permit the collection of samples of water from critical portions of the units.

c. Chemical feed - Chemicals should be applied at such points and by such means as to insure satisfactory mixing of the chemicals with the water.

d. Mixing - Mixing devices employed should be so constructed as to:

1. provide good mixing of the raw water with previously formed sludge particles, and

2. prevent deposition of solids in the mixing zone.

e. Flocculation - Flocculation equipment should:

1. be adjustable,

2. provide for coagulation to occur in a separate chamber or baffled zone within the unit,

3. provide the flocculation and mixing period to be not less than 30 minutes.

f. Sludge concentrators - The equipment should provide either internal or external concentrators in order to obtain a concentrated sludge with a minimum of waste water.

g. Sludge removal - Sludge removal design should provide that:

1. sludge pipes shall be not less than three inches in diameter and so arranged as to facilitate cleaning,

2. entrance to sludge withdrawal piping shall prevent clogging,

3. valves shall be located outside the tank for accessibility,

4. operator may observe or sample sludge being withdrawn from the unit,

5. backflow from sanitary sewer systems be impossible.

h. Cross-connections:

1. blow-off outlets and drains should terminate and discharge at places satisfactory to the Department.

2. cross-connection control should be included for the potable water lines used to backflush sludge lines.

i. Detention period - Systems using a sludge blanket should have a minimum detention time of 1 hour with the flow rate not to exceed 1.0 gpm/ft2.

j. Suspended slurry concentrate - Units should be designed so that continuous slurry concentrates of 1% or more, by weight, can be satisfactorily maintained.

k. Water Losses

1. units should be provided with suitable controls for sludge withdrawal,

2. total water losses should not exceed:

(i) 5% for clarifiers,

(ii) 3% for softening units.

3. solids concentration of sludge bled to waste should be:

(i) 3% by weight for clarifiers,

(ii) 5% per cent by weight for softeners,

l. Weirs or orifices - The units should be equipped with either overflow weirs or orifices. Weirs shall be:

1. adjustable,

2. at least equivalent in length to the perimeter of the tank,

3. constructed so that surface water does not travel over 10 feet horizontally to the collection trough.

m. Weir loading - Should be same as conventional settling.

4.2 FILTRATION - Acceptable filters include, at the discretion of the Department, the following types:

a. Gravity filters,

b. Pressure filters.

The application of any one type must be supported by water quality data representing a reasonable period of time to characterize the variations in water quality. Experimental treatment studies may be required to demonstrate the applicability of the method of filtration proposed.

4.2.1 Gravity Filters

a. Number - At least two units shall be provided. Where declining rate filtration is provided, the variable aspect of filtration rates, and the number of filters must be considered when determining the design capacity for the filters.

b. Rate of Filtration

1. standard rate filtration - The permissible rate of filtration shall be determined by the quality of the raw water, the degree of pretreatment provided, the filter media provided the quality of operation provided and other considerations required by the Department. The nominal rate shall be 2 gpm/ft^2 of filter area for turbidity removal plants, and 3 gpm/ft^2 of filter area for iron removal plants,

2. high rate filtration - Filtration rates for turbidity or iron removal plants of up to 4 gpm/ft^2 are acceptable with the following.

i. mixing, flocculation, and sedimentation must meet the requirements of section 4.1.

ii. dual or mixed filter media must be used.

iii. additional instrumentation for coagulation control may be required for those plants with filter rates greater than 3 gpm/ft^2. (Examples: raw and settled water continuous monitoring turbidimeters, pilot filter or zetameter.)

iiii. filtration rates above 4 gpm/ft^2 will be considered on a case-by-case basis with a trial period to demonstrate effective treatment at the increased rate.

c. Declining Rate Filtration - This is a design where no rate-of-flow controllers are installed. The rate of flow through the filter media is greatest when the media has just been back washed and gradually declines as the media becomes filled with contaminants.

1. the design must include means to insure that the water level during operation will not fall below the level of the top of the media.

2. the filtration rate must not exceed 6 gpm/ft^2 when the filter is clean (immediately following back wash) and uses dual or mixed media.

3. this design is normally appropriate only when four or more filters are used in the plant.

d. Direct Filtration - Will be considered on a case-by-case basis depending on the quality and variability of the source water. All filters shall have dual or mixed media. A flash mix shall be provided and flocculation basins may also be required.

e. Structural Details and Hydraulics - The filter structure shall be so designed as to provide for:

1. vertical walls within the filter, unless otherwise approved,
2. no protrusion of the filter walls into the filter media,
3. enclosure in a building,
4. head room to permit normal inspection and operation,
5. minimum depth of filter of 8-1/2 feet,
6. minimum water depth over the surface of the sand of 3 feet,
7. trapped effluent to prevent backflow of air to the bottom of the filters,
8. prevention of floor drainage to the filter with a minimum 4-inch curb around the filters,
9. prevention of flooding by providing overflow,
10. maximum velocity of treated water in pipe and conduits to filters of 2 fps,
11. minimal disturbance of the media from incoming water,
12. washwater drain capacity to carry maximum flow,
13. walkways around filters, to be not less than 24 inches wide,
14. no common wall between settling basins and filters.

f. Washwater Troughs - Washwater troughs shall be so designed to provide:

1. the bottom elevation above the maximum level of expanded media during washing,

2. the top elevation above the filter surface not to exceed 30 inches,

3. a 2-inch freeboard at the maximum rate of wash,

4. the top or edge to be level,

5. spacing so that each trough serves the same number of square feet of filter area,

6. maximum horizontal travel of suspended particles to reach trough not to exceed 3 feet.

g. Filter Material - Installation of media shall be in accordance with current AWWA standards.

1. sand - the media shall be clean silica sand having:

    i. a depth of at least 30 inches,

    ii. an effective size of from 0.35 mm to 0.55 mm, depending upon the quality of the raw water, and

    iii. a uniformity coefficient not greater than 1.70.

2. dual media (Sand/Anthracite) - a combination of sand and clean crushed anthracite may be used. The anthracite shall have:

    i. an effective size of 0.8 mm - 1.2 mm, and
    ii. a uniformity coefficient not greater than 1.85
    iii. anthracite layer shall not exceed 20 inches in 30-inch bed
    iv. granular activated carbon may be substituted for anthracite if approved by the Division of Water Supply.

3. mixed Media - to be approved by the Department.

4. a 3-inch layer of torpedo sand may be used as a supporting media for the filter sand; such torpedo sand shall have:

    i. an effective size of 0.8 mm to 2.0 mm, and,

    ii. a uniformity coefficient not greater than 1.7.

5. gravel - gravel, when used as the supporting media, shall consist of hard, rounded particles.

    i. the minimum gravel size of the bottom layer should be 3/4 inch or larger

ii. for proper grading of intermediate layers:

(1) the minimum particle size of any layer should be as large as the maximum particle size in the layer next above and

(2) within any layer the maximum particle size should not be more than twice the minimum particle size.

iii. the depth of any gravel layer should not be less than 2 inches or less than twice the largest gravel size for that layer, whichever is greater. The bottom layer should be thick enough to cover underdrain laterals, strainers, or other irregularities in the filter bottom.

iv. the total depth of gravel above the underdrains should not be less than 10 inches.

6. reduction of gravel depths may be considered upon justification to the Department when proprietary filter bottoms are installed.

7. media retention systems with no support gravel will be considered for approval on a case-by-case basis.

h. Filter Bottoms and Strainer Systems - Departures from these standards may be acceptable for high rate filters and for proprietary bottoms. Porous plate bottoms shall not be used. The design of manifold type collection systems shall be such as to:

1. minimize loss of head in the manifold and laterals,

2. assure even distribution of washwater and even rate of filtration over the entire area of the filter,

3. provide the ratio of the area of the final openings of the strainer systems to the area of the filter at about 0.003,

4. provide the total cross-sectional area of the laterals at about twice the total area of the final openings,

5. provide the cross-sectional area of the manifold at l-1/2 to 2 times the total area of the laterals.

i. Surface Wash - Surface or subsurface wash facilities are required except for filters exclusively for iron or manganese removal, and may be accomplished by a system of fixed nozzles or a revolving-type apparatus.

1. all surface wash devices shall be designed with:

i. provisions for water pressures of 45 to 75 psi,

ii. air vacuum relief valve or a reduced pressure backflow preventer if the surface wash supply is provided through a separate line from the high service line,

iii. air wash can be considered based on experimental data and operating experiences.

j. Appurtenances - The following shall be provided for every filter:

1. sampling tap on the effluent line,

2. indicating loss-of-head gauge,

3. indicating flow-rate control; a modified rate controller which limits the rate of filtration to a maximum rate may be used,

4. provisions for draining the filter to waste with appropriate measures for backflow prevention (see Section 4.11.),

5. turbidimeter with recorder reading in NTU's on effluent line of each filter when raw water is from a surface source or ground source is in an area where turbidity may be a problem.

6. a 1 to 1½ inch pressure hose and storage rack on the operating floor for washing filter walls. The hose connection shall be protected with a vacuum breaker.

k. Backwash - Provisions shall be made for washing filters as follows:

1. a rate to provide for a 50 percent expansion of the media is recommended; for a sand filter, a minimum rate of 18.75 gpm/ft^2 is required, consistent with water temperatures and specific gravity of the filter media;

2. filtered water provided at the required backwash rate by washwater tanks, a washwater pump, from the high service main, or a combination of these;

3. washwater pumps in duplicate unless an alternate means of obtaining washwater is available,

4. water supply to back wash one filter for at least 15 minutes at the design rate of wash,

5. washwater regulator or valve on the main washwater line to obtain the desired rate of filter wash with the washwater valves on the individual filters open wide,

6. rate-of-flow indicator on the main washwater line, located so that it can be easily read by the operator during the washing process,

7. after washwater pumps are turned off and influent line is opened, a rewash cycle shall be performed for about 5 minutes during which water is filtered to the drain; piping must be provided for this purpose.

8. upon written request to this Department, if filter operation is automatic, the maximum permissible filter rate may be exceeded through remaining filters when one is being backwashed such that the plant flow would remain the same.

l. Miscellaneous - Roof drains shall not discharge into the filters or basins and conduits preceding the filters. All filters must be enclosed.

4.2.2 Pressure Filters - The use of these filters may be considered for iron and manganese removal and for turbidity removal from ground water sources. Pressure filters shall not be used in the filtration of surface waters or following lime soda softening.

a. General - Minimum criteria relative to number, rate of filtration, structural details and hydraulics, filter media, etc., provided for gravity filters also apply to pressure filters where appropriate.

b. Details of Design - The filters shall be designed to provide for:

1. head gauges on the inlet and outlet pipes of each filter,

2. an easily readable meter or flow indicator on each battery of filters; a flow indicator is recommended for each filtering unit,

3. filtration and backwashing of each filter individually with an arrangement of piping as simple as possible to accomplish these purposes,

4. minimum side wall shell height of 5 feet; a corresponding reduction in side wall height is acceptable where proprietary bottoms permit reduction of the gravel depth,

5. the top of the washwater collection trough to be at least 18 inches above the surface of media,

6. the underdrain system to collect efficiently the filtered water and to distribute the backwash water at a rate not less than 15 gpm/ft2 of filter area,

7. backwash flow indicators and controls that are easily readable while operating the control valves,

8. air release valve on the highest point of each filter,

9. accessible manhole to facilitate inspections and repairs,

10. means to observe the wastewater during backwashing,

11. construction to prevent cross-connection,

12. depth of filter media shall be the same as for gravity filters.

4.3 PACKAGE TREATMENT PLANTS, MEMBRANES AND OTHER TECHNOLOGIES - Will be reviewed on a case-by-case basis based on demonstrated performance criteria.

4.3.1 Package Treatment Plants – may be acceptable for source waters that are generally low in turbidity and do not experience large or frequent turbidity spikes. Filter backwash and clarifier flush/rinse frequencies along with water production efficiency must be considered for each application. Adequate detention times must be evaluated for oxidation processes, coagulation, TOC reduction and taste & odor control.

4.3.2 Membrane Filtration – is generally acceptable for turbidity/particulate removal. Each membrane module must have a continuous filtrate turbidity monitor and provisions for direct integrity testing. Other treatment processes such as coagulation, flocculation and oxidation must be used in conjunction with membranes where dissolved constituents such as TOC, iron and manganese are present in sufficient quantities to require treatment/removal. Clarification/sedimentation should be provided prior to membrane filtration where turbidity and suspended solids are very high in the raw water.

4.3.3 Cartridge and Bag Filters – will be considered for approval on a case-by-case basis depending on raw water quality and the size of the water system.

