Introduction to Water Treatment

Grades 3 & 4
Week 2

Course # 3101

Fleming Training Center
Your Partner in Clean Water

TDEC
TENNESSEE DEPARTMENT OF ENVIRONMENT AND CONSERVATION

Fleming Training Center
January 23-27, 2017

State of Tennessee

Water Treatment
January 23-27, 2017

Course # 3101 - Week 2

Monday, January 23

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	Fluoride Control	Amanda
2:00	Membrane Filtration	Amanda

Tuesday, January 24

8:30	Adsorption	Amanda
10:30	Aeration	Amanda
11:45	Lunch	
1:00	Tour - Consolidated Utility District WTP	

Wednesday, January 25

8:30	Water Softening	Amanda
10:00	Ion Exchange	Amanda
11:45	Lunch	
1:00	Lab (Hands-On Review)	Amanda

Thursday, January 26

8:30	Cross Connection	Ben Rodriquez
9:45	Records Keeping & Design Criteria	Amanda
11:30	Lunch	
12:45	Tour—Murfreesboro WTP	

Friday, January 27

8:30	Class Review	Amanda
11:45	Lunch	
1:00	Class Exam and Evaluations	Amanda

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Section 1

Corrosion

Stabilization

Corrosion and Scaling Control

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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

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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

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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

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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

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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

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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

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Corrosion

Definition of Corrosion
Factors Affecting Corrosion
Types of Corrosion

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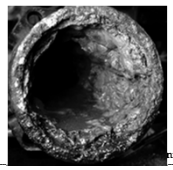
Corrosion

- 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*



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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

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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

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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

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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

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Corrosion

Types of Corrosion

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

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Localized Corrosion

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Localized Corrosion

Sink hole caused by 8-in main break

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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**

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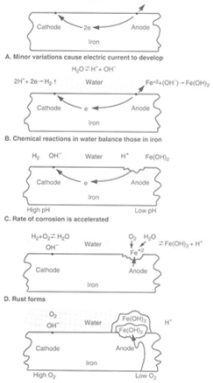
Galvanic Corrosion



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Scale Formation

Definition of Scale Formation
Factors Affecting Scale Formation
Types of Scale Formation

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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

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Scale Formation

Scale-Forming Compounds

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

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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

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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

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Scale Formation

Control Methods

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

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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

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Control Methods

Stability Scale

Corrosive Water ←	Stable Water	→ Scale-Forming

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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

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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

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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

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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

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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

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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

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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

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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

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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

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Control Methods

Polyphosphates

- Work as <u>sequestering agents</u>
  - 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

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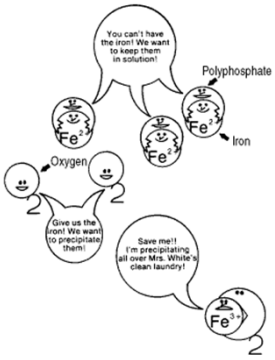
Control Methods



Control Methods

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

Control Methods

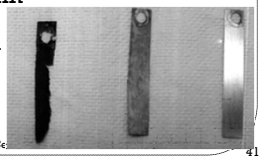
- Sodium silicate
  - Combines with calcium to form a hard, dense coating on interior of pipe
  - Works well in waters with low hardness & alkalinity and relatively high flow velocities
  - Must be approved by NSF (National Sanitation Foundation)
  - Thick, opaque alkaline liquid
  - Available in barrels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

Langelier Index

- Used to indicate how close the water is to the equilibrium point
- Langelier 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

Langelier Index

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

Stability

Langelier Index

- Calculate the Langelier 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

A = 2.12 log (Ca) = 1.70
B = 9.80 log (alkalinity) = 2.00

Stability

Langelier Index

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

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

This water is <u>moderately aggressive.</u>

Stability

Langelier Index

- Calculate the Langelier 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

A = 2.04 log (Ca) = 2.10
B = 9.80 log (alkalinity) = 2.15

Stability

Langelier Index = pH - pH_S

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

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

This water is <u>non-aggressive.</u>

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

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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

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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

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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

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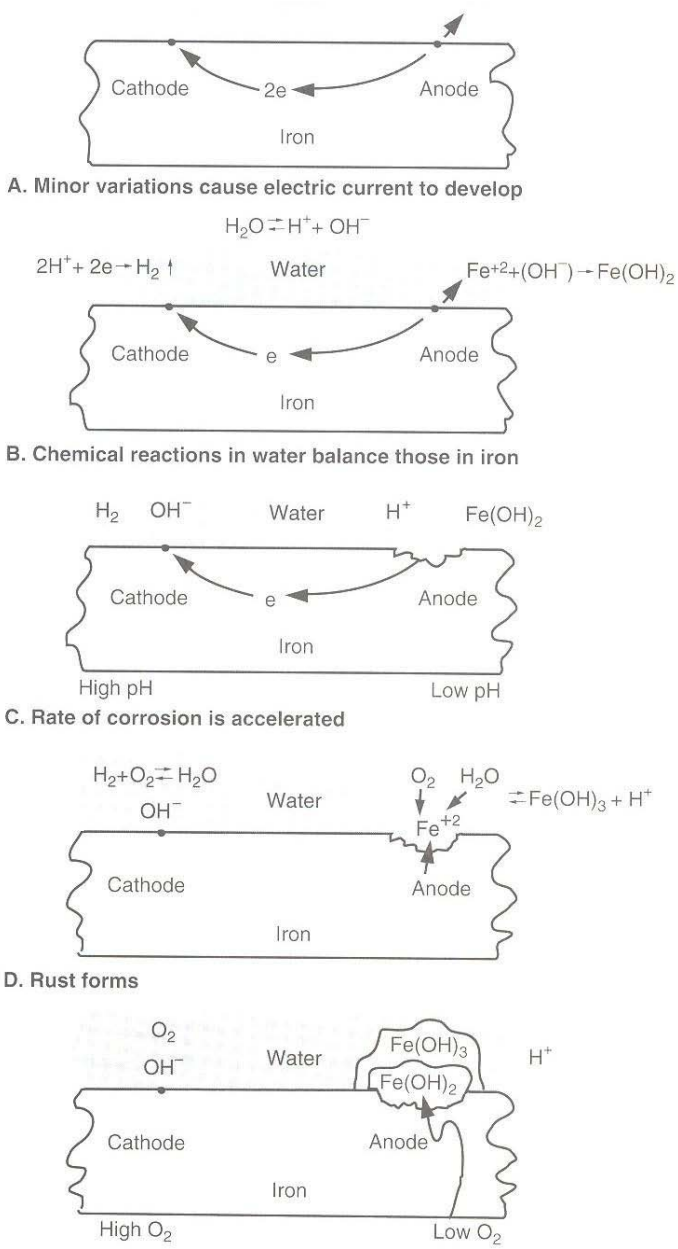
Stabilization Vocabulary

_____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



Section 2

Iron & Manganese

Iron and Manganese Control

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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

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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 <u>oxidation</u>

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Iron and Manganese

Problems of Excessive Fe and Mn

- Aesthetic problems
- Operational problems

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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

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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

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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

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Iron

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

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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

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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

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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)

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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

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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

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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

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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

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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

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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

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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

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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

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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
  - Membrane filter technology

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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 without sedimentation

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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

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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

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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

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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 removed but are kept in the finished water.