4.4 DISINFECTION - Chlorine is the preferred disinfecting agent. Other agents will be considered by the Department, provided reliable feeding equipment is available and testing procedures for a residual are recognized in "Standard Methods for the Examination of Water and Wastewater," latest edition. Continuous disinfection is recommended for all water supplies and is required at all community public water systems serving more than 50 connections or 150 persons.

4.4.1 Equipment

a. Type - Solution feed gas type chlorinator and hypochlorite feeders of the positive displacement type are acceptable (see Part 5). Alternative chlorine feeders such as tablet chlorinators may be considered for some applications.

b. Capacity - The chlorinator capacity shall be such that a free chlorine residual of at least 2 mg/L can be attained in the water after a contact time of at least 30 minutes when maximum flow rates coincide with anticipated maximum chlorine demands. The equipment shall be of such design that it will operate accurately over the desired feeding range.

c. Dual Chlorination - Two chlorinators shall be provided and operated simultaneously such that each feeds approximately half the chlorine requirement.

d. Spare Parts - Spare parts shall be provided so that either unit could be equipped to supply the entire chlorine requirement.

e. Automatic Switchover - Automatic switchover of chlorine cylinders should be provided where necessary to assure continuous disinfection. This does not take the place of having dual chlorination.

f. Automatic Proportioning - Automatic proportioning chlorinator will be required where the rate of flow either is not reasonably constant or where the quality of the water is subject to rapid changes.

4.4.2 Contact Time and Point of Application

a. Due consideration shall be given to the contact time of the chlorine in water with relation to pH, ammonia, taste producing substances, temperature, bacterial quality, trihalomethanes formation potential and other pertinent factors. Chlorine should be applied at a point which will provide adequate contact time. All basins used for disinfection must be designed to minimize short-circuiting.

b. At plants treating surface water, provisions should be made for applying chlorine to the raw water, top of filters, and filtered water.

c. At plants treating groundwater, provision should be made for applying chlorine to the clearwell inlet and the high lift pump suction.

d. Free residual (breakpoint) chlorination is required; 30 minutes contact time should be provided for ground waters and 2 hours for surface waters.

4.4.3 Chlorinator Piping

a. The water supply piping shall be designed to prevent contamination of the treated water supply by source of questionable quality.

b. Pipe material - The pipes carrying elemental liquid or dry gaseous chlorine under pressure and liquid chlorine must be schedule 80 seamless steel tubing or other materials recommended by the Chlorine Institute (never use PVC). Rubber, PVC, polyethylene, or other materials recommended by the Chlorine Institute must be used for chlorine solution piping and fittings. Nylon products are not acceptable for any part of the chlorine solution piping system.

c. Backflow Protection - All chlorine solution lines feeding into water having less than a full cycle of treatment (ahead of filters) shall be vented to the outside atmosphere. This venting shall be provided in such a manner that backflow into treated waters is prevented. Vacuum breakers and other mechanical devices shall not be substituted for a vent. Vents for chlorine lines shall:

1. be the same size as the solution line piping,
2. be connected to the solution line at a point where it is elevated a minimum of 6 feet above the maximum water level in the receiving basin,
3. have no shut off valves,
4. be extended to a high enough elevation outside the building that overflow from the vent tube during surges is prevented,
5. have a nylon or other suitable insert screen covering the vent which has been turned downward near its end,
6. not be subject to back pressures.

d. Distribution Panels - The Department recommends the use of chlorine solution distribution panels to ease the change of chlorine solution application points or the change of chlorine feed equipment. If a distribution panel is installed all chlorine solution lines except those feeding into the clear well or filter effluent must be vented as specified in section 4.4.3c. This venting is to be located between the distribution panel discharge and the point of application. Where chlorine solution from one chlorine feed unit is to be split to feed at more than one application point, a suitable rotameter shall be installed to allow accurate proportioning of the total flow among the application points.

4.4.4 Housing - Adequate housing must be provided for the chlorination equipment and for storing the chlorine supply (See Section 5.3).

4.4.5 Chlorine Dioxide – May be used for oxidation, disinfection and/or treatment of tastes and odors. Chlorine dioxide may be considered in conjunction with other treatment processes for meeting surface water treatment requirements or as an alternative to raw water chlorination where disinfection by-products must be reduced. Water systems that add chlorine dioxide must monitor for chlorine dioxide residual and chlorite.

4.4.6 UV Light - May be used for disinfection at water treatment plants in conjunction with chlorination and other treatment processes to meet surface water treatment requirements. UV light may also be used at groundwater treatment plants. Water systems using UV light must also provide chlorination for residual disinfection.

4.4.7 Ozone – May be used at water treatment plants for oxidation, disinfection, and meeting surface water treatment requirements. Water systems using ozone must monitor for bromate.

4.4.8 Hydrogen Peroxide – May be used at water treatment plants for raw water oxidation and/or disinfection. Hydrogen peroxide may be used to replace raw water chlorination where disinfection by-products must be reduced.

4.4.9 Permanganates – Potassium permanganate or sodium permanganate may be used for raw water oxidation and/or disinfection. Permanganates may be used to replace raw water chlorination where disinfection by-products must be reduced.

4.4.10 Chloramines – Will be considered for use in water distribution systems if other methods to reduce disinfection by-products have failed to achieve compliance. Effects of chloramination on water chemistry, corrosivity and microbiological water quality must be evaluated.

4. 5 SOFTENING - In all but a very few locations in Tennessee softening of available raw water is not needed. Unless there is a demonstrated need, softening should be avoided because of the additional expense and because of the increased sodium content of the water when ion exchange softening is used.

4.5.1 Lime-Soda Process - The applicable design standards for mixing, flocculation and sedimentation are the same for the lime-soda process as for conventional clarification. Where softening is included as a treatment process in conjunction with clarification, the clarification criteria shall govern(see sections 4.1.2, 4.1.3 and 4.1.4). For criteria pertaining to softening with solids contact units see section 4.1.5.

a. Aeration - Determinations should be made for the C02 content of the raw water. When concentrations exceed 10 mg/L, the economics of removal by aeration as opposed to removal with lime should be considered (See Section 4.6).

b. Stabilization - Equipment for stabilization of water softened by the lime-soda process is required.

c. Sludge Collection - Mechanical sludge removal equipment shall be provided in the sedimentation basin (see section 4.11 for sludge disposal).

d. Sludge Disposal - Provisions must be included for proper disposal of softening sludges(See Section 4.11).

e. Disinfection - The use of excess lime shall not be considered an acceptable substitution for chlorination or any other approved method of disinfection (See Section 4.4).

4.5.2 Cation Exchange Process - Iron, manganese, or a combination of the two, in the oxidized state or unoxidized state, should not exceed 0.3 mg/L in the water as applied to the ion exchange resin. Pretreatment is required when the content of iron, manganese, or a combination of the two, is 1 mg/L or more.

a. Design - The units may be of pressure or gravity type, using automatic or manual regeneration. Automatic regeneration is suggested for small plants.

b. Exchange Capacity - The design capacity for hardness removal should not exceed 20,000 grains per cubic foot when resin is regenerated with 0.3 pounds of salt per kilogram of hardness removed..

c. Depth of Media - The depth of the exchange material should not be less than 3 feet.

d. Flow Rates - The rate of softening should not exceed 7 gallons per square foot per minute and the backwash rate should be 6 to 8 gallons per square foot per minute. Rate-of-flow controllers or the equivalent must be installed for the above purposes.

e. Freeboard - The freeboard will depend upon the specific gravity of the media. Generally, the washwater collector should be 24 inches above the top of the media.

f. Underdrains and Supporting Gravel - The bottoms strainer systems, and support for the exchange material shall conform to criteria provided for rapid rate gravity filters (See Sections 4.2.lg and 4.2.1h).

g. Brine Distribution - Facilities should be included for even distribution of the brine over the entire surface.

h. Cross Connection Control - Backwash, rinse and air relief discharge pipes should be installed in such a manner as to prevent any possibility of back-siphonage.

i. Bypass - A bypass shall be provided around softening units to produce a blended water of desirable hardness. Meters should be installed on the bypass line and on each softener unit. An automatic proportioning or regulating device and shut-off valve should be provided on the bypass line. In some installations it may be necessary to treat the bypassed water to obtain acceptable levels of iron and/or manganese in the finished water.

j. Additional Limitations - Waters having 1.0 units or more turbidity should not be applied directly to the cation exchange softener. Silica gel materials should not be used for waters having a pH above 8.4 or containing less than 6 mg/L silica and should not be used when iron is present. The cation exchange material shall be a type that is not damaged by residual chlorine. Phenolic resin should not be used.

k. Sampling Taps - Smooth-nose sampling taps must be provided for the collection of representative samples for both bacteriological and chemical analyses. The taps shall be located to provide for sampling of the softener influent, softener effluent, and the blended water. The sampling taps for the blended water shall be at least 20 feet downstream from the point of blending. Petcocks are not acceptable as sampling taps. Sampling taps should be provided on the brine tank discharge piping.

l. Brine and Salt Storage Tanks

1. salt dissolving or brine tanks and wet storage tanks must be covered and must be corrosion resistant.

2. the make-up water inlet must be protected from back siphonage. Water for filling the tank should be distributed over the entire surface by pipes above the maximum brine level in the tank. The tanks should be provided with an automatic declining level control system on the make-up water line.

3. wet salt storage basins must be equipped with manholes or hatchways for access and for direct dumping of salt from truck or railcar. Openings must be provided with raised curbs and watertight covers having overlapping edges similar to those required for finished water reservoirs.

4. overflows, where provided, must be turned down, have a proper free fall discharge and be protected with corrosion resistant screens or self-closing flap valves.

5. two wet salt storage tanks or compartments designed to operate independently should be provided.

6. the salt is to be supported on graduated layers of gravel under which is a suitable means of collecting the brine.

7. alternative designs which are conducive to frequent cleaning of the wet salt storage tank may be considered.

m. Storage Capacity - Salt storage basins should have sufficient capacity to store in excess of 1-1/2 carloads or truckloads of salt, and to provide for at least 30 days of operation.

n. Stabilization - Stabilization for corrosion control shall be provided (See Section 4.9).

o. Waste Disposal - Suitable disposal must be provided for brine waste (See Section 4.11).

p. Construction Material - Pipes and contact materials must be resistant to the aggressiveness of salt. Plastic and red brass are acceptable piping material. Steel and concrete must be coated with a non-leaching protective coating which is compatible with salt and brine.

q. Housing - Salt Storage tanks and feed equipment should be enclosed and separated from other operating areas in order to prevent damage to equipment.

4.6 AERATION - Aeration treatment devices as described herein may be used for oxidation, separation of gases or for taste and odor control.

4.6.1 Natural Draft Aeration - Design should provide that:

a. Water is distributed uniformly over the top tray,

b. Water is discharged through a series of three or more trays with separation of trays not less than 12 inches,

c. Trays are loaded at a maximum rate of 20 gpm for each square foot of the top tray area,

d. Trays have heavy wire mesh or perforated bottoms,

e. Perforations are 3/16 to 1/2 inches in diameter, spaced 1 to 3 inches on centers, when perforations are used,

f. 8 to 12 inches of inert media are used, such as coke or limestone, that will not disintegrate due to freezing cycles,

g. Aerated water receives disinfection treatment,

h. Sufficient trays to reduce carbon dioxide to 10-15 mg/L,

i. Location to take advantage of prevailing wind direction.

4.6.2 Forced or Induced Draft Aeration - Devices shall be designed to:

a. Provide adequate countercurrent of air through enclosed aeration column,

b. Be insect proof and lightproof,

c. Be such that air introduced into column shall be screened through insect tight screen and be as free of dust as possible,

d. Insure that water outlet is adequately sealed to prevent unwanted loss of air,

e. Be such that sections of the aerator can be easily reached and removed for maintenance.

4.6.3 Other Methods of Aeration - Other methods of aeration may be used if applicable to the treatment needs. Such methods include but are not restricted to spraying, diffused air and mechanical aeration. The treatment processes must be designed to meet the particular needs of the water to be treated and are subject to the approval of the Department.

4.6.4 Wind Protection - Aerators that discharge through the atmosphere should be protected by being placed in a louvered enclosure so designed as to provide easy access to the interior.

4.6.5 Protection from Contamination - Aerators that are used for oxidation or removal of dissolved gases from waters that will be given no further treatment other than chlorination shall be protected from contamination from insects and birds.

4.6.6 Bypass - A bypass shall be provided for all aeration units.

4.6.7 Corrosion Control - The aggressiveness of the water after aeration should be determined and corrected by additional treatment, if necessary (See Section 4.9).