Section 3

Fluoride

Fluoridation

California State University: Sacramento Manual

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Importance of Fluoridation

- 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

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Importance of Fluoridation

- 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)

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Fluoridation

- Controlled fluoridation started in 1945
  - Grand Rapids, Michigan
  - Newburgh, New York
  - Control cities of Muskegon and Kingston
- After fluoridating for 10 years, 60% reduction of caries in children who drank fluoridated water
- Mottling of teeth occurs with levels > 1.5 mg/L
- Steps should be taken to reduce fluoride in waters with more than 1.4-2.4 mg/L naturally
- Recommended MCL dependent on annual average maximum daily air temperature

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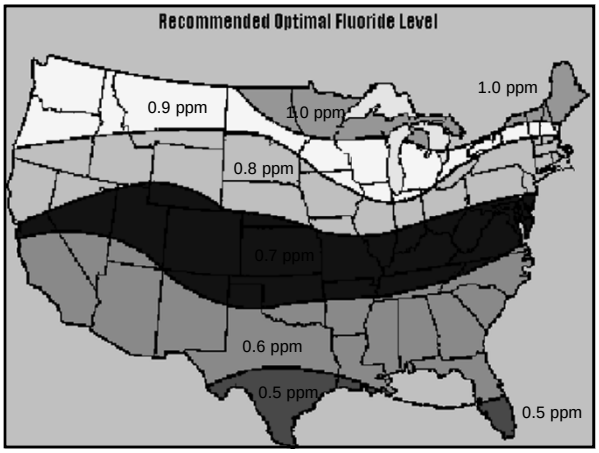

Fluorosis

- 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 2 mg/day for many years

Mild Dental Fluorosis
White mottling of the teeth

Severe Dental Fluorosis
Dark brown stains on teeth

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Fluoride Consumption

- If a person drinks 1 liter of water containing 1mg/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

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General Practices

- There are no Tennessee 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

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Sampling Requirements

- Daily sampling and analysis
- One quarterly sample required by state, if fluoride is fed

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Compounds Used to Feed Fluoride Ion

- Most commonly used compounds
  - Sodium fluoride
  - Sodium fluorosilicate
  - Hydrofluosilicic acid (most common)
- Factors to consider when choosing compound
  - Solubility of chemical in water
  - Operator safety
  - Ease of handling
  - Storage and feeding requirements
  - Costs
- Check natural fluoride level before feeding additional compound

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	Sodium Fluorosilicate	Sodium Fluoride	Hydrofluosilicic Acid
Form	Powder	Powder / crystalline	Liquid
Molecular weight	188.1	42.0	144.1
Purity, %	98-99	95-98	22-30 (by weight)
Fluoride Ion, %	60.7	45.3	79.2
Density	55-72 lb/ft^3	65-90 lb/ft^3	10.5 lb/gal
Solubility in Water, %	0.76	4.05	100 (infinite)
pH of saturated solution	3.5	7.6	1.2

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Fluoride Chemicals

Sodium Fluoride (NaF)

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

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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

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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

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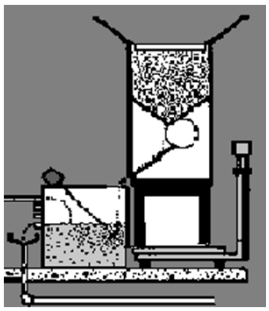
Fluoridation Systems



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Fluoridation Systems

- 3 different ways for water to be fluoridated
  - Naturally present in raw water
  - Blending 2 water sources
  - Adding fluoride ion to water

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Chemical Feeders

- Fluoride ions added by chemical solution or dry feeders
- Fluoride feeders must be very accurate
- Solution feeders – deliver a fixed amount of liquid
  - Positive displacement diaphragm pumps
  - Peristaltic pumps
  - Electronic pumps
- Dry feeders
  - Volumetric
    - Simpler, less expensive, less accurate, feed smaller amounts
  - Gravimetric
    - More accurate than volumetric, more expensive, require more space, amount fed based on weight of chemical

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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

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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

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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

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Saturators

- Principle: saturated solution will result if water is allowed to trickle through a bed containing sodium fluoride
- NaF has a constant solubility and produces a fluoride solution of uniform strength
  - Fluoride solution will stabilize at 4% at normal temps
- Maintain a depth of 6-10 inches of sodium fluoride
- Should be stirred every day to prevent fluoride solids from building up on the bottom
- Make-up water $CaCO_3$ hardness
  - < 10 mg/L = no problems
  - 10-75 mg/L = scaling will occur and increase maintenance
  - > 75 mg/L = water must be softened before preparing a fluoride solution

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Saturators

- Two Types
  - Downflow saturators
    - Water flows from top to bottom
    - Bed of granular NaF sits on layer of sand and gravel
    - May need to be cleaned daily
    - **Not approved for use in Tennessee**
  - Upflow saturators
    - Water introduced at bottom
    - Bed of undissolved NaF on bottom of tank below which water is forced upward under pressure
    - Creates a cross-connection so must have siphon-breaker
    - Should only need cleaning per year

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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

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Auxiliary Equipment

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Safety Equipment

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

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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

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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

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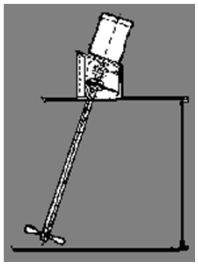
Mixers



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

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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 connections sealed to prevent corrosion

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Hoppers

- On dry feeders, hold chemical 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

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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 swung into position and cut open
- Requires operator to wear dust mask

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Operation of Fluoridation Systems

Operation of Feeders
Injection Point
Chemical Storage

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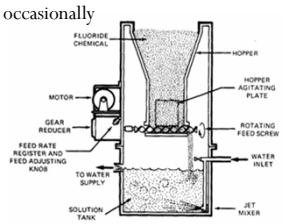
Dry Feeders

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



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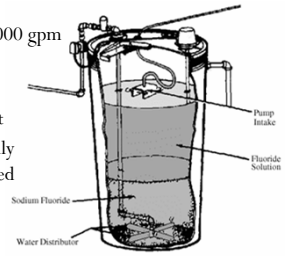
Saturators

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



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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

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Chemical Storage

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

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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

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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

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Storage

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

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Analysis of Fluorides in Drinking Water

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

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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)

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Operating Problems

Varying Concentrations

Dangers of Improper Concentrations

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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

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Low Concentrations

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

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High Concentrations

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

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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

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Control Tests

- Check raw fluoride level
- Check finished fluoride level
- Automatic monitors continuously record level
  - Have alarm if max concentration is exceeded

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Symptoms of Overexposure

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

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Safety – Fluoride Poisoning

- Fatal doses range from 4-5 grams (1 tablespoon)
  - Equivalent to approximately 2000 times the amount in water supply
  - Unlikely to get same symptoms from inhalation as from consumption, however symptoms should not be ignored
- Symptoms - consumption
  - Vomiting, stomach cramps, diarrhea
  - Very weak, trouble speaking, very thirsty, poor color vision
- Symptoms – inhalation
  - Biting pain in the nose with runny nose or nose bleed
  - Bad stomach cramps

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Fluoride Math

Dosage and Feed Rates for Fluoride

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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

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Fluoride Chemicals Purity

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

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Fluoride Chemicals

Ion Concentration Percent (AFI)

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

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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

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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

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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?

lbs/day = (dosage, mg/L)(flow, MGD)(8.34 lbs/gal) / (AFI, as decimal)(purity, as decimal)

= (0.9 mg/L)(0.75 MGD)(8.34 lbs/gal) / (0.452)(0.98)

= 12.7 lbs/day

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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?

lbs/day = (dosage, mg/L)(flow, MGD)(8.34 lbs/gal) / (AFI, as decimal)(purity, as decimal)

= (0.82 mg/L)(0.20 MGD)(8.34 lbs/gal) / (0.607)(0.985)

= 2.29 lbs/day

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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?

lbs/day = (dosage, mg/L)(flow, MGD)(8.34 lbs/gal) / (AFI, as decimal)(purity, as decimal)

= (0.75mg/L)(12 MGD)(8.34 lbs/gal) / (0.792)(0.230)

= 412 lbs/day

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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?

gal/min = (capacity, gpm)(dosage, mg/L) / (18,000 mg/L)

= (250 gpm)(1.0 mg/L) / 18,000 mg/L

gal/day = (0.014 gal/min) (1440 min/day)

= 20.16 gallons a day

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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?

mg/L = (fluoride fed, lbs)(AFI, as decimal)(purity, as deci.) / (MGD)(8.34 lbs/gal)

= (25 lbs)(0.607)(0.985) / (1.75 MGD)(8.34 lbs/gal)

= 1.02 mg/L

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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?

mg/L = (fluoride fed, lbs)(AFI, as decimal)(purity, as deci.) / (MGD)(8.34 lbs/gal)

mg/L = (5 lbs)(0.452)(0.98) / (0.2 MGD)(8.34 lbs/gal)

= 1.33 mg/L

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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?

mg/L = (fluoride fed, lbs)(AFI, as decimal)(purity, as deci.) / (MGD)(8.34 lbs/gal)

mg/L = (284 lbs)(0.792)(0.23) / (6.2 MGD)(8.34 lbs/gal)

= 1.0 mg/L

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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?

mg/L = (solution fed, gal)(18,000) / (gpd)

= (9 gal)(18,000) / (200,000 gpd)

= 0.81 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.**

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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.