4. 7 IRON AND MANGANESE CONTROL - Iron and manganese control, as used herein, refers solely to treatment processes designed specifically for this purpose. The treatment process used will depend upon the character of the raw water. The selection of one or more treatment processes must meet specific local conditions as determined by engineering investigations, including chemical analysis of representative samples of water to be treated, and receive the approval of the Department. It may be necessary to operate a pilot plant in order to gather all information pertinent to the design.

4.7.1 Removal by Oxidation, Detention and Filtration.

a. Oxidation - Oxidation may be by aeration, as indicated in Section 4.6, or by chemical oxidation with chlorine or potassium permanganate.

b. Detention - A minimum detention of 20 minutes shall be provided following oxidation by aeration in order to insure that the oxidation reactions are as complete as possible. The detention basin shall be designed as a holding tank with no provisions for sludge collection but with sufficient baffling to prevent short circuits. Sedimentation basins should be provided when treating water with high iron and/or manganese content or where chemical coagulation is used to reduce the load on the filters.

c. Filtration - Filters shall conform to Section 4.2, except nominal rate shall not exceed 3 gpm/ft^2 of filter area.

4.7.2 Removal by Lime-Soda Process - See Section 4.5.1.

4.7.3 Removal by Units Using Continuous Potassium Permanganate "Regeneration" - This process, consisting of a continuous feed of potassium permanganate to the influent of a manganese green-sand filter, is more applicable to the removal of manganese than to the removal of iron, due to economic considerations. The following apply:

a. The permanganate should be applied as far ahead of the filter as practical.

b. Other oxidizing agents or processes such as chlorination or aeration may be used prior to the permanganate feed to reduce the cost of the chemical.

c. Anthracite media cap of at least six inches shall be provided over manganese treated greensand.

d. Normal filtration rate is 3 gpm/ft^2.

e. Normal wash rate is 8 to 10 gpm/ft^2.

f. Air washing should be provided.

g. Sample taps should be provided:

1. prior to application of permanganate,
2. immediately ahead of filtration,
3. at point between anthracite coal media and the manganese treated greensand,
4. halfway down the manganese treated greensand,
5. at the filter effluent.

4.7.4 Sequestration by polyphosphates - This process is only suitable only for concentrations of iron and manganese that are below the respective MCL's. The dosage should not exceed 10 mg/L. Where phosphate treatment is used, satisfactory chlorine residuals should be maintained in the distribution system.

a. Feeding equipment shall conform to requirements of Part 5.

b. Stock phosphate solution must be kept covered and disinfected by carrying approximately 10 mg/L chlorine residual.

c. The point of application should be prior to any aeration or oxidation if no iron or manganese removal treatment is provided.

d. Phosphate chemicals must be food grade and meet or exceed AWWA Specifications.

4.7.5 Sampling Equipment - Smooth-nosed sampling taps shall be provided for control purposes. Taps shall be located on each raw water source, each treatment unit influent and each treatment unit effluent.

4.7.6 Testing Equipment - Testing equipment shall be provided for all plants. The equipment should have the capacity to accurately measure the iron content to a minimum of 0.1 mg/L and the manganese content to 0.05 mg/L.

4.8 FLUORIDATION - Commercial sodium fluoride, sodium silicofluoride and hydrofluosilicic acid shall conform to the applicable AWWA Standards. Other chemicals which may be made available must be approved by the Department.

4.8.1 Fluoride Compound Storage - Compounds shall be stored in covered or unopened shipping containers. Bulk storage units and day tanks, including carboys and drums in use for hydrofluosilicic acid, shall be vented to the atmosphere at a point outside any building.

4.8.2 Dry Conveyers - Provision must be made for the proper transfer of dry fluoride compounds from shipping containers to storage bins or hoppers, in such a way as to minimize the quantity of fluoride dust.

4.8.3 Chemical Feed Installations

a. Shall conform to Part 5,

b. Shall provide scales or loss-of-weight recorders for dry or acid chemical feeds. Dry volumetric feeders are to have percent-of-cycle timer or variable speed SCR drive. A minimum of 35-gallon dissolver with mechanical agitation,

c. Shall have an accuracy that actual feed will be within 5% of that intended,

d. Shall be such that the point of application of hydrofluosilicic acid, if into a pipe, shall be in the lower third of the pipe and project upward,

e. Downflow saturators are not acceptable,

f. Shall provide adequate anti-siphon devices for all fluoride feed lines,

g. Piping from bulk storage to day tank should be schedule 80 PVC.

4.8.4 Protective Equipment - Suitable protective equipment shall be provided.

4.8.5 Dust Control Equipment - Suitable equipment shall be provided for wet-mopping and hosing dust that might accumulate in the plant.

4.8.6 Testing Equipment - Equipment shall be provided for measuring the quantity of fluoride ion in the water. Such equipment shall be subject to the approval of the Department.

4.9 CORROSION CONTROL - Corrosion is caused by a reaction between the pipe material and the water in direct contact with each other. Consequently, there are three basic approaches to corrosion control:

a. Using pipe materials and designing the system so it is not corroded by a given water,

b. Modifying the water quality so it is not corrosive to the pipe material,

c. Placing a protective barrier or lining between the water and the pipe.

4.9.1 System design

a. Choose compatible materials throughout system where possible to avoid forming galvanic cells,

b. Avoid dead ends and stagnant areas,

c. Reduce mechanical stress, sharp turns and elbows,

d. Provide adequate insulation and avoid uneven heat distribution,

e. Eliminate grounding of electrical circuits to system.

4.9.2 Cathodic Protection - Metal tanks and reservoirs should be considered for protection from corrosion by this method.

4.9.3 Modification of Water Quality

a. pH adjustment by addition of lime, caustic soda or soda ash, in order to stabilize the water with regard to calcium carbonate.

b. Control of oxygen. Advantages of aeration for iron, H_2S or $C0_2$ removal should be balanced against the fact that dissolved oxygen is a corrosive agent.

4.9.4 Use of inhibitors. These may be used as appropriate.

a. Addition of lime or alkalinity increases the tendency of water to deposit $CaCO_3$ forming a protective coating inside of pipe.

b. Inorganic phosphorus. Care is needed to select a chemical which not only masks the symptoms, but also reduces corrosion. (Sodium hexametaphosphate in low dosages of 2-4 mg/L only masks the symptoms while corrosion continues). Recent developments indicate the addition of zinc with a phosphate is effective in both inhibiting corrosion and controlling red water.

c. Sodium silicate. Effective in water with low hardness, alkalinity and pH less than 8.4 under relatively high velocity conditions.

4.9.5 Coatings and linings - Metal distribution system components' surfaces in contact with water shall be protected by being coated or lined.

a. Pipe linings include coal tar enamels, epoxy paint, and cement mortar.

b. Storage tanks are protected by such coatings as coal tar enamels, paints, vinyls, and epoxy.

4.10 TASTE AND ODOR CONTROL

4.10.1 Chlorination - Chlorination can be used for the removal of some objectionable odors. Adequate contact time must be provided to complete the chemical reactions involved.

4.10.2 Chlorine Dioxide - Chlorine dioxide has been generally recognized as a treatment for tastes caused by industrial wastes, such as phenols; however, chlorine dioxide can be used in the treatment of any taste or odor that is treatable by an oxidizing compound. Provision shall be made for proper storing and handling of sodium chlorite, so as to eliminate any danger of explosion (See Part 5).

4.10.3 Powdered Activated Carbon

a. Powdered activated carbon may be added prior to coagulation to provide maximum contact time, although facilities to allow the addition at several points is preferred, but not near the point of chlorine application.

b. The carbon can be added as a pre-mixed slurry or by means of a dry-feed machine as long as the carbon is properly "wetted".

c. Agitation is necessary to keep the carbon from depositing in the mixing chamber.

d. Provision shall be made for adequate dust control.

e. The required dosage of carbon in a water treatment plant depends upon the tastes and/or odors involved, but provision shall be made for adding 0 mg/L to at least 40 mg/L.

f. Powdered activated carbon shall be handled as a potentially combustible material. It should be stored in a building or compartment as nearly fireproof as possible. Other chemicals should not be stored in the same compartment. Carbon feeder rooms should be equipped with explosion-proof electrical outlets, lights and motors.

4.10.4 Granular Activated Carbon Adsorption Units - Granular activated carbon units shall not be used in place of filters described in Section 4.2. Rates of flow shall be consistent with the type and intensity of the problem. The design used must be supported by the results of pilot plant studies when granular activated carbon units are used for organic removal.

4.10.5 Copper Sulfate and Other Copper Compounds - Continuous or periodic treatment of water with copper compounds to kill algae or other growths shall be controlled to prevent copper in excess of 1.0 mg/L as copper in the plant effluent or distribution system. Care shall be taken in obtaining a uniform distribution:

a. If alkalinity is less than 50 mg/L, dose at 0.9 lb/acre-foot,

b. If alkalinity is greater than 50 mg/L, dose at 5.4 lb/acre-foot.

4.10.6 Aeration - See Section 4.6.

4.10.7 Potassium Permanganate - Application of potassium permanganate may be considered provided the point of application is prior to filtration.

4.10.8 Ozone - Ozonation can be used as a means of taste and odor control. Adequate contact time must be provided to complete the chemical reactions involved. Ozone is generally more desirable for treating water with high threshold odors.

4.10.9 Other Methods - The decision to use any other methods of taste and odor control should be made only after careful laboratory tests and on consultation with the Department.

4.10.10 Flexibility - Plants treating water that is known to have taste and odor problems should be provided with equipment that makes several of the control processes available so that the operator will have flexibility in operation.

4.11 WASTE DISPOSAL - Provisions must be made for proper disposal of water treatment plant waste such as sanitary, laboratory, clarification, softening and ion sludges, filter backwash, and brines. The quantity of waste produced in water treatment shall be minimized by choice of treatment processes and chemicals. If supernatant water from backwash/sludge holding tanks or lagoons is to be recycled through the treatment plant, potential impacts on the treatment process must be considered. Recycled water must be returned to the head of the treatment plant or to an alternate location approved by the Division of Water Supply. Recycled water should be settled/clarified to reduce contaminants that may be concentrated in sludges and backwash water.

4.11.1 Waste Water and Sludge - The following means of waste and sludge disposal may be considered:

a. Lagoons - Design should provide:

1. location free from flooding,
2. when necessary, dikes, deflecting gutters, or other means of diverting surface water,
3. a minimum usable depth of 4 to 5 feet with adequate freeboard,
4. 3 to 5 years solids storage volume,
5. multiple cells,
6. adjustable decanting devices,
7. convenient cleaning,
8. effluent sampling point,
8. adequate safety provisions.

b. Sludge Beds - Beds for lime softening sludges should provide for an application of slurry of at least 12 inches. Multiple beds should be provided so designed as to permit a minimum of one year's total storage. The storage capacity should be based on assumption that for each part per million of hardness removed there will be two parts per million of dry solids, and the accumulated sludge density being 120 pounds per cubic foot. Distribution channels are required for spreading sludge over the entire area. Provisions must be made for easy access and for paved loading ramps and underdrains. See Section 4.11.1.1 for provisions on flooding and surface water diversion.

c. Disposal to Sanitary Sewer System

1. approval must be obtained from sewer system officials.

2. consideration shall be given to the effects the water plant waste will have at the sewer plant including:

    i. effect on the sewage treatment process,

    ii. additional sludge to be handled.

3. consideration shall be given to the effects of disposal into the sewage collection system. A schedule for disposal shall be determined in conjunction with sewer system officials.

d. Other methods - These include holding tanks, vacuum filters, centrifuging, and recalcining. Detailed studies should be made to justify their use.

4.11.2 Sanitary Waste - The sanitary waste from water treatment plants, pumping stations, etc., must receive treatment. Waste from these facilities must be discharged either directly to a sanitary sewer system or to an individual waste disposal facility providing suitable

Section 11

Lab

HACH® 2100N LABORATORY TURBIDIMETER QUICK REFERENCE GUIDE

NEPHELOMETRIC MEASUREMENT PROCEDURE

1. Collect a representative sample in a clean container. Fill the sample cell to the line (approximately 30 mL). Take care to handle the sample cell by the top. Cap the sample cell. (*Note: Instrument warm-up stabilization time with Ratio on is 30 minutes and with Ratio off is 60 minutes. Typical application is to leave the instrument on 24 hours a day.)*

2. Hold the sample cell by the cap, and wipe to remove water spots and finger prints.

3. Apply a thin bead of silicone oil from the top to the bottom of the cell—just enough to coat the cell with a thin layer of oil. Using the oiling cloth provided, spread the oil uniformly. Then, wipe off the excess. The cell should appear nearly dry with little or no visible oil. (*Note: See Section 2.3.2 Applying Silicone Oil in the instrument manual.)*

4. Place the sample cell in the instrument cell compartment, and close the cell cover. (*Note: For immediate update of the display, press* **ENTER.**)

5. If necessary, insert the EPA filter. Select manual or automatic ranging by pressing the **RANGE** key.

6. Select the appropriate **SIGNAL AVERAGING** setting (on or off) by pressing the **SIGNAL AVG** key.

7. Select the appropriate **RATIO** setting (on or off) by pressing the **RATIO** key. (*Note: Values >40 NTU require Ratio on*.)

8. Select the appropriate measurement unit (NTU, EBC or NEPH) by pressing the **UNITS/EXIT** key.

9. Read and record the results.

CALIBRATION

Preparing Recommended Formazin Dilutions

Hach Company recommends use of 20-, 200-, 1000- and 4000-NTU Formazin standards for calibration of the Model 2100N Turbidimeter. Prepare all Formazin dilutions immediately before calibration, and discard the dilutions after use. While 4000-NTU stock solutions are stable for up to one year, diluted solutions deteriorate more rapidly. Prepare dilutions of 20, 200 and 1000 NTUs according to the directions in *Table 2 (Formazin Standard Preparation)* in *Section 3* of the Instrument Manual. The dilution water also is used to make an initial blank measurement (refer to *Section 3.2 Calibration* in the Instrument Manual).

NOTE

The calibration is based on a first order linear equation consisting of up to three independent variables. Unpredictable results may occur if standards other than the recommended calibration points are used. The factory-suggested calibration points are those determined by Hach Company chemists and engineers to provide the best calibration accuracy. Use of standards other than those specified may result in less accurate calibrations.

Calibrating with Formazin Standards

The electronic and optical design of the 2100N Turbidimeter provides long-term stability and minimizes the need for frequent calibration. The three-detector ratioing optical system compensates for electronic and optical system variations between calibrations. When data is used for USEPA reporting, recalibrate at least every 90 days, or as stipulated by the regulating authority. Refer to *Section 3.2 Calibration* in the Instrument Manual.

1. Fill a clean sample cell to the line (≅ 30 mL) with dilution water. Wipe the cell clean and apply a thin film of silicone oil.

2. Place the sample cell into the cell holder, and *close the cell cover.*

3. Press the **CAL** key. The S0 annunciator lights. The NTU value of the dilution water used in the previous calibration is displayed.

4. Press the **ENTER** key. The instrument display counts down from 60 to 0, and then makes a measurement. This result is stored and used to compensate for the turbidity of the dilution water.

5. The instrument automatically increments to the next standard, displays the expected NTU value (e.g., 20.00 NTU), and the S1 annunciator lights. Remove the sample cell from the cell holder.

6. Fill a clean sample cell to the line with well-mixed, 20-NTU Formazin standard. Wipe the sample cell clean, and apply a thin film of silicone oil on its surface. Place it into the cell holder, and *close the cell cover*.

7. Press the **ENTER** key. The display counts down from 60 to 0, and makes a measurement. The instrument automatically increments to the next standard, the display shows 200.0 NTU, and the S2 annunciator lights. Remove the sample cell from the instrument.

8. Fill a clean sample cell to the line with well-mixed, 200-NTU Formazin standard. Wipe the cell clean and apply a thin film of silicone oil to the surface. Place it into the cell holder, and *close the cell cover*. Press the **ENTER** key. The instrument display counts down from 60 to 0, and then makes a measurement. The instrument automatically increments to the next standard, the display shows 1000 NTU, and the S3 annunciator lights. Remove the sample cell from the instrument.

9. Fill a clean sample cell to the line with well-mixed, 1000-NTU Formazin standard. Wipe the cell clean and apply a thin film of silicone oil to the surface. Place it in the cell holder and *close the cell cover*. Press the **ENTER** key. The instrument display counts down from 60 to 0, and then makes a measurement. The display automatically increments to the next standard, the display shows 4000 NTU, and the S4 annunciator lights. Remove the sample cell from the instrument.

10. Fill a clean sample cell to the line with well-mixed, 4000-NTU Formazin standard. Wipe the cell clean and apply a thin film of silicone oil to the surface. Place it in the cell holder and *close the cell cover*. Press the **ENTER** key. The instrument counts down from 60 to 0, and then makes a measurement. The display automatically increments back to the dilution water standard. The S0 annunciator lights, and the previously measured value of the dilution water is displayed.

11. Press the **CAL** key. The instrument makes calculations based on the new calibration data, stores the new calibration and returns the instrument to the measurement mode.

Reviewing the Calibration Sequence

Press the **CAL** key and then use the **UP ARROW** key to scroll through the standards to review calibration data currently in effect. If the instrument is connected to a printer, pressing the **PRINT** key prints all of the calibration data in effect. Press the **UNITS/EXIT** key to return to the operating mode without altering the current calibration data.

Using Gelex® Secondary Turbidity Standards

Periodically, as experience or regulating authorities indicate, verify the instrument calibration using Gelex Secondary Standards. If the reading in the range of use is not within 5% of the standard's assigned value, recalibrate using Formazin primary standards (refer to *Section 3.2.5 Using Gelex Secondary Turbidity Standards* in the Instrument Manual).

1. Calibrate the instrument with Formazin (refer to *Section 3.2 Calibration* in the Instrument Manual).

2. Verify that the instrument is set for the NTU mode, Ratio on and Automatic Ranging.

3. Thoroughly clean the outside of the Gelex vials, and apply a thin coating of silicone oil.

4. Place the lowest NTU Gelex Standard in the sample compartment with the triangle on the vial aligned with the index mark on the instrument sample compartment. Close the sample cell cover.

5. Press the **ENTER** key. Record the value displayed. Remove the standard from the instrument, and mark this value on the vial with a water soluble marker.

6. Repeat steps 3 through 5 for the other Gelex standards.

NOTE

Reassign new values to the Gelex standards each time the instrument is calibrated with Formazin.

ERROR CODES

Error codes may result from instrument malfunction or operator error. **Errxx** error codes are cleared from the display by pressing the **ENTER** key. The meter continues operating in the error condition; a calibration in progress can be continued. Any calibration being calculated (at the time the message appears) is discarded; the old calibration is retained. *Table 1* lists the error codes displayed for specific conditions.

Table 1. Error Codes

Code	Probable Cause	Corrective Action
Err01	Dilution water calculated to be >0.5 NTU	Start calibration over with higher quality dilution water, or filter the water with a membrane filter before use.
Err02	Two calibration standards have the same value, or their difference is less than 60.0 NTU. Standard 1 is too low (<10 NTU)	Recheck preparation of standards and repeat calibration.
Err03	Low light error	Reinsert sample. Check that lamp is on. Dilution may be necessary.
Err04	Memory malfunction	Switch instrument off and back on with I/O. Call Hach Service.
Err05	A/D over-range	Contact Hach Service.
Err06	A/D under-range	Contact Hach Service.
Err07	Light leak	Contact Hach Service.
Err08	Bad lamp circuit	Contact Hach Service.
Err09	Printer timeout error	Check that external printer is properly connected. Check that external printer is selected (on-line).
Err10	System voltage out of range	Switch instrument off and back on with I/O. Call Hach Service.
Err11	System loop test error	Switch instrument off and back on with I/O. Call Hach Service.

Diagnostic Functions

The diagnostic mode accesses system function information that is useful primarily when the instrument function is in doubt. Hach service technicians use the information for precise troubleshooting, speeding repairs, and avoiding unnecessary service returns.

Access diagnostic information by pressing and holding the **RIGHT ARROW** key for 3 seconds. Use the **ARROW** keys to edit the display to read the diagnostic code number of interest. Press the **ENTER** key to display the diagnostic value. More information may be obtained by purchasing the instrument service manual, or contacting the service center nearest you.

Diagnostic Codes

Code	Display	Description
00	bP on/bP of	Keyboard Beeper On/Off
01	FS Pr/SL Pr	Fast/Slow Print Device
21	Pr In	Printer Test
22	*	Display Test
23	*	Keyboard Test
24	*	Memory Test

Refer to *Table 6 Diagnostic Codes* in *Section 8 Troubleshooting* of the instrument manual for a list of diagnostic codes.

HACH COMPANY
WORLD HEADQUARTERS
P.O. BOX 389
Loveland, Colorado 80539
Telephone: (970) 669-3050
FAX: (970) 669-2932

Chlorine, Free

DOC316.53.01023

USEPA DPD Method[1]

Method 8021

(0.02 to 2.00 mg/L)

Powder Pillows or AccuVac® Ampuls

Scope and Application: For testing free chlorine (hypochlorous acid and hypochlorite ion) in water, treated waters, estuary and seawater. USEPA accepted for reporting for drinking water analyses.[2]

[1] Adapted from *Standard Methods for the Examination of Water and Wastewater.*

[2] Procedure is equivalent to USEPA and Standard Method 4500-Cl G for drinking water.

Test preparation

How to use instrument-specific information

The *Instrument-specific information* table displays requirements that may vary between instruments. To use this table, select an instrument then read across to find the corresponding information required to perform this test.

Table 1 Instrument-specific information

Instrument	Powder pillows		AccuVac Ampuls	
	Sample cell	**Cell orientation**	**Sample cell**	**Adapter**
DR 5000	2495402	Fill line faces user	2427606	—
DR 3900	2495402	Fill line faces user	2427606	LZV846 (A)
DR 3800, DR 2800, DR 2700	2495402	Fill line faces right	2122800	LZV584 (C)

Before starting the test:

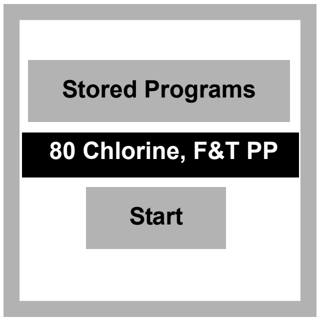
If the test over-ranges, dilute the sample with a known volume of high quality, chlorine demand-free water and repeat the test. Some loss of chlorine may occur due to the dilution. Multiply the result by the dilution factor. Alternatively, samples with high chlorine concentrations may be analyzed directly without dilution by using Method 10069, Chlorine, Free HR, or Method 10245, Chlorine Free MR .
The SwifTest Dispenser for Free Chlorine can be used in place of the powder pillow in step 4.
Analyze samples immediately. Do not preserve for later analysis.
The sample cell shown is a generic representation. Refer to *Instrument-specific information* for the correct sample cell and adapter configuration.
An empty AccuVac ampule can be used as a blank in place of the sample cell in Step 2.
Do not use the same sample cells for free and total chlorine. If trace iodide from the total chlorine reagent is carried over into the free chlorine determination, monochloramine will interfere. It is best to use separate, dedicated sample cells for free and total chlorine determinations.

Collect the following items:

Description	Quantity
Powder Pillow Test:	
DPD Free Chlorine Reagent Powder Pillows, 10-mL	1
Sample Cells (see *Instrument-specific information*)	2
AccuVac Test:	
DPD Free Chlorine Reagent AccuVac® Ampuls	1
Beaker, 50-mL	1
Sample Cell (see *Instrument-specific information*)	1

See *Consumables and replacement items* for reorder information.

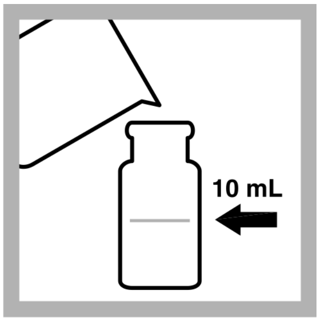
Powder pillow procedure



1. Select the test.

Insert an adapter if required (see *Instrument-specific information*).

Refer to the user manual for orientation.



2. Blank Preparation: Fill a sample cell with 10 mL of sample.

3. Wipe the blank and insert it into the cell holder.

ZERO the instrument.

The display will show:

0.00 mg/L Cl_2

4. Prepared Sample: Fill a second cell with 10 mL of sample.

Add the contents of one DPD Free Chlorine Powder Pillow to the sample cell.

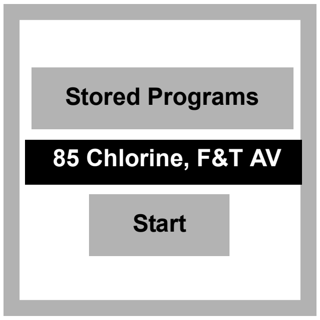
5. Swirl the sample cell for 20 seconds to mix.

A pink color will develop if chlorine is present. Proceed to step 6 immediately.