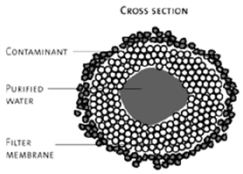
Answers to Math

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

Section 4

Membrane Filtration

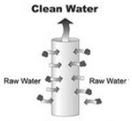
MEMBRANE TECHNOLOGY



HISTORY

- Mid-late 1980's- membrane filtration used primarily for industrial applications such as the wine and juice industries
- Companies such as Aquasource and Memcor began to market membrane technology for treatment of drinking water in the early 1990's
- Small scale pilot studies at drinking water facilities showed membranes improved filtrate quality and reduced DBP's
- First full scale microfiltration membrane facility, the Saratoga WTP in California, went online in 1993
- In 1994 a Rice University study showed that low pressure membrane filtration would be cost-effective at capacities of 5 MGD

HISTORY



Above: A strand of membrane in action
Below: A cassette housing membranes

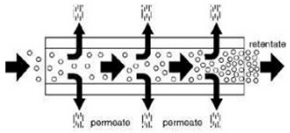
- In 1997 a study showed that if membranes were installed downstream of conventional coagulation, flocculation and sedimentation that the membrane could be operated at a higher rate, making it cost effective for even 50 MGD capacity
- The potential for large scale membrane facilities resulted in the formation of additional membrane manufacturers and improvements in membrane technology
- Companies such as Pall, Zenon, and Koch began to develop new membrane technology
- The largest low pressure membrane filtration plant to date is in Azerbaijan.
  - It treats 150 + MGD

WHY MEMBRANE TECHNOLOGY?

- **Regulatory**- the SWTR requires a higher level of turbidity and particulate removal. Membranes can consistently obtain that level of turbidity removal.
- **Cost**- since the early 1990's the capital cost of membrane treatment has decreased. In addition, the implementation of innovative backwash and cleaning strategies have reduced the operational costs.
- **Operational flexibility**- low pressure membrane filtration processes are highly flexible and can be used in conjunction with other processes to achieve specific treatment objectives. In addition, membrane facilities can be easy to operate because the process is not dependent on water chemistry or flow.

Pressure forces the water through the pores in the membrane.

Raw water is passed through a membrane



The particles that are too large to pass through are collected, and wasted.

The pure water, or permeate, is collected on the other side of the membrane.

MEMBRANES: SCIENCE AND THEORY

- Pure water transport across a clean porous membrane is affected most by the trans-membrane pressure and the viscosity of the water
- **Trans-membrane pressure**: The force which drives liquid flow through a cross flow membrane. During filtration, the feed side of the membrane is under higher pressure than the permeate side. The pressure difference forces liquid through the membrane

FLUX

- The word *flux* comes from Latin: *fluxus* which means "flow"
- Volumetric flux describes the volume of flow across a unit of area
- Typical units for membrane volumetric flux are gallons per square foot of membrane per day or liters per square meter of membrane per hour

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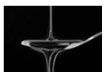
TEMPERATURE EFFECTS



- Think about maple syrup, when maple syrup is cold it is very thick and viscous
- If you put it in the microwave and warm it up it pours much more easily

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TEMPERATURE EFFECTS

- Water behaves much like maple syrup
- The viscosity or resistance to flow of water is dependent on temperature
- The colder the water, the higher the viscosity
- Viscosity will affect membrane performance by either reducing the flux or by requiring an increase in trans-membrane pressure to keep the flux constant

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SEASONAL EFFECTS

- Higher trans-membrane pressures may be required in the winter to offset the effect of temperature on the viscosity of the water
- Membrane fouling may also change with season and temperature
- Source water is variable, there is seasonal variation in the amounts of organics, metals, nitrates, etc.

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REDUCTIONS IN MEMBRANE PRODUCTIVITY

Reductions in membrane productivity can result for a number of reasons including:

- Membrane Compaction
- Membrane Fouling
  - Inorganic fouling
  - Organic fouling
    - Biofouling

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MEMBRANE COMPACTION

- Membrane compaction is a physical compression of the membrane
  - This compression results in a decrease in flux
  - The rate of compaction is directly proportional to an increase in temperature and pressure
- Compaction occurs naturally over time requiring a greater feed pressure
- Compaction is permanent and can occur quickly in membranes if operated at higher pressures for any extended period of time
- Usually membrane compaction results in a few percent flux decline, and has strongest effect during the initial operating period

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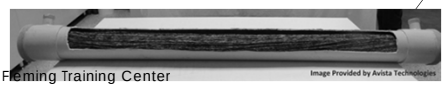
FOULING

- Fouling is defined as the reduction in flux at constant pressure resulting from the adsorption or deposition of suspended matter in the membrane pores or on the membrane surface
- The three fouling mechanisms are:
  - Pore adsorption
  - Pore blocking
  - Cake formation



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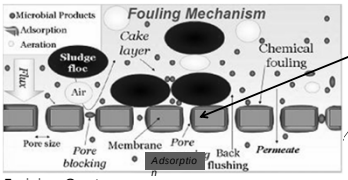
FOULING

- **Pore adsorption**
  - occurs when particles smaller than the pore deposit themselves on the pore walls which reduces the effective size of the pores



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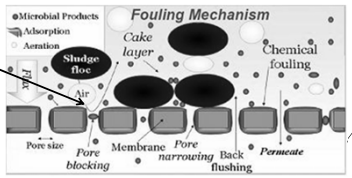
FOULING

- **Pore blocking**
  - occurs when particles as large as the pore become lodged in the pore and block the passage
  - the effective number of pores is reduced



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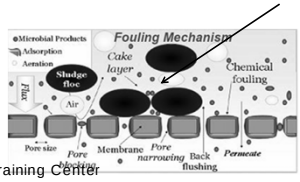
FOULING

- **Cake formation**
  - this occurs when particles too large to enter the pores become deposited on the surface of the membrane
  - Cake formation results in a reduced flux across the membrane



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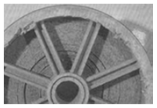
INORGANIC FOULING

- Inorganic fouling can occur when inorganic particles such as silt, clay, iron, manganese, nitrates, etc are deposited on the surface of the membrane



Membrane fouled with inorganic material.

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ORGANIC FOULING

- Organic fouling occurs when natural organic matter (NOM) in source water prevents flux across the membrane by plugging pores in the membrane

A membrane severely fouled by organics

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BIOFOULING

- Biofouling occurs when microorganisms adhere to the membrane surface and begin to grow colonies on or in the membrane
  - the microbes will eventually obstruct the flow through the membrane.

Extreme biofouling of membrane.

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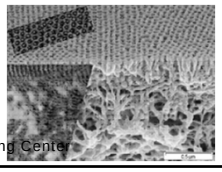
MEMBRANE MATERIALS

- The most common membrane materials are either organic polymers or ceramic materials
- The polymer membrane materials vary with resistance to fouling, operating temperature and pH ranges and resistance to oxidants



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POLYMER MATERIALS

Membrane material	Type	Oxidant tolerance	pH range	Resistance to fouling
PVDF	MF/UF	Very high	2-11	Excellent
Polypropylene(PP)	MF	Low	2-13	Acceptable
Polyethersulfone (PES)	UF	High	2-13	Very Good
Polysulfone (PS)	UF	Moderate	2-13	Good
Cellulose Acetate (CA)	UF	Moderate	5-8	Good

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CERAMIC MEMBRANES

- Ceramic membranes are made by heating materials like aluminum oxide, titanium dioxide or carbon composites into a brittle clay like ceramic form
- The ceramic membranes are thicker and have a greater resistance to water transport, so the trans-membrane pressures may need to be increased
- The benefits of ceramic membranes include: that they are easier to clean and maintain than polymer membranes, and that they are able to withstand higher temperatures and pressures and can operate at a pH of 0-14

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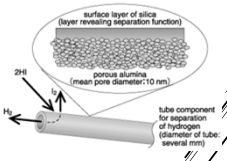
CERAMIC MEMBRANES



Ceramic Membrane Elements and Housings

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MEMBRANE MODULE TYPES

There are several commercially available membrane technologies including:

- Spiral wound
- Tubular
- Hollow fiber
- Plate and Frame
- Cassette

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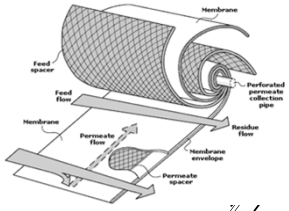
SPIRAL WOUND MEMBRANE

- Not commonly used for microfiltration or ultrafiltration
- The flat sheet nature makes it difficult to keep clean



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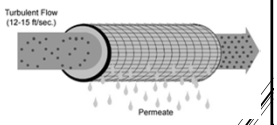
TUBULAR MEMBRANE MODULE

- Rather than a sheet of microfiltration membrane, the membrane is made in a tube fit into a module
- The membrane is on the inside of the tube with a HDPE support tube
- This arrangement allows the membrane to be backwashed which controls fouling



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TUBULAR MEMBRANE MODULE

- The membranes which are composed of polymer or ceramic are placed inside plastic or stainless steel modules and sealed by a gasket or ring clamp
- The tubular membranes have relatively large inner diameters (1-2.5 cm)
- The feed water which is under pressure flows through the inner lumen of the tube
- The permeate is collected in the outer shell of the module

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TUBULAR MEMBRANE MODULE

Advantages

- Large diameter of channels allows for treatment of water with large particles or high solids
- High cross flow velocities (up to 5 m per second) can be used to control fouling
- Easy to clean because of large diameter channels

Disadvantages

- Low surface area to volume ratio or "packing density" of membrane

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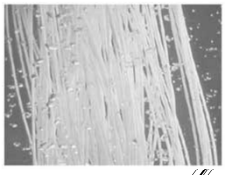
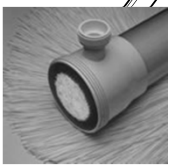
HOLLOW FIBER MEMBRANE

- Can be arranged in a tubular housing or as a cassette type module
- Can be backwashed to prevent fouling



Full Scale Unit

Bench Scale Unit



HOLLOW FIBER MEMBRANE

- Consists of several hundred to several thousand fibers encased in a module
- The fibers are bonded at each end with an epoxy or urethane resin
- The inner lumens or internal fiber diameters are very small (0.4 to 1.5 mm)
- There are two different regimes in hollow fiber filtration: inside out, and outside in

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HOLLOW FIBER MEMBRANE

Advantages

- Low pressure drop across the module
- High surface to volume ratio or "packing density"
- Low trans-membrane pressures 3-15 psi
- Fibers can be backwashed

Disadvantages

- Small tube diameter are susceptible to plugging
- The large number of fibers may cause difficulty in detecting the loss of membrane integrity

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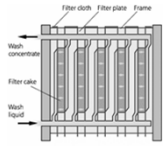
PLATE AND FRAME TYPE

- Membrane filter plates: a flexible membrane is fixed to the support body
- Materials for the membranes include Polypropylene, synthetic rubber (for example NBR, EPDM) or thermoplastic elastomer (TPE)
- The membrane is impermeable and serves to compress the cake within the chamber after the filtration process is complete
- Most often used in industrial applications, or wastewater, not used in water treatment



Filter cake washing in a plate and frame filter press

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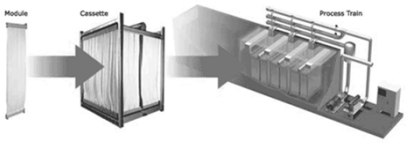
CASSETTE TYPE MEMBRANE



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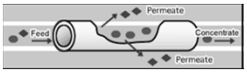
INSIDE-OUT FILTRATION



- A high cross-flow velocity over the membrane surface prevents membrane fouling.
- Easier to backwash
- This makes inside-out filtration suitable for concentration and purification of highly concentrated solutions

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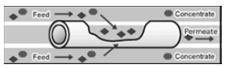
OUTSIDE-IN FILTRATION



- Utilizing the larger area of the outer surface of the membrane fiber, the filtration load per unit area may be reduced
- Lower head loss through the module
- These features make this mode of operation well suited for high volume water clarification
- It is more difficult to backwash and control flow to the membrane
- Cleaning technique such as 'air-scrubbing' may be utilized

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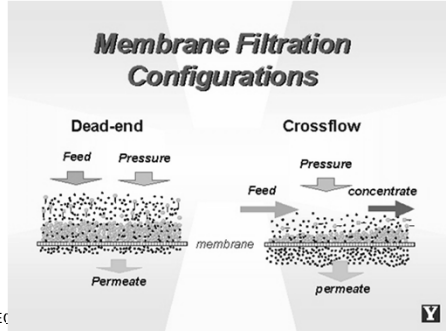
MEMBRANE CONFIGURATIONS



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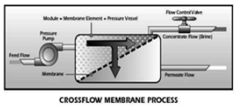
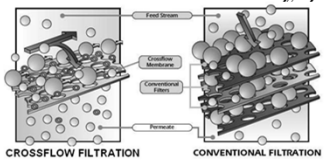
CROSSFLOW FILTRATION

- In some cases, crossflow filtration is used
- The direction of the flow can help to prevent the deposition of materials on the membrane surface thereby reducing fouling





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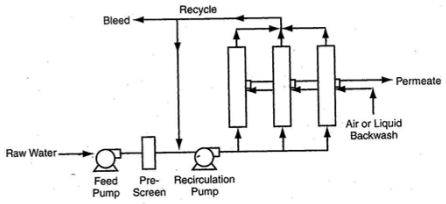
SYSTEM CONFIGURATIONS



Pressure driven system configuration with crossflow

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CROSSFLOW

- Feed water is pumped with a crossflow tangential to the membrane
- The water that does not pass through the membrane is recirculated as concentrate and blended with the feed water
- Pressure on the concentrate side is conserved and deducted from the total head requirement
- A bleed stream can be used to control the concentration of solids in the recirculation loop
- Concentrate can be wasted at any time from the recirculation loop

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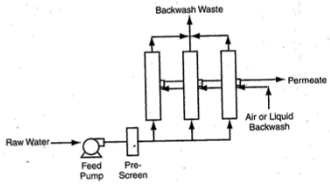
SYSTEM CONFIGURATION



Pressure driven direct flow

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DIRECT FLOW

- Also called dead-end or deposition mode
- Water is applied directly to the membrane
- All feed water passes through the membrane between backwashings
- There is 100% recovery of this water, however, some must be used for backwashing
- Considerable energy savings because recirculation is not required

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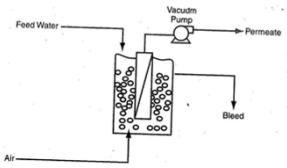
SYSTEM CONFIGURATION



Direct flow submersible

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SUBMERSIBLE

- Fibers are submerged in the feed water
- A vacuum is applied to the inner lumen of the fibers to create a pressure differential necessary for filtration to occur
- The outside of the fibers are scoured by air periodically or continuously
- Backwashing with the permeate is conducted at regular intervals

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SYSTEM OPERATIONS

The two primary operational concepts are:

- To operate at a constant pressure
- To operate at a constant flux

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CONSTANT PRESSURE

Advantages:

- Feed pumps can be sized to maintain the constant pressure with simple on/off controls
- Energy requirements are constant

Disadvantages:

- Permeate flow will decrease over time due to membrane plugging prior to backwash
- Output of plant is reduced

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CONSTANT FLUX

Advantages:

- No over-sizing of the system is needed
- Out-put remains the same
- Most often used by full scale membrane plants

Disadvantages:

- Feed pressure must increase to maintain constant flux between backwashes
- Energy efficiency decreases with increased trans-membrane pressure

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PUMP REQUIREMENTS

- **Variable speed centrifugal:**
  - used to deliver raw water to membranes at the required flow and pressure (usually 20 -30 psi)
- **Permeate vacuum pump**
  - used for systems that operate under a vacuum, one dedicated to each membrane bank, sized to produce the permeate flow of each membrane bank
- **Recirculation pump**
  - used for inside-out crossflow configurations, one dedicated for each membrane bank
- **Backwash pump**
  - used for backwashing, may use liquid or gas medium

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MEMBRANE BACKWASHING

- For most systems it is performed automatically
- Can be set for a run time, usually every 30-120 minutes
- Can also be set to backwash when a certain trans-membrane pressure is reached or when a certain amount of permeate has been produced
- The duration of backwash lasts from 1-5 minutes

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BACKWASHING

- The permeate collected in a reservoir is employed to backwash the membrane
- A liquid stream under pressure from a backwash pump dislodges solids from the surface of the membrane
- For submerged systems, backwashing occurs for 30 seconds every 15 minutes to several hours
- The backpulsing dislodges any deposition that has accumulated

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PRETREATMENT

- **Prefiltration**
  - may be required to remove large particles that could plug the inlet to the fibers.
- **pH adjustment**
  - may be required to keep feed water in the optimum range for the membrane polymer type.
- **Adsorption and Coagulation**
  - coagulants and PAC can be used to prevent fouling of the membrane.
- **Pre-oxidation**
  - used to oxidize metals such as iron and manganese so that they do not form in the membrane or the permeate.