6. Within one minute of adding the reagent, insert the prepared sample into the cell holder.

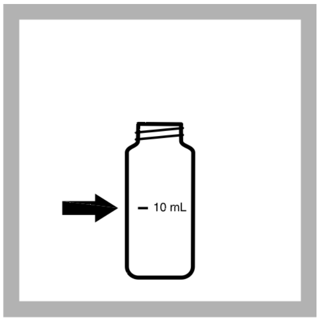
Results are in mg/L Cl_2.

AccuVac Ampuls procedure



1. Select the test.

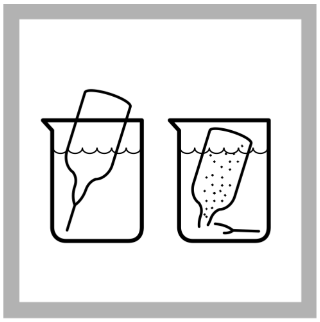
Insert an adapter if required (see *Instrument-specific information*).



2. Blank Preparation: Fill a sample cell with 10-mL of sample.

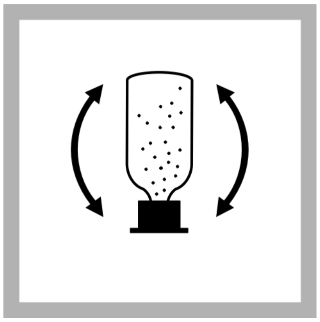
3. Wipe the blank and insert it into the cell holder.

ZERO the instrument. The display will show: 0.00 mg/L Cl_2

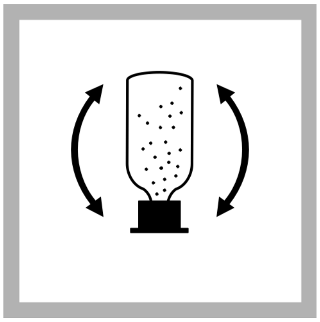


4. Prepared Sample: Collect at least 40 mL of sample in a 50-mL beaker.

Fill a DPD Free Chlorine Reagent AccuVac Ampul with sample. Keep the tip immersed while the Ampul fills completely.



5. Quickly invert the Ampul several times to mix. Wipe off any liquid or fingerprints.



6. Within one minute after sample addition, wipe the AccuVac Ampul and insert it into the cell holder.

READ the results in mg/L Cl_2

Interferences

Table 2 Interfering substances and levels

Interfering substance	**Interference levels and treatments**
Acidity	Greater than 150 mg/L $CaCO_3$. May not develop full color or color may fade instantly. Neutralize to pH 6–7 with 1 N Sodium Hydroxide. Determine amount to be added on separate sample aliquot, then add the same amount to the sample being tested. Correct for volume addition.
Alkalinity	Greater than 250 mg/L $CaCO_3$. May not develop full color or color may fade instantly. Neutralize to pH 6–7 with 1 N Sulfuric Acid. Determine amount to be added on separate sample aliquot, then add the same amount to the sample being tested. Correct for volume addition.
Bromine, Br_2	Interferes at all levels
Chlorine Dioxide, ClO_2	Interferes at all levels
Chloramines, organic	May interfere
Hardness	No effect at less than 1000 mg/L as $CaCO_3$
Iodine, I_2	Interferes at all levels
Manganese, Oxidized (Mn^{4+}, Mn^{7+}) or Chromium, Oxidized (Cr^{6+})	**1.** Adjust sample pH to 6–7. **2.** Add 3 drops Potassium Iodide (30-g/L) to a 10-mL sample. **3.** Mix and wait one minute. **4.** Add 3 drops Sodium Arsenite [1] (5-g/L) and mix. **5.** Analyze 10 mL of the treated sample as described in the procedure. **6.** Subtract the result from this test from the original analysis to obtain the correct chlorine concentration.
Monochloramine	Causes a gradual drift to higher readings. When read within 1 minute after reagent addition, 3 mg/L monochloramine causes less than a 0.1 mg/L increase in the reading.
Ozone	Interferes at all levels
Peroxides	May interfere
Extreme sample pH or highly buffered samples	Adjust to pH 6–7 using acid (Sulfuric Acid, 1.000 N) or base (Sodium Hydroxide, 1.00 N).

[1] Samples treated with sodium arsenite for interferences will be hazardous waste as regulated by Federal RCRA for arsenic (D004). See the current MSDS for proper disposal of hazardous material.

Sample collection, preservation and storage

- Analyze samples for chlorine immediately after collection. Free chlorine is a strong oxidizing agent and it is unstable in natural waters. It reacts rapidly with various inorganic compounds and more slowly oxidizes organic compounds. Many factors, including reactant concentrations, sunlight, pH, temperature and salinity influence decomposition of free chlorine in water.
- Avoid plastic containers since these may have a large chlorine demand.
- Pretreat glass sample containers to remove any chlorine demand by soaking in a dilute bleach solution (1 mL commercial bleach to 1 liter of deionized water) for at least 1 hour. Rinse thoroughly with deionized or distilled water. If sample containers are rinsed thoroughly with deionized or distilled water after use, only occasional pre-treatment is necessary.

- A common error in testing for chlorine is not obtaining a representative sample. If sampling from a tap, let the water flow for at least 5 minutes to ensure a representative sample. Let the container overflow with the sample several times, then cap the sample containers so there is no headspace (air) above the sample. If sampling with a sample cell, rinse the cell several times with the sample, then carefully fill to the 10-mL mark. Perform the chlorine analysis immediately.

Accuracy check

Standard additions method (Sample spike)
Required for accuracy check:

- Chlorine Standard Solution, 2-mL PourRite® Ampule, 25–30 mg/L
- Breaker, PourRite Ampules
- Pipet, TenSette®, 0.1–1.0 mL and tips

1. After reading test results, leave the sample cell (unspiked sample) in the instrument.
2. Select Options>More>Standard Additions from the instrument menu.
3. Enter the average chlorine concentration shown on the label of the ampule container.
4. A summary of the standard additions procedure will be displayed. Press **OK** to accept the default values for standard concentration, sample volume and spike volumes. After the values are accepted, the unspiked sample reading will appear in the top row.
5. Open one Voluette ampule standard.
6. Prepare spiked samples: add 0.1 mL, 0.2 mL and 0.3 mL of standard to three 10-mL portions of fresh sample.

   Note: *For AccuVac® Ampuls, add 0.4 mL, 0.8 mL and 1.2 mL of standard to three 50-mL portions of fresh sample.*

7. Follow the test procedure for each of the spiked samples using the powder pillows or AccuVac ampules, starting with the smallest sample spike. Measure each of the spiked samples in the instrument.
8. Select **GRAPH** to view the results. Select **IDEAL LINE** (or best-fit) to compare the standard addition results to the theoretical 100% recovery.

Note: *If results are not within acceptable limits (± 10%), be sure that the sample volumes and sample spikes are measured accurately. The sample volumes and sample spikes that are used should agree with the selections in the standard additions menu. If all procedures are followed correctly but the standard additions results are not within acceptable limits, the sample may contain an interference.*

Method performance

Program	Standard	Precision 95% Confidence Limits of Distribution	Sensitivity Concentration change per 0.010 Abs change
80	1.25 mg/L Cl_2	1.23–1.27 mg/L Cl_2	0.02 mg/L Cl_2
85	1.25 mg/L Cl_2	1.21–1.29 mg/L Cl_2	0.02 mg/L Cl_2

Summary of method

Chlorine in the sample as hypochlorous acid or hypochlorite ion (free chlorine or free available chlorine) immediately reacts with DPD (N,N-diethyl-p-phenylenediamine) indicator to form a pink color, the intensity of which is proportional to the chlorine concentration. Test results are measured at 530 nm.

Consumables and replacement items

Required reagents

Description	Quantity/Test	Unit	Catalog number
DPD Free Chlorine Reagent Powder Pillows, 10-mL	1	100/pkg	2105569
OR			
DPD Free Chlorine Reagent AccuVac® Ampuls	1	1	2502025

Required apparatus

Description	Quantity	Unit	Catalog number
Beaker, 50-mL	1	each	50041H
AccuVac Snapper	1	each	2405200
Sample cell, 10 mL round, 25 x 54 mm	1	each	2122800
Sample cell, 10 mL round, 25 x 60 mm	1	6/pkg	2427606
Sample cell, 10 mL square, matched pair	2	2/pkg	2495402

Recommended standards

Description	Unit	Catalog number
Chlorine Standard Solution, 2-mL PourRite® Ampule, 25–30 mg/L	20/pkg	2630020
PourRite Ampule breaker, 2-mL	each	2484600

Optional reagents and apparatus

Description	Unit	Catalog number
Chlorine-demand Free Water	500 mL	2641549
Cylinder, mixing, 25 mL	each	2088640
Cylinder, mixing, 50 mL	each	189641
Sodium Hydroxide, 1 N	100 mL	104532
Sulfuric Acid, 1 N	100 mL	127032
Potassium Iodide, 30-g/L	100 mL	34332
Sodium Arsenite, 5-g/L	100 mL	104732
SwifTest Dispenser for Free Chlorine[1]	each	2802300
Pipet, TenSette®, Pipet, 0.1 - 1.0 mL	each	1970001
Pipet Tips, for TenSette Pipet 1970001	50/pkg	2185696
Pipet Tips, for TenSette Pipet 1970001	1000/pkg	2185628
pH Paper, 0 - 14 pH range	100/pkg	2601300
Voluette Ampule breaker, 10 mL	each	2196800
AccuVac, vials for sample blanks	25/pkg	2677925
Chlorine Standard Solution, 2-mL PourRite® Ampule, 50–75 mg/L	20/pkg	1426820
Chlorine Standard Solution, 10-mL Voluette® Ampule, 50–75 mg/L	16/pkg	1426810
DPD Free Chlorine Reagent Powder Pillows, 10-mL	1000/pkg	2105528
DPD Free Chlorine Reagent Powder Pillows, 10-mL	300/pkg	2105503
DPD Free Chlorine Reagent, 10 mL, SwifTest Dispenser refill vial	250 tests	2105560
SpecCheck Secondary Standard Kit, Chlorine DPD, 0–2.0 mg/L Set	each	2635300

[1] Includes one vial of 2105560 for 250 tests

Fluoride

DOC316.53.01184

USEPA[1] SPADNS 2[2]

Method 10225

(0.02 to 2.00 mg/L F^-)

Reagent Solution or AccuVac® Ampuls

Scope and Application: For water, wastewater and seawater; USEPA accepted for reporting for drinking and wastewater analyses (distillation required; see *Distillation* in this procedure).

[1] Procedure is equivalent to USEPA method 340.1 for drinking water and wastewater analysis

[2] Adapted from *Standard Methods for the Examination of Water and Wastewater, 4500-F B & D.*

Test preparation

How to use instrument-specific information

The *Instrument-specific information* table displays requirements that may vary between instruments. To use this table, select an instrument then read across to find the corresponding information required to perform this test.

Table 1 Instrument-specific information

Instrument	Powder pillows		AccuVac Ampuls	
	Sample cell	Cell orientation	Sample cell	Adapter
DR 5000	2495402	Fill line faces user	2427606	—
DR 3900	2495402	Fill line faces user	2427606	LZV846 (A)
DR 3800, DR 2800, DR 2700	2495402	Fill line faces right	2122800	LZV584 (C)

Before starting the test:

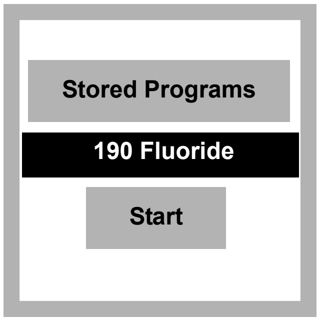
The sample and deionized water should be at the same temperature (± 1 °C). Temperature adjustments may be made before or after reagent addition.
SPADNS 2 Reagent is corrosive. Use care while handling the reagent.
For best results, measure the volume of SPADNS 2 Reagent as accurately as possible.
If the instrument displays Over Measure Range!, dilute a fresh sample with an equal volume of deionized water and repeat the test, using this solution in step 2. Multiply the result by 2.
SPADNS 2 Reagent contains a non-toxic reducing agent to prevent chlorine interference. SPADNS 2 does not contain sodium arsenite.

Collect the following items:

Description	Quantity
Solution test	
SPADNS 2 Reagent Solution	4 mL
Deionized Water	10 mL
Pipet, volumetric, 2-mL	1
Pipet, volumetric, 10-mL	1
Pipet Filler Bulb	1
Sample cells (see *Instrument-specific information*)	2
Thermometer	1
AccuVac test	
SPADNS 2 Fluoride Reagent AccuVac® Ampuls	2
Deionized Water	40 mL
Beaker, 50-mL	1

See *Consumables and replacement items* for reorder information.

SPADNS 2 reagent solution

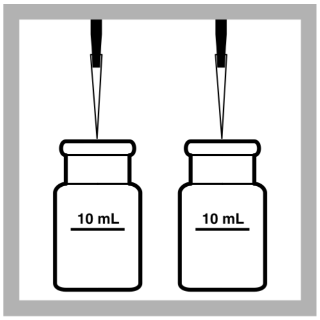


1. Select the test.

Insert an adapter if required (see *Instrument-specific information*).

2. Prepared Sample: Pipet 10.0 mL of sample into a dry sample cell.

3. Blank Preparation: Pipet 10.0 mL of deionized water into a second dry sample cell.



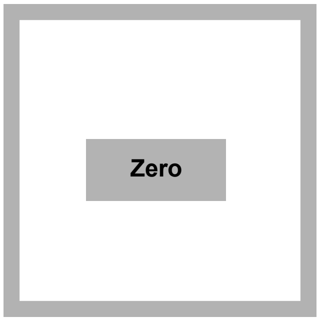
4. Carefully pipet 2.0 mL of SPADNS 2 Reagent into each cell. Swirl to mix.

SPADNS 2 reagent solution (continued)

5. Start the instrument timer.

A one-minute reaction period will begin.

6. When the timer expires, insert the blank.



7. **ZERO** the instrument.

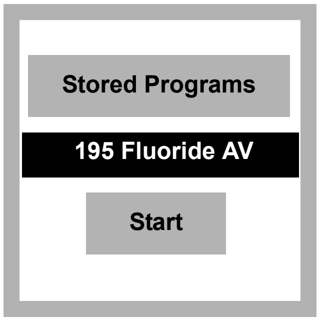
The display will show:

0.00 mg/L F–

8. Insert the prepared sample cell.

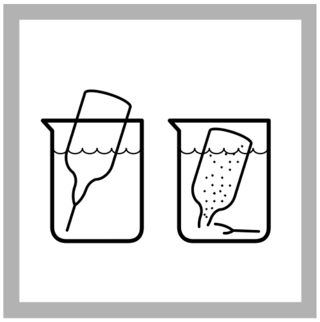
READ the results in mg/L F–.

SPADNS 2 AccuVac® Ampuls



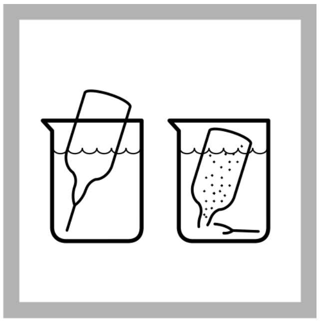
1. Select the test.

Insert an adapter if required (see *Instrument-specific information*).



2. **Prepared Sample:** Collect at least 40 mL of sample in a 50-mL beaker.

Fill one SPADNS 2 Fluoride Reagent AccuVac Ampul with sample. Keep the tip immersed while the Ampul fills completely.



3. **Blank Preparation:** Pour at least 40 mL of deionized water into a second beaker.

Fill a second Ampul with deionized water. Keep the tip immersed while the Ampul fills completely.

4. Quickly invert both Ampuls several times to mix.

SPADNS 2 AccuVac® Ampuls (continued)

5. Start the instrument timer.

A one-minute reaction period will begin.

6. When the timer expires, insert the blank into the cell holder.

ZERO the instrument.

The display will show:

0.00 mg/L F–

7. Insert the prepared sample into the cell holder

READ the results in mg/L F–.

Interferences

This test is sensitive to small amounts of interference. Glassware must be very clean (acid rinse before each use). Repeat the test with the same glassware to make sure that the results are accurate.

Table 2 Interfering substances

Interfering substance	Interference level
Alkalinity (as $CaCO_3$)	At 5000 mg/L causes a - 0.1 mg/L F– error
Aluminum	At 0.1 mg/L causes a - 0.1 mg/L F– error. To check for interferences from aluminum, read the concentration one minute after reagent addition, then again after 15 minutes. An appreciable increase in concentration suggests aluminum interference. Waiting 2 hours before making the final reading will eliminate the effect of up to 3.0 mg/L aluminum.
Chloride	At 7000 mg/L causes a +0.1 mg/L F– error
Chlorine	SPADNS 2 Reagent contains enough non-toxic reductant to eliminate interference up to 5 mg/L chlorine. For higher chlorine levels: **1.** Dilute sample with deionized water by a factor that will lower chlorine concentration to below 5 mg/L. **2.** Perform the SPADNS 2 reagent solution or AccuVac procedure. **3.** Multiply results by the dilution factor to obtain mg/L Fluoride.
Iron, ferric	At 10 mg/L causes a - 0.1 mg/L F– error
Phosphate, ortho	At 16 mg/L causes a +0.1 mg/L F– error
Sodium Hexametaphosphate	At 1.0 mg/L causes a +0.1 mg/L F– error
Sulfate	At 200 mg/L causes a +0.1 mg/L F– error

Distillation

Distillation Solution Preparation:

1. Measure 60 mL of deionized water into a 250 mL glass Erlenmeyer flask.
2. With constant stirring, add 120 mL of concentrated Sulfuric Acid. ***Caution: The mixture will become very hot. Allow the solution to cool before handling.***

To eliminate most interferences, dilute the sample from the acid solution as described below:

1. Set up the distillation apparatus for general purpose distillation. Refer to the Distillation Apparatus manual for proper assembly. Use a 125-mL Erlenmeyer flask to collect the distillate.
2. Turn on the water and maintain a steady flow through the condenser.
3. Measure 100 mL of sample into the distillation flask using a 100-mL graduated cylinder. Add a magnetic stir bar and 5 glass beads.
4. Turn the stirrer power switch on. Turn the stir control to 5.
5. Using a 250-mL graduated cylinder, carefully add 150 mL of Distillation Solution into the flask.

Note: *When distilling samples with high amounts of chloride, add 5 mg of Silver Sulfate to the sample for every mg/L of chloride in the sample.*

6. With the thermometer in place, turn the heat control to 10. The yellow pilot lamp indicates the heater is on.
7. When the temperature reaches 180 °C or when 100 mL of distillate has been collected, turn the still off (requires about 1 hour).
8. Dilute the distillate to a volume of 100 mL, if necessary. The distillate may now be analyzed by the SPADNS, SPADNS 2 or the fluoride ion-selective electrode method.

Sample collection, preservation and storage

- Samples may be stored in glass or plastic bottles for at least seven days when cooled to 4 °C (39 °F) or lower.
- Warm samples to room temperature before analysis.

Accuracy check

Standard solution method
Note: *Refer to the instrument user manual for specific software navigation instructions.*

A variety of standard solutions for the entire range of the test is available. Use standard solutions instead of sample to verify the technique.

Minor variations between lots of reagent become measurable above 1.5 mg/L. While results in this region are usable for most purposes, better accuracy may be obtained with steps 1–3.

1. Dilute a fresh sample 1:1 with deionized water.
2. Perform the test again
3. Multiply the result by 2.
4. To adjust the calibration curve with the reading obtained with the standard solution, select **Options>More>Standard Adjust** from the instrument menu.

5. Turn on the Standard Adjust feature and accept the displayed concentration. If an alternate concentration is used, enter the concentration and adjust the curve to that value.

Method performance

Program	Standard	Precision 95% Confidence Limits of Distribution	Sensitivity Concentration change per 0.010 Abs change
190	1.00 mg/L F^-	0.97–1.03 mg/L F^-	0.024 mg/L F^- at 1 mg/L
195	1.00 mg/L F^-	0.92–1.08 mg/L F^-	0.03 mg/L F^- at 1 mg/L

Safety

Follow good safety habits and laboratory techniques throughout the procedure. Consult the *Material Safety Data Sheet* for information specific to the reagents used.

Pollution prevention and waste management

SPADNS 2 Reagent does not contain sodium arsenite. Instead, it contains a non-toxic species to prevent chlorine interference. Dispose of all waste safely in accordance with local and federal guidelines.

Summary of method

The SPADNS 2 Method for fluoride determination involves the reaction of fluoride with a red zirconium-dye solution. The fluoride combines with part of the zirconium to form a colorless complex that bleaches the red color in an amount proportional to the fluoride concentration. This method is equivalent to the EPA method for NPDES and NPDWR reporting purposes when the samples have been distilled. Seawater and wastewater samples require distillation. Test results are measured at 580 nm.

Consumables and replacement items

Required reagents

Description	Quantity/Test	Unit	Catalog number
SPADNS 2 Reagent Solution	4 mL	500 mL	2947549
OR			
SPADNS 2 Fluoride Reagent AccuVac® Ampuls	2	25/pkg	2527025
Water, deionized	10 mL	4 L	27256

Required apparatus (solution)

Description	Quantity	Unit	Catalog number
Pipet Filler, safety bulb	1	each	1465100
Pipet, volumetric, Class A, 2.00-mL	1	each	1451536
Pipet, volumetric, Class A, 10.00-mL.	1	each	1451538
Sample cell, 10 mL square, matched pair	2	2/pkg	2495402
Thermometer	1	each	2635700

Required apparatus (AccuVac)

Description	Quantity	Unit	Catalog number
Beaker, 50-mL	1	each	50041H
Sample cell, 10 mL round, 25 x 54 mm	1	each	2122800
Sample cell, 10 mL round, 25 x 60 mm	1	6/pkg	2427606

Recommended standards

Description	Unit	Catalog number
Fluoride Standard Solution, 0.2-mg/L F^-	500 mL	40502
Fluoride Standard Solution, 0.5-mg/L F^-	500 mL	40505
Fluoride Standard Solution, 0.8-mg/L F^-	500 mL	40508
Fluoride Standard Solution, 1.0-mg/L F^-	1000 mL	29153
Fluoride Standard Solution, 1.0-mg/L F^-	500 mL	29149
Fluoride Standard Solution, 1.2-mg/L F^-	500 mL	40512
Fluoride Standard Solution, 1.5-mg/L F^-	500 mL	40515
Fluoride Standard Solution, 2.0-mg/L F^-	500 mL	40520
Fluoride Standard Solution, 100-mg/L F^-	500 mL	23249
Standard, Drinking Water, Mixed Parameter, Inorganic for F^-, NO_3, PO_4, SO_4	500 mL	2833049

Distillation reagents and apparatus

Description	Quantity	Unit	Catalog number
Cylinder, graduated, 100-mL	1	each	50842
Cylinder, graduated, 250-mL	1	each	50846
Distillation Heater and Support Apparatus Set,115 VAC, 50/60 Hz	1	each	2274400
AND			
Distillation Heater and Support Apparatus Set,230 VAC, 50/60 Hz	1	each	2274402
OR			
Distillation Apparatus Set, General Purpose	1	each	2265300
Flask, Erlenmeyer, 125-mL	1	each	2089743
Flask, Erlenmeyer, 250 mL, Glass	1	each	50546
Glass Beads	1	100/pkg	259600
Stir Bar, magnetic	1	each	1076416
Sulfuric Acid, ACS	1	500 mL	97949

Optional reagents and apparatus

Description	Unit	Catalog number
Silver Sulfate	113 g	33414
Balance Analytical 80 g x 0.1 mg 100–240 V	each	2936701
Weighing papers	500/pkg	1473800

FOR TECHNICAL ASSISTANCE, PRICE INFORMATION AND ORDERING:
In the U.S.A. – **Call toll-free 800-227-4224**
Outside the U.S.A. – **Contact the HACH office or distributor serving you.**
On the Worldwide Web – **www.hach.com**; E-mail – **techhelp@hach.com**

HACH COMPANY
WORLD HEADQUARTERS
Telephone: (970) 669-3050
FAX: (970) 669-2932

Edition 6

Manganese

DOC316.53.01057

1-(2-Pyridylazo)-2-Naphthol PAN Method[1]

Method 8149

LR (0.006 to 0.700 mg/L)

Powder Pillows

Scope and Application: For water and wastewater; digestion is required for determining total manganese

[1] Adapted from Goto, K., et al., *Talanta*, 24, 652-3 (1977)

Test preparation

How to use instrument-specific information

The *Instrument-specific information* table displays requirements that may vary between instruments. To use this table, select an instrument then read across to find the corresponding information required to perform this test.

Table 1 Instrument-specific information

Instrument	Sample cell	Cell orientation
DR 5000	2495402	Fill line faces user
DR 3900	2495402	Fill line faces user
DR 3800, DR 2800, DR 2700	2495402	Fill line faces right

Before starting the test:

Rinse all glassware with 1:1 Nitric Acid Solution. Rinse again with deionized water.
The alkaline cyanide solution contains cyanide. Cyanide solutions should be collected for disposal as a reactive (D001) waste. Be sure cyanide solutions are stored in a caustic solution with pH >11 to prevent release of hydrogen cyanide gas. Refer to the current MSDS for safe handling and disposal instructions.
Total manganese determination requires a prior digestion. Refer to the *Water Analysis Guide* for more information.