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POST TREATMENT

Disinfection: required by State and Federal Regulations

Optional additions:

- Fluoridation
- Corrosion Control

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CLEANING

- When fouling materials can no longer be removed by backwashing, chemical cleaning is required
- Considerations include the cleaning and rinse volumes, temperature of cleaning water, reuse and disposal of chemicals
- Many different chemicals can be used including detergents, acids, bases, oxidizing agents and enzymes
- Chlorine is often used on PVDF membranes in concentrations from 2-2000 mg/L
- Heating the cleaning solution to 35-40°C can enhance cleaning effectiveness

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MEMBRANE INTEGRITY TESTING

- One of the most critical aspects of employing membrane technology is integrity testing
- Integrity testing ensures that the membranes are an effective barrier between the feed water and the permeate being produced

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INTEGRITY TESTING

There are several methods that can be used to monitor membrane integrity including:

- Turbidity monitoring
- Particle counting
- Particle monitoring
- Biological monitoring
- Air pressure decay testing
- Diffusive air flow testing
- Water displacement testing
- Bubble testing
- Sonic wave sensing
- Visual inspection

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TURBIDITY MONITORING

- Most commonly used method of measuring the performance of filtration systems
- Most membrane systems can provide permeate with turbidities less than 0.1 NTU
- Use of turbidity as the sole method for determining membrane integrity does not provide adequate sensitivity to detection of small pinholes in membrane fibers

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PARTICLE COUNTING AND MONITORING

- Multichannel particle counting is a standard particle counting method used in many water treatment plants
- The advantage is that it is a continuous online measurement, however, several sensors are required to establish the sensitivity needed to detect loss of membrane integrity
- Another method of measuring particles is particle monitoring which is based on dynamic light obscuration
- Particle monitors are usually cheaper and easier to operate than particle counters, however, they also require multiple sensors for the sensitivity level of membranes

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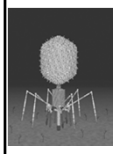
BIOLOGICAL MONITORING



- One of the most sensitive methods for evaluating membrane integrity is viral seeding
- Viruses at densities in the range of 106-107 PFU/mL are introduced into the effluent
  - **Plaque:** an area of cells in a layer which display a cytopathic effect
  - **Plaque-forming unit (PFU):** a virus or group of viruses which cause a plaque

  At various times, samples are collected from the permeate to determine if those viruses have passed through the membrane

  Often used for pilot- or bench scale studies, because you don't want to introduce viruses into water that is being consumed

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AIR PRESSURE DECAY TESTING

- The membrane module is pressurized to approximately 15 psi from the feed side
- Minimal loss of held pressure (usually less than 1 psi every 5 minutes) at the filtrate side indicates a passed test
- A significant decrease of the held pressure indicates a failed test

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DIFFUSIVE AIR FLOW TESTING

- The diffusive air flow test uses the same concept as the air pressure decay test but it is performed by monitoring the displaced liquid volume caused by leaking air from the compressed membrane fibers
- This test is more sensitive than air pressure decay because it is easier to measure small changes in liquid volume than small changes in air pressure

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BUBBLE TESTING

- Bubble testing can identify a fiber or seal location that is leaking in a membrane module
- This test is usually run after the compromised module is identified by another monitoring method such as air pressure decay or a sonic sensor
- Basically the module is submerged while air is passed through it, bubbles formed by escaping air identify the location of the leaking fiber
- The leaking fiber is either sealed using epoxy glue or by inserting a pin of the same diameter into the inlet

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SONIC WAVE SENSING

- Sonic sensor equipment consists of a sound wave sensor attached to a headphone
- The headphones are manually placed at the top, middle, and bottom of the membrane module during the air pressure decay test
- The headphones can detect sound waves produced by air escaping from a compromised membrane
- This test has to be followed by the bubble test and visual inspection

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VISUAL INSPECTION

- If a pressure based integrity test is used, visual inspection can be conducted simultaneously by watching the fibers for bubbles escaping
- Often the module may have to be removed from the housing so that visual inspection can be performed

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CLEANING CHEMICALS

- **Acids**
  - citric acid is most commonly used, it works well on inorganic contaminants such as iron. Other acids such as hydrochloric or sulfuric may be used
- **Bases**
  - caustic soda is the most commonly used, also good on inorganics
- **Oxidants**
  - free chlorine is very effective at removing organic contaminants
- **Surfactants**
  - release contaminants instead of dissolving them. Works well on PAC or if the membrane has a limited pH range

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PROCESS RESIDUALS

- Waste characteristics depend on the source water being treated
- Waste usually contains inorganic and organic colloids, pathogens, and turbidity
- If coagulants, PAC or other pretreatment chemicals are used the residual is similar to that produced by conventional treatment plants
- Chemical cleaning waste has a different composition and usually a small volume compared with the concentrate and backwash residuals

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PROCESS RESIDUALS

Methods of disposal include:

- Surface Water Discharge
- Sewer Discharge
- Land Application
- Recycling

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PROCESS RESIDUALS

Surface Water Discharge-

- Surface water discharge must meet the requirements of a site specific NPDES permit
- May require treatment prior to surface water discharge
- For most installations, a settling basin or lagoon will suffice

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PROCESS RESIDUALS

Sewer discharge-

- Most commonly used method of backwash waste disposal
- Sewer disposal of backwash waste is controlled by the receiving wastewater treatment plant's NPDES permit and available sewer capacity
- May not be feasible at all locations

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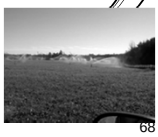
PROCESS RESIDUALS

Land application-

- Includes percolation ponds or lagoons, spray irrigation and leach fields
- May require chemical neutralization
- Periodic removal of accumulated solids from lagoons may be required



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PROCESS RESIDUALS

Recycling-

- At large installations recycling is accompanied by some type of settling process to concentrate solids
- Backwash water and cleaning water are sent to a clarifier or settling basin
- The supernatant is collected off the surface of the settling basin and mixed with feed water

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OPERATIONS

Membrane Filtration

- Treatment is independent of pre-treatment conditions and raw water turbidity.
- Pore size in membranes forms an effective barrier to cyst sized particles.
- No need for a filter to waste step at the beginning of a filtration run.

Conventional Filtration

- Requires optimized chemical pretreatment (coagulation, flocculation, sedimentation).
- Operators must adjust treatment for changing water conditions.
- Giardia and Cryptosporidium may pass through filter.
- Must filter to waste prior to returning to the filtration cycle after backwashing.

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OPERATIONS

Membrane Filtration

- Increased turbidity may have no effect on performance or it may cause a decline in flux or a decrease in time interval between backwashing and cleaning.
- Goal is to maintain finished water productivity, quality of the filtrate remains the same.

Conventional Filtration

- Increased turbidity will require additional coagulant to be added, or increased flocculation/settling, shorter filter runs, increased backwashing or may result in reduced finished water quality.
- Goal is to maintain finished water quality.

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OPERATIONS

Modes of Operation

- Filtration
- Backwash
- Air scrub
- Chemically enhanced backwash (some systems)
- Chemical clean in place (CIP)
- Membrane Integrity Testing

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OPERATIONS

- Generally filtration, backwash and air scrubbing are automatically controlled by the system based on operator selected points such as:
  - Trans-membrane pressure (TMP)
  - Flux rate or volume filtered
  - Filter run time
- Clean in place is usually selected manually.
- Integrity testing is conducted automatically or at operator selected intervals.

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OPERATIONS

- Data Collection
  - Careful data collection and good recordkeeping are important to the successful long-term performance of membrane systems
  - Data should be collected as soon as the unit begins service and should include:
    - Flow of feed water, filtrate, and retentate
    - Temperature
    - Turbidity of feed and filtrate
    - Results of integrity testing
    - TMP

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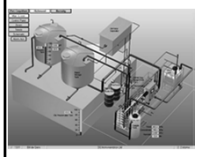
OPERATIONS



- Most data is collected automatically using a SCADA system
- It is important to collect both pre and post cleaning data

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TROUBLESHOOTING

Condition	Ideas to consider
Failed Integrity Test	Verify readings
	Determine if membranes are fully wetted or have become hydroscopic
	Locate and isolate modules with flaws or leaking seals or O rings
	Conduct new integrity test with problem modules removed to make sure all the problems have been found
	Determine the nature of the failure
	Repair flawed module and return to service
	Conduct new integrity test to make sure the problem is resolved

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TROUBLESHOOTING

Condition	Ideas to Consider
High turbidity in filtrate	Conduct integrity test
	If integrity test indicates no broken fibers or leaks, verify turbidity reading
	Measure turbidity in a grab sample
	Clean and calibrate turbidimeter, look for problems (air bubbles)

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TROUBLESHOOTING

Condition	Ideas to consider
High rate of fiber breakage	Check pressures and water hammer potential being applied during operating cycles. Inaccurate pressure can result in damage during a backwash or integrity test.
	Check for exposure to highly concentrated chemicals, evaluate quality of CIP and CEB (chemically enhanced backwash) chemicals
	Check for exposure to extreme temperatures
	Consider the age of the membranes
	Have the integrity and strength of membranes evaluated by the manufacturer (membrane autopsy)
	If fibers are not old, consider a warranty claim
	Old or improperly operated membranes may become brittle, they need to be operated wet.

TROUBLESHOOTING

Condition	Ideas to Consider
Interval between cleanings is too short	Verify that the data are normalized for temperature, flux may be too high for the application
	Raw water quality may have changed
	Evaluate pretreatment processes, mishandled polymer can result in significant irreversible flux loss.
	Evaluate backwash and chemically enhanced backwash (CEB) procedures, and the chemicals used.
	Consider the effects of pH, may cause aluminum scale on membrane if alum is used in pretreatment
	Evaluate CIP procedures with manufacturer and engineers, compare with other utilities
	Chemically enhanced backwash if not already in use may increase the interval between CIPs.

TROUBLESHOOTING

Condition	Ideas to consider
CIP does not return unit to baseline	Check normalized clean water resistance and permeability values
	Evaluate CIP procedure, more aggressive cleaning may be needed (higher temp, stronger chemical concentration if compatible with membrane)
	Consider changing the order of chemicals (acid before caustic, etc)
	Consider the effects of pH, may cause aluminum scale on membrane if alum is used in pretreatment
	Evaluate CIP procedures with manufacturer and engineers, compare with other utilities
	Consider using soft water for CIP solutions

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REGULATIONS

- Currently state primacy agencies award different log removal credits for MF/UF membrane systems
- In 2003 USEPA proposed specific language relative to the use and application of membranes to meet requirements of the Long-Term 2 Enhanced Surface Water Treatment Rule (LT2SWTR)
- A draft of a guidance manual (Membrane Filtration Guidance Manual) is available to assist the drinking water community and regulatory agencies in permitting membrane systems

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TN RULES FOR MEMBRANES

Systems receive LT 2 *Cryptosporidium* treatment credit for membrane filtration that meets the following criteria:

- The removal efficiency is demonstrated during challenge testing
- The maximum removal efficiency can be verified through direct integrity testing used with the membrane filtration process.
- The system must conduct continuous indirect integrity monitoring.

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TN RULES FOR MEMBRANES

Challenge Testing

- Challenge testing must be conducted on either a full-scale membrane module or a smaller-scale membrane module, identical in material and similar in construction to the full-scale module
- Challenge testing must be conducted using *Cryptosporidium* oocysts or a surrogate that is removed no more efficiently than *Cryptosporidium* oocysts
- The organism or surrogate used during challenge testing is referred to as the challenge particulate
- The concentration of the challenge particulate, in both the feed and filtrate water, must be determined using a method capable of discretely quantifying the specific challenge particulate used in the test; gross measurements such as turbidity may not be used

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TN RULES FOR MEMBRANES

Challenge Testing

- The maximum feed water concentration that can be used during a challenge test is based on the detection limit of the challenge particulate in the filtrate and must be determined according to the following equation:

Maximum Feed Concentration = 3.16 × 106 × (Filtrate Detection Limit)

- Challenge testing must be conducted under representative hydraulic conditions at the maximum design flux and maximum design process recovery specified by the manufacturer for the membrane module.

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TN RULES FOR MEMBRANES

Challenge Testing-

- Removal efficiency of a membrane module must be calculated from the challenge test results and expressed as a log removal value (LRV) according to the following equation:

LRV = LOG(Cf) × LOG(Cp)

  - Cf = the feed concentration measured during the challenge test
  - Cp = the filtrate concentration measured during the challenge test

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TN RULES FOR MEMBRANES

Challenge Testing

- The removal efficiency of a membrane filtration process demonstrated during challenge testing must be expressed as a log removal value (LRVCTest)
- If fewer than 20 modules are tested, then the LRVC-Test is equal to the lowest of the representative LRVs among the modules tested
- If 20 or more modules are tested, then LRVC-Test is equal to the 10th percentile of the representative LRVs among the modules tested
- The challenge test must establish a quality control release value (QCRV) for a non-destructive performance test that demonstrates the *Cryptosporidium* removal capability of the membrane filtration module

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TN RULES FOR MEMBRANES

Direct Integrity Testing

- A direct integrity test is defined as a physical test applied to a membrane unit in order to identify and isolate integrity breaches
  - *i.e.*, one or more leaks that could result in contamination of the filtrate
- Systems must conduct direct integrity testing in a manner that demonstrates a removal efficiency equal to or greater than the removal credit awarded to the membrane filtration process

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TN RULES FOR MEMBRANES

Direct Integrity Testing

- The direct integrity method must have a resolution of 3 micrometers or less
- The direct integrity test must have a sensitivity sufficient to verify the log treatment credit awarded to the membrane filtration process by the State
- Systems must establish a control limit within the sensitivity limits of the direct integrity test that is indicative of an integral membrane unit capable of meeting the removal credit awarded by the State
- If the result of a direct integrity test exceeds the control limit established, the system must remove the membrane unit from service
- Systems must conduct a direct integrity test to verify any repairs, and may return the membrane unit to service only if the direct integrity test is within the established control limit

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TN RULES FOR MEMBRANES

Direct Integrity Testing

- Systems must conduct direct integrity testing on each membrane unit at a frequency of not less than once each day that the membrane unit is in operation
- The State may approve less frequent testing, based on demonstrated process reliability, the use of multiple barriers effective for *Cryptosporidium*, or reliable process safeguards

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TN RULES FOR MEMBRANES

Indirect Integrity Monitoring

- Indirect integrity monitoring is defined as monitoring some aspect of filtrate water quality that is indicative of the removal of particulate matter
- Unless the State approves an alternative parameter, continuous indirect integrity monitoring must include continuous filtrate turbidity monitoring
- Continuous monitoring must be conducted at a frequency of no less than once every 15 minutes
- Continuous monitoring must be separately conducted on each membrane unit

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TN RULES FOR MEMBRANES

Indirect Integrity Monitoring

- If indirect integrity monitoring includes turbidity and if the filtrate turbidity readings are above 0.15 NTU for a period greater than 15 minutes (i.e., two consecutive 15-minute readings above 0.15 NTU), then direct integrity testing must immediately be performed on the associated membrane unit
- If indirect integrity monitoring includes a State-approved alternative parameter and if the alternative parameter exceeds a State-approved control limit for a period greater than 15 minutes, direct integrity testing must immediately be performed on the associated membrane units.