Collect the following items:

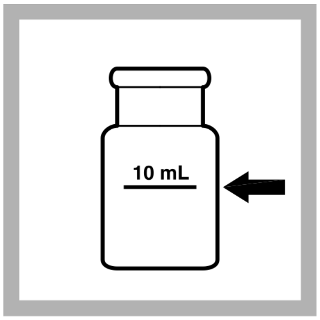
Description	Quantity
Alkaline Cyanide Reagent	12 drops
Ascorbic Acid Powder Pillows	2
PAN Indicator Solution, 0.1%	12 drops
Deionized Water	10 mL
Sample Cells (see *Instrument-specific information*)	2
Stoppers for 18 mm tube	2

See *Consumables and replacement items* for reorder information.

PAN method for powder pillows

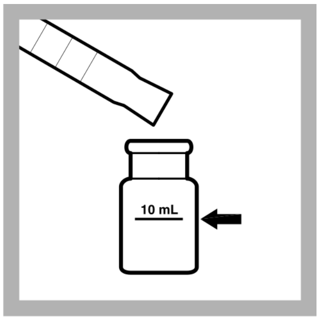
1. Select the test.

Insert an adapter if required (see *Instrument-specific information*).



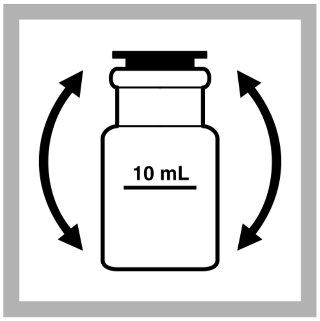
2. Blank Preparation: Pour 10.0 mL of deionized water into a sample cell.

Total manganese determination requires prior digestion.

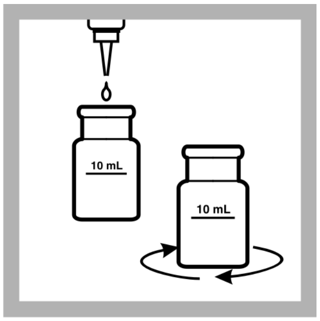


3. Prepared Sample: Pour 10.0 mL of sample into another sample cell.

4. Add the contents of one Ascorbic Acid Powder Pillow to each cell.

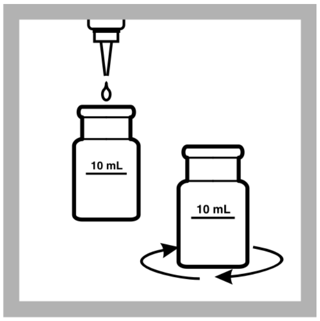


5. Stopper and invert to dissolve the powder.



6. Add 12 drops of Alkaline-Cyanide Reagent Solution to each cell. Swirl gently to mix.

A cloudy solution may form. The turbidity should dissipate after step 7.



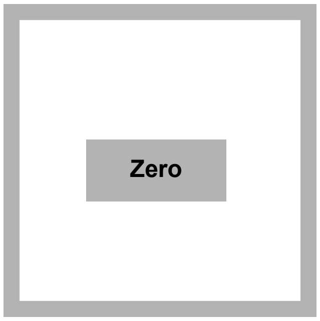
7. Add 12 drops of PAN Indicator Solution, 0.1%, to each sample cell. Swirl gently to mix.

An orange color will develop in the sample if manganese is present.

8. Start the instrument timer.

A two-minute reaction period will begin.

9. When the timer expires, wipe the blank and place it in the cell holder.

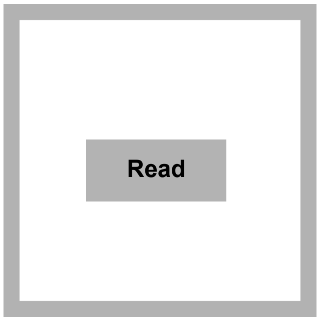


10. ZERO the instrument.

The display will show:

0.000 mg/L Mn

11. Wipe the prepared cell and place it in the holder.



12. READ the results in mg/L Mn.

Interferences

For samples that contain hardness greater than 300 mg/L $CaCO_3$, add 4 drops of Rochelle Salt Solution to the sample **after** adding the Ascorbic Acid Powder Pillow in step 4.

Table 2 Interfering substances

Interfering substance	Interference level
Aluminum	20 mg/L
Cadmium	10 mg/L
Calcium	1000 mg/L as $CaCO_3$
Cobalt	20 mg/L
Copper	50 mg/L
Iron	25 mg/L (If sample contains more than 5 mg/L iron, allow a 10-minute reaction period in step 8.)
Lead	0.5 mg/L
Magnesium	300 mg/L as $CaCO_3$
Nickel	40 mg/L
Zinc	15 mg/L

Sample collection, preservation and storage

- Collect samples in a clean plastic container.
- Adjust the pH to 2 or less with Concentrated Nitric Acid* (about 2 mL per liter).
- Preserved samples can be stored up to six months at room temperature.
- Adjust the pH to between 4–5 with 5.0 N Sodium Hydroxide before analysis.
- Correct the test result for volume additions.

Accuracy check

Standard additions method (sample spike)
Required for accuracy check:

- Manganese PourRite® Ampule Standard, 10-mg/L Mn
- Mixing cylinders (3)
- Ampule breaker, PourRite
- TenSette Pipet

1. After reading test results, leave the sample cell (unspiked sample) in the instrument.
2. Select Options>More>Standard additions from the instrument menu.
3. Accept the default values for standard concentration, sample volume and spike volumes. After the values are accepted, the unspiked sample reading will appear in the top row. See the user manual for more information.
4. Open the standard solution ampule.
5. Use the TenSette Pipet to prepare spiked samples: add 0.1 mL, 0.2 mL and 0.3 mL of standard to three 10 mL portions of fresh sample. Mix thoroughly.

6. Follow the *PAN method for powder pillows* test procedure for each of the spiked samples using the powder pillows, starting with the 0.1 mL sample spike. Measure each of the spiked samples in the instrument.
7. Select **GRAPH** to view the results. Select **IDEAL LINE** (or best-fit) to compare the standard addition results to the theoretical 100% recovery.

Standard solution method

Note: *Refer to the instrument user manual for specific software navigation instructions.*

Required for accuracy check:

- Manganese Voluette Standard Solution, 250 mg/L Mn
- 1 L Class A volumetric flask
- Deionized water
- Class A volumetric pipet, 2 mL
- Pipet filler, safety bulb

1. Prepare a 0.5 mg/L manganese standard solution as follows:
    a. Pipet 2.0 mL of Manganese Standard, 250 mg/L as Mn, into a 1000 mL (1 liter) volumetric flask.
    b. Dilute to the mark with deionized water. Mix well. Prepare this solution daily.
2. Use this solution in place of the sample. Follow the *PAN method for powder pillows* test procedure.
3. To adjust the calibration curve using the reading obtained with the standard solution, select Options>More>Standard Adjust from the instrument menu.
4. Turn on the Standard Adjust feature and accept the displayed concentration. If an alternate concentration is used, enter the concentration and adjust the curve to that value.

Method performance

Program	Standard	Precision 95% Confidence Limits of Distribution	Sensitivity Concentration change per 0.010 Abs change
290	0.500 mg/L Mn	0.491–0.509 mg/L Mn	0.006 mg/L Mn

Summary of method

The PAN method is a highly sensitive and rapid procedure for detecting low levels of manganese. An ascorbic acid reagent is used initially to reduce all oxidized forms of manganese to Mn^{2+}. An alkaline-cyanide reagent is added to mask any potential interferences. PAN Indicator is then added to combine with the Mn^{2+} to form an orange-colored complex. Test results are measured at 560 nm.

Consumables and replacement items

Required reagents

Description	Quantity/Test	Unit	Catalog number
Manganese Reagent Set, 10 mL (50 tests), includes:	—	—	2651700
Alkaline Cyanide Reagent	12 drops	50 mL SCDB	2122326
Ascorbic Acid Powder Pillows	2 pillows	100/pkg	1457799
PAN Indicator Solution, 0.1%	12 drops	50 mL SCDB	2122426
Water, deionized	10 mL	4 L	27256

Required apparatus

Description	Quantity	Unit	Catalog number
Sample cell, 10 mL square, matched pair	2	2/pkg	2495402
Stoppers for 18 mm Tube	2	6/pkg	173106

Recommended standards

Description	Unit	Catalog number
Manganese Standard Solution, 10-mg/L Mn, 2 mL PourRite® ampule	20/pkg	2605820
Manganese Standard Solution, 250-mg/L Mn, 10-mL Voluette® ampule	16/pkg	1425810
Voluette Ampule breaker 10 mL	each	2196800
PourRite® Ampule breaker 2 mL	each	2484600

Optional reagents and apparatus

Description	Unit	Catalog number
Cylinder, mixing, 25 mL	each	2088640
Nitric Acid, concentrated	500 mL	15249
pH paper, 0-14	100/pkg	2601300
Pipet Filler, safety bulb	each	1465100
Pipet, TenSette® 0.1–1.0 mL	each	1970001
Pipet, TenSette, 1.0–10.0 mL	each	1970010
Pipet Tips, for TenSette Pipet 1970001	50/pkg	2185696
Pipet Tips, for TenSette Pipet 1970001	1000/pkg	2185628
Pipet Tips, for TenSette Pipet 1970010	50/pkg	2199796
Pipet Tips, for TenSette Pipet 1970010	250/pkg	2199725
Rochelle Salt Solution	29 mL	172533
Sodium Hydroxide, 5.0 N	100 mL	245032
Stopper for 18 mm tube	25/pkg	173125
Volumetric flask, Class A, 1000 mL	each	1457453
Volumetric pipet, Class A, 2 mL	each	1451536
PourRite® Ampule breaker 2 mL	each	2484600
Manganese Standard Solution, 2-mL PourRite® Ampule, 25 mg/L	20/pkg	2112820

Iron, Total

DOC316.53.01053

USEPA[1] FerroVer® Method[2]

Method 8008

0.02 to 3.00 mg/L

Powder Pillows or AccuVac® Ampuls

Scope and Application: For water, wastewater and seawater; digestion is required for determining total iron

[1] USEPA approved for reporting wastewater analysis, *Federal Register,* June 27, 1980; 45 (126:43459)

[2] Adapted from *Standard Methods for the Examination of Water and Wastewater.*

Test preparation

How to use instrument-specific information

The *Instrument-specific information* table displays requirements that may vary between instruments. To use this table, select an instrument then read across to find the corresponding information required to perform this test.

Table 1 Instrument-specific information

Instrument	Powder pillows		AccuVac Ampuls	
	Sample cell	Cell orientation	Sample cell	Adapter
DR 5000	2495402	Fill line faces user	2427606	—
DR 3900	2495402	Fill line faces user	2427606	LZV846 (A)
DR 3800, DR 2800, DR 2700	2495402	Fill line faces right	2122800	LZV584 (C)

Before starting the test:

Digestion is required for determining total iron for EPA reporting purposes. Use the mild or vigorous digestion. Refer to the *Water Analysis Guide* for more information.
For more accurate results, determine a reagent blank value for each new lot of reagent. Follow the procedure using deionized water in place of the sample. Subtract the reagent blank value from the final results or perform a reagent blank adjust. See the user manual for more information.
Adjust pH of stored samples before analysis.
For turbid samples, treat the blank with one 0.1-g scoop of RoVer Rust Remover. Swirl to mix.

Collect the following items:

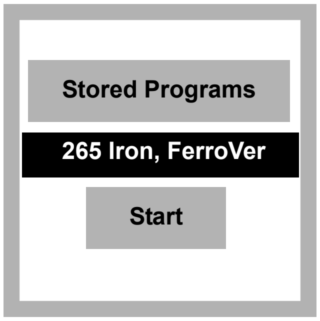
Description	Quantity
Powder Pillow Test:	
FerroVer® Iron Reagent Powder Pillow	1
Sample Cells (see *Instrument-specific information*)	2

Collect the following items: (continued)

Description	Quantity
AccuVac® Ampul test:	
FerroVer® Iron Reagent AccuVac® Ampul	1
Beaker, 50-mL	1
Sample Cells (see *Instrument-specific information*)	1
Stopper of 18 mm tubes	1

See *Consumables and replacement items* for reorder information.