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HELPFUL INFORMATION

EPA's Membrane Filtration Guidance Manual

http://epa.gov/OGWDW/disinfection/lt2/pdfs/guide_lt2_membranefiltration_final.pdf

AWWA Manual of Water Supply Practices

M53 Microfiltration and Ultrafiltration Membranes for Drinking Water

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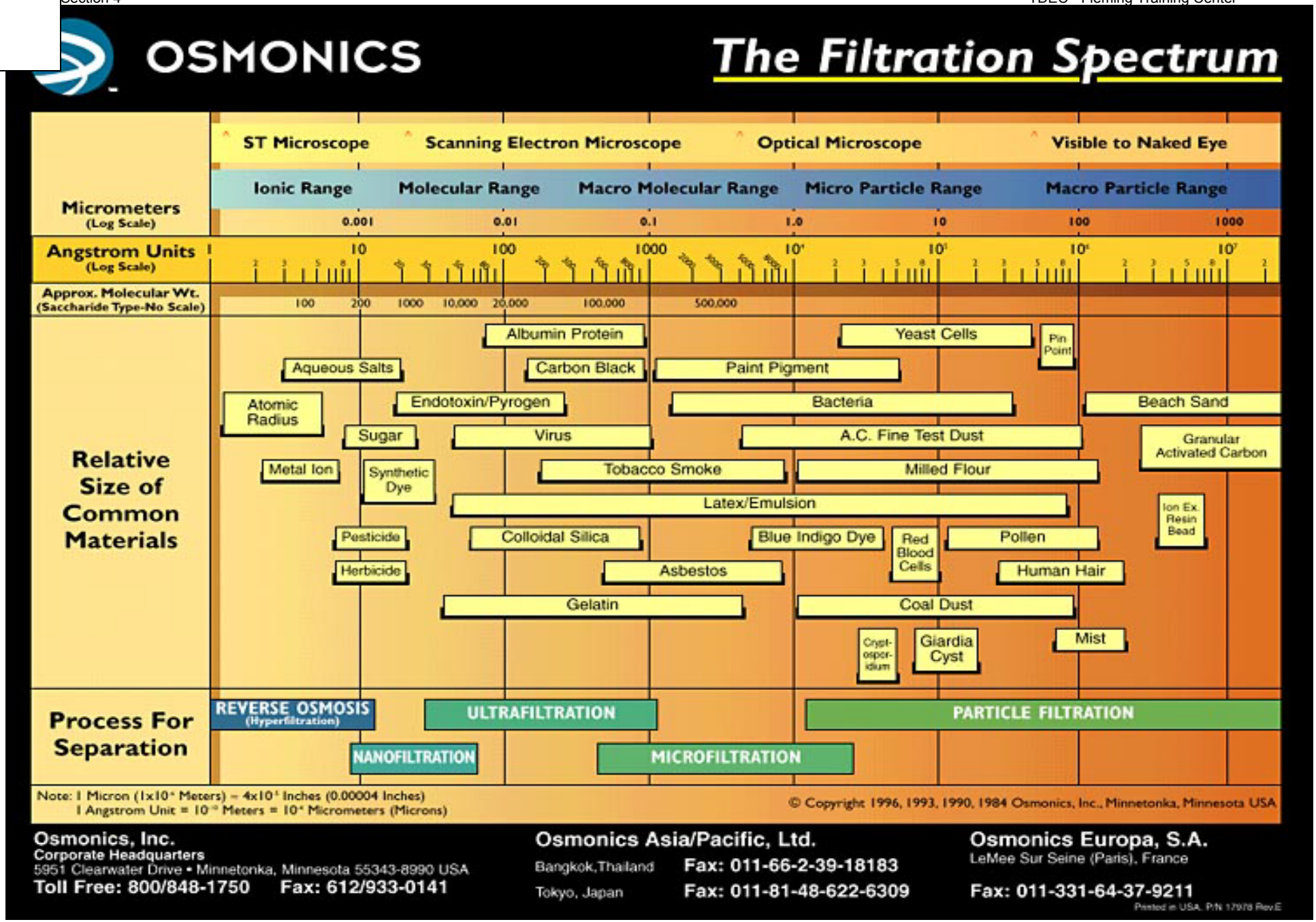
OSMONICS
The Filtration Spectrum
ST Microscope
Scanning Electron Microscope
Optical Microscope
Visible to Naked Eye
Ionic Range
Molecular Range
Macro Molecular Range
Micro Particle Range
Macro Particle Range
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100,000
500,000
Relative Size of Common 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
Cryptosporidium
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)
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Section 5

Softening

1

Softening

Hardness
Lime-softening
Ion Exchange

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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

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Water Hardness

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

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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

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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 - $MgSO_4$

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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

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Types of Water Hardness

Calcium vs. Magnesium Hardness

- Calcium hardness caused by calcium
- Magnesium hardness caused by magnesium

- Total hardness = Ca hardness + Mg hardness

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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

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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

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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

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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

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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

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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

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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

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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

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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

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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

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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

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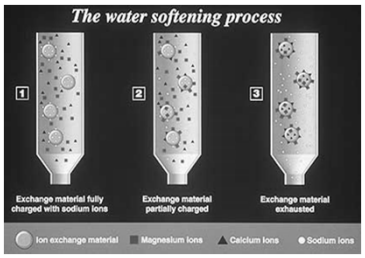
Softening Process



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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

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Softening Process

Chemical Reactions

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

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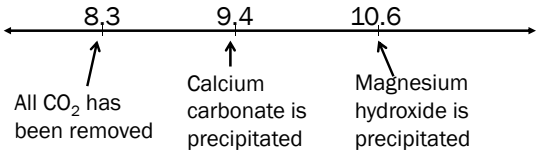
Softening Process

pH Scale



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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

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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

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Softening Process

Regulations

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

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Softening Process

Operating Problems

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

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Softening Process

Interferences

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

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Softening Process

Record Keeping

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

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

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
  - Arsenate
  - Nitrate
  - Hardness (calcium and magnesium)
- Common alternative to cold process lime-soda ash softening

Ion Exchange

- Requires an ion exchange medium called a resin
- 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

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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

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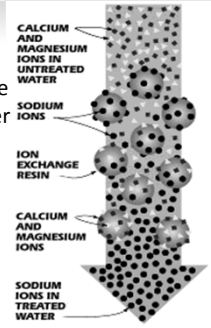
Ion Exchange Resins

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



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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-base anion exchangers operate over the entire pH range
- Weak-base anion exchangers do not remove anions above pH 6

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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

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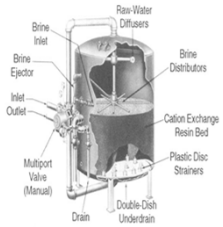
Ion Exchange Units



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

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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

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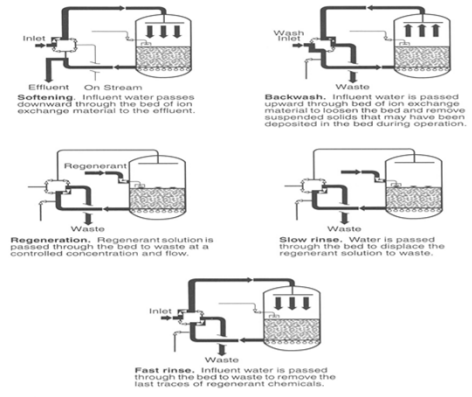
Ion Exchange

Operation of Processes

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



Courtesy of Infilco Degremont Inc., Richmond, Va.

FIGURE 12–5 Four cycles in the ion exchange process

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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

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Ion Exchange Cycles

Regeneration

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

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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

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Ion Exchange Cycles

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

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

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

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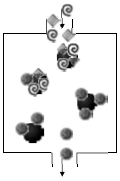
Ion Exchange Resin
Sodium Ion
Magnesium Ion
Calcium Ion

Softening Process

Hard Water containing Calcium & Magnesium

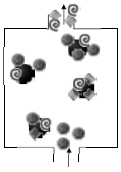
Ion Exchange Resin with Sodium Attached



Softened Water containing Sodium

Regeneration Process

Waste Water Calcium & Magnesium



Ion Exchange Resin with Calcium & Magnesium

Brine Solution containing Sodium

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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)

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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

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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

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Operating Problems

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

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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

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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

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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

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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

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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

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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

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Record Keeping

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

Section 7

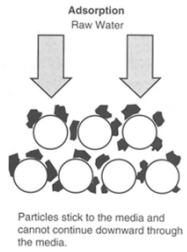
Adsorption

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 number of locations the concentration has been high enough that the well has been discontinued or special treatment began to remove the SOC's

7

ORGANIC CHEMICAL REMOVAL

- The best place to control organics in drinking water is at the source.
  - Control of watershed
  - Control of algae growth
- Groundwater systems might establish restrictions on land use in the recharge zone or construct barriers to prevent contaminants from flowing toward a well in the aquifer.