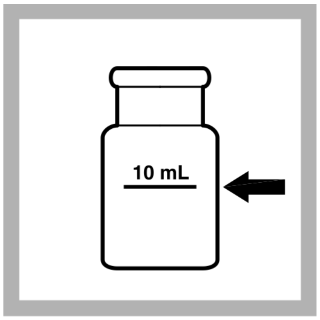
FerroVer method for powder pillows



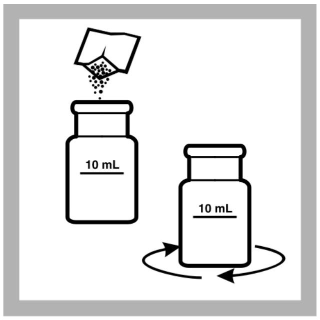
1. Select the test.

Insert an adapter if required (see *Instrument-specific information*).

Refer to the user manual for orientation.



2. Prepared sample: Fill a clean sample cell with 10 mL of sample



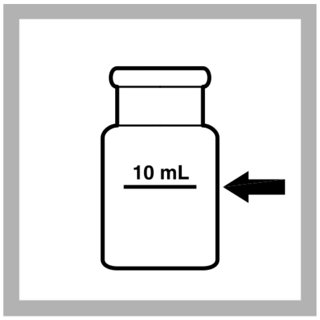
3. Add the contents of one FerroVer Iron Reagent Powder Pillow to the sample cell. Swirl to mix.

Accuracy is not affected by undissolved powder.

4. Start the instrument timer.

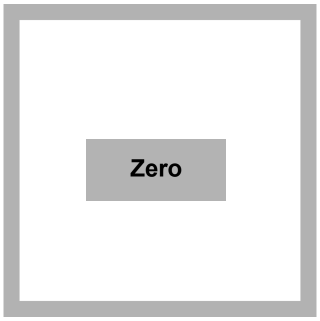
A three-minute reaction period will begin. An orange color will form, if iron is present.

(Allow samples that contain rust to react for at least 5 minutes.)



5. Blank preparation: Fill a second sample cell with 10 mL of sample.

6. When the timer expires, insert the blank into the cell holder.



7. ZERO the instrument.

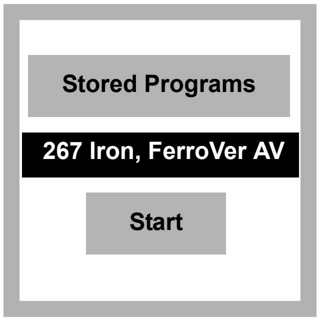
The display will show:

0.00 mg/L Fe

8. Insert the prepared sample into the cell holder.

READ the results in mg/L Fe.

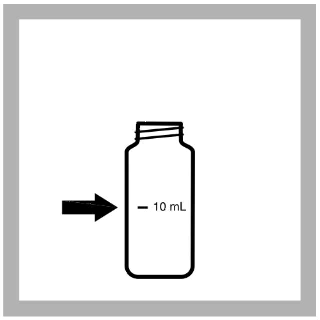
FerroVer method for AccuVac® Ampuls



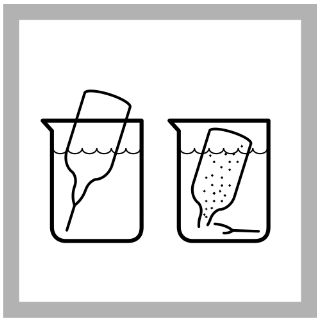
1. Select the test.

Insert an adapter if required (see *Instrument-specific information*).

Refer to the user manual for orientation.



2. Blank Preparation: Fill a round sample cell with 10 mL of sample.



3. Prepared Sample: Collect at least 40 mL of sample in a 50-mL beaker. Fill a FerroVer Iron AccuVac® Ampul with sample from the beaker. Keep the tip immersed while the Ampul fills completely.

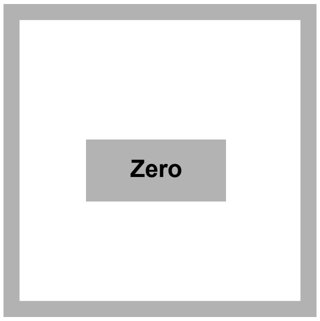
4. Quickly invert the Ampul several times to mix.

Accuracy is not affected by undissolved powder.

5. Start the instrument timer.

A three-minute reaction period will begin. An orange color will develop if iron is present.

6. Wipe the blank and insert it into the cell holder.



7. **ZERO** the instrument.

The display will show:

0.00 mg/L Fe

8. Wipe the Ampul and insert it into the cell holder.

READ the results in mg/L Fe.

Interferences

Table 2 Interfering substances

Interfering substance	Interference level
Calcium, Ca^{2+}	No effect at less than 10,000 mg/L as $CaCO_3$.
Chloride, Cl^{-}	No effect at less than 185,000 mg/L.
Copper, Cu^{2+}	No effect. Masking agent is contained in FerroVer Reagent.
High Iron Levels	Inhibit color development. Dilute sample and re-test to verify results.
Iron Oxide	Requires mild, vigorous or Digesdahl digestion. After digestion, adjust sample to pH 3–5 with sodium hydroxide, then analyze.
Magnesium	No effect at 100,000 mg/L as calcium carbonate.

Table 2 Interfering substances (continued)

Interfering substance	Interference level
Molybdate Molybdenum	No effect at 50 mg/L as Mo.
High Sulfide Levels, S^{2-}	**1.** Treat in fume hood or well-ventilated area. Add 5 mL hydrochloric acid[1], ACS to 100 mL sample in a 250 mL Erlenmeyer flask. Boil 20 minutes. **2.** Cool. Adjust pH to 3–5 with Sodium Hydroxide[1]. Readjust volume to 100 mL with deionized water. **3.** Analyze using *FerroVer method for powder pillows* or *FerroVer method for AccuVac® Ampuls*.
Turbidity	**1.** Add 0.1 g scoop of RoVer® Rust Remover to the blank. Swirl to mix. **2.** Zero the instrument with this blank. **3.** If sample remains turbid, add three 0.2 g scoops of RoVer to a 75 mL sample. Let stand 5 minutes. **4.** Filter through a Glass Membrane Filter and Filter Holder[1]. **5.** Use the filtered sample as the prepared sample and the blank.
Extreme Sample pH	Adjust pH to 3–5.
Highly Buffered Samples	Adjust pH to 3–5.

[1] See *Optional reagents and apparatus*.

Sample collection, preservation and storage

- Collect samples in acid-cleaned glass or plastic containers. No acid addition is necessary if analyzing the sample immediately.
- To preserve samples, adjust the pH to 2 or less with concentrated nitric acid (about 2 mL per liter). Preserved samples may be stored up to six months at room temperature.
- Before analysis, adjust the pH to between 3 and 5 with 5.0 N Sodium Hydroxide Standard Solution.
- Correct the test result for volume additions.
- If only dissolved iron is to be determined, filter the sample before acid addition.

Accuracy check

Standard additions method (sample spike)

Required for accuracy check:

- Iron Voluette® Ampule Standard, 25 mg/L
- Ampule breaker
- TenSette Pipet and Pipet Tips

1. After reading test results, leave the sample cell (unspiked sample) in the instrument.
2. Select Options>More>Standard Additions from the instrument menu.
3. Accept the default values for standard concentration, sample volume and spike volumes. After the values are accepted, the unspiked sample reading will appear in the top row. See the user manual for more information.
4. Open the standard solution ampule.
5. Prepare a 0.1 mL sample spike by adding 0.1 mL of standard to 10 mL of unspiked sample. Start the instrument timer. After the timer expires, read the result.

6. Prepare a 0.2 mL sample spike by adding 0.1 mL of standard to the 0.1 mL sample spike. Start the instrument timer. After the timer expires, read the result.
7. Prepare a 0.3 mL sample spike by adding 0.1 mL of standard to the 0.2 mL sample spike. Start the instrument timer. After the timer expires, read the result.
8. Select **GRAPH** to view the results. Select **IDEAL LINE** (or best-fit) to compare the standard addition results to the theoretical 100% recovery.

Standard additions method for AccuVac Ampuls (sample spike)

1. Fill three mixing cylinders each with 50 mL of sample and spike with 0.2 mL, 0.4 mL and 0.6 mL of standard. Stopper and invert to mix.
2. Transfer 40 mL from each of the three mixing cylinders to three 50 mL beakers.
3. Analyze each standard addition sample as described in the *FerroVer method for AccuVac® Ampuls*.
4. Accept each standard additions reading. Each addition should reflect approximately 100% recovery.

Standard solution method

Note: *Refer to the instrument user manual for specific software navigation instructions.*

Required for accuracy check:

- Iron Standard Solution, 100 mg/L
- 100-mL volumetric flask
- Class A volumetric pipet, 2 mL
- Deionized water
- Pipet filler

1. Prepare a 2.00-mg/L Fe standard solution as follows:
   a. Pipet 2.00 mL of Iron Standard Solution, 100 mg/L, into a 100 mL volumetric flask.
   b. Dilute to the mark with deionized water. Mix well. Prepare this solution daily.
2. Use the 2.00 mg/L Fe standard solution in place of the sample. Follow the *FerroVer method for powder pillows* test procedure.
3. To adjust the calibration curve using the reading obtained with the Standard Solution, select Options>More>Standard Adjust from the instrument menu.
4. Turn on the Standard Adjust feature and accept the displayed concentration. If an alternate concentration is used, enter the concentration and adjust the curve to that value. Mixed-parameter standards are also available to simulate various matrices.

Method performance

Program	Standard	Precision 95% Confidence Limits of Distribution	Sensitivity Concentration change per 0.010 Abs change
265	2.00 mg/L Fe	1.99–2.01 mg/L Fe	0.021 mg/L Fe
267	2.00 mg/L Fe	1.98–2.02 mg/L Fe	0.023 mg/L Fe

Summary of method

FerroVer Iron Reagent converts all soluble iron and most insoluble forms of iron in the sample to soluble ferrous iron. The ferrous iron reacts with the 1-10 phenanthroline indicator in the reagent to form an orange color in proportion to the iron concentration. Test results are measured at 510 nm.

Consumables and replacement items

Required reagents

Description	Quantity/Test	Unit	Catalog number
FerroVer® Iron Reagent Powder Pillows (for 10-mL sample)	1	100/pkg	2105769
OR			
FerroVer® Iron Reagent AccuVac® Ampuls	1	25/pkg	2507025

Required apparatus

Description	Quantity	Unit	Catalog number
Beaker, 50 mL	1	each	50041H
Sample cell, 10 mL round, 25 x 54 mm	1	each	2122800
Sample cell, 10 mL round, 25 x 60 mm	1	6/pkg	2427606
Sample cell, 10 mL square, matched pair	2	2/pkg	2495402
Stopper for 18 mm tube	1	6/pkg	173106

Recommended standards

Description	Unit	Catalog number
Iron Standard Solution, 100 mg/L	100 mL	1417542
Iron Standard Solution, 10 mL Voluette® Ampule, 25 mg/L as Fe	16/pkg	1425310
Metals Drinking Water Standard, LR for Cu, Fe, Mn	500 mL	2833749
Metals Drinking Water Standard, HR for Cu, Fe, Mn	500 mL	2833649
Water, deionized	4 L	27256
Pipet, TenSette, 0.1–1.0 mL	each	1970001
Pipet Tips, for TenSette Pipet 1970001	50/pkg	2185696
Pipet Tips, for TenSette Pipet 1970001	1000/pkg	2185628
Flask, volumetric, Class A, 100 mL	each	1457442
Pipet, volumetric, Class A, 2.00 mL	each	1451536
Pipet Filler, safety bulb	each	1465100

Optional reagents and apparatus

Description	Unit	Catalog number
Beaker, 50 mL	each	50041H
Cylinder, mixing, 50 mL	each	189641
Hydrochloric Acid, concentrated	500 mL	13449
Nitric Acid, concentrated	500 mL	15249

Optional reagents and apparatus (continued)

Description	Unit	Catalog number
Sodium Hydroxide Standard Solution, 5.0 N	100 mL	245032
Glass Membrane Filter, 47 mm	100/pkg	253000
Glass Membrane Filter Holder	each	234000
RoVer Rust Remover	454 g	30001
Spoon, measuring, 0.1 g	each	51100

FOR TECHNICAL ASSISTANCE, PRICE INFORMATION AND ORDERING:
In the U.S.A. – **Call toll-free 800-227-4224**
Outside the U.S.A. – **Contact the HACH office or distributor serving you.**
On the Worldwide Web – **www.hach.com**; E-mail – **techhelp@hach.com**

HACH COMPANY
WORLD HEADQUARTERS
Telephone: (970) 669-3050
FAX: (970) 669-2932

Edition 6