8

REMOVAL BY OTHER PROCESSES

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

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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

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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

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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

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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

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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

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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

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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

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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

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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

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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

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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

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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

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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)

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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

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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

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TESTS OF GAC IN FILTERS

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

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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

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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

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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

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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 or oils
- Do not store near chlorine (HTH) or potassium permanganate because of spontaneous combustion
- Explosion-proof light fixtures, electrical wiring
- Tanks should be vented, have dust collectors

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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

30

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

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Aeration

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- 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

2

Goals of Aeration

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- 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

3

Effects of Aeration

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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

4

Effects of Aeration

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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

5

Effects of Aeration

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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

6

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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

7

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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

8

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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

9

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Effects of Aeration

Tastes and Odors

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

10

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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

11

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Types of Aerators

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

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Water-Into-Air Aerators

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Types

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

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Water-Into-Air Aerators

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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

14

Water-Into-Air Aerators

TDEC - Fleming Training Center

Cascade Aerators

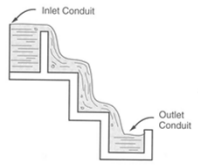
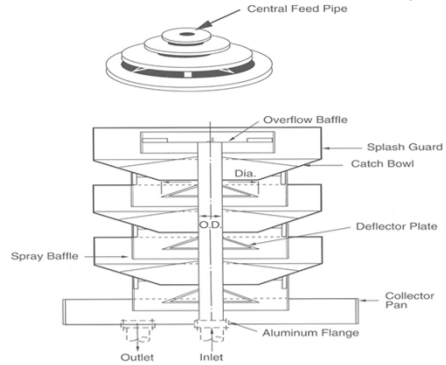


FIGURE 14–2 Stairway-type cascade aerator

15

TDEC - Fleming Training Center



Courtesy of US Filter-General Filter Products

FIGURE 14–3 Ring-type cascade aerator

Water-Into-Air Aerators

TDEC - Fleming Training Center

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

17

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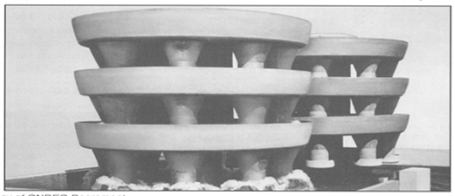
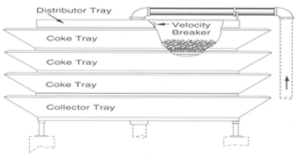


Courtesy of ONDEO Degremont

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

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Slat and Coke Tray Aerators

- Consists of 3-5 stacked trays with spaced slats
- Contains media made of coke, rock, ceramic balls, and limestone
- Used to oxidize iron and lower concentration of dissolved gases

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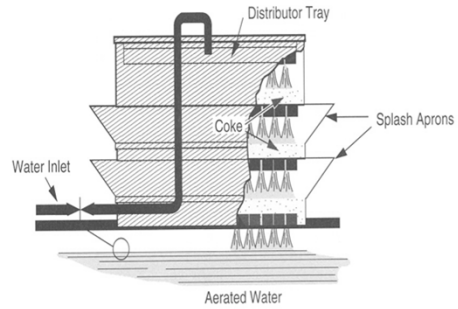

Courtesy of Power Magazine, *McGraw-Hill Inc.*

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

Water-Into-Air Aerators

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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

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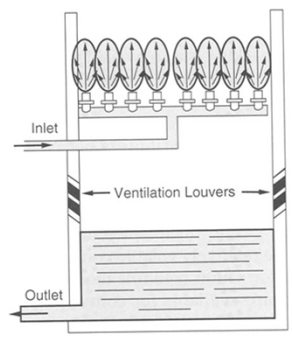

Courtesy of ONDEO Degremont Inc., Richmond, Va.

FIGURE 14-9 Spray tower

Water-Into-Air Aerators

TDEC - Fleming Training Center

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
- Minimum air-to-water ratio = 25:1
- Maximum air-to-water ratio = 80:1

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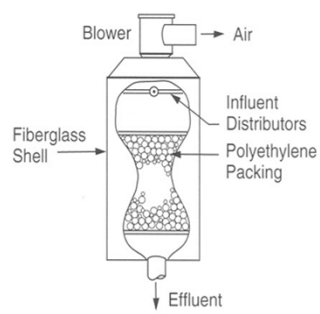
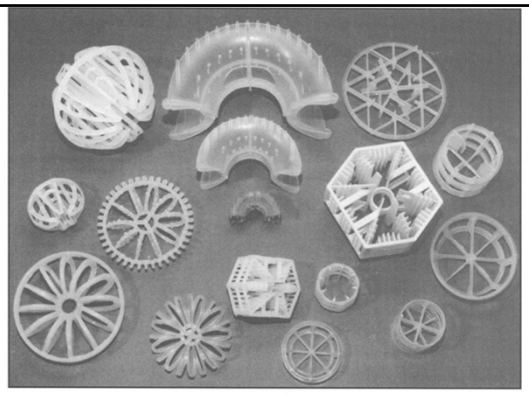


FIGURE 14-12 Cutaway view of interior of a packed tower



Source: US Environmental Protection Agency.

FIGURE 14–11 Typical plastic packing pieces

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)

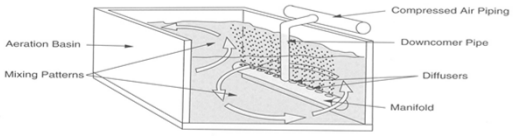


FIGURE 14–14 Diffuser aeration system

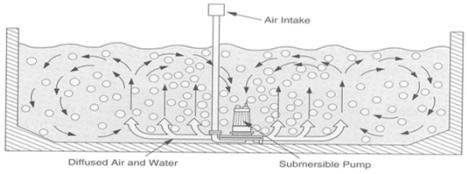


FIGURE 14–17 Draft-tube aerator

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)

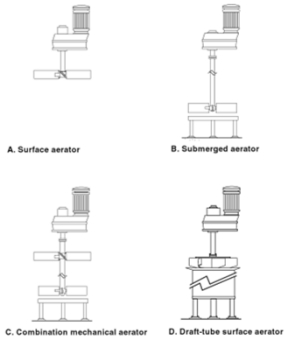


FIGURE 14-18 Four types of mechanical aerators
Courtesy of Philadelphia Mixers Corporation.

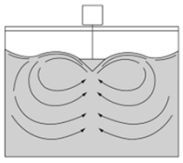


FIGURE 14-19 Mixing pattern of surface aerator
Courtesy of Dorr-Oliver EIMCO.

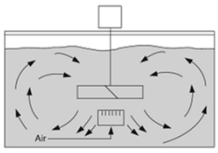


FIGURE 14-20 Mixing pattern of submerged turbine aerator
Courtesy of Dorr-Oliver EIMCO.

Limitations of Aerators

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- 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
- Amount of O_2 that will dissolve depends on water temperature
  - Decrease temperature, increase saturation concentration

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

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

- Case studies of backflow incidents
- Basics of Cross-Connection Control
- Hydraulics
- Definitions
- Backflow Preventers
- Applications

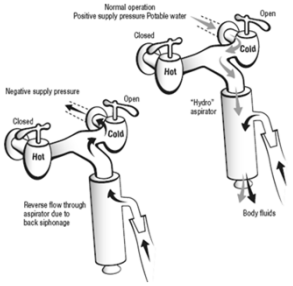
Backflow Case Study

Human Blood in the Water System

Blood observed in drinking fountains at a funeral home

Hydraulic aspirator used to drain body fluids during embalming

Contamination caused by low water pressure while aspirator was in use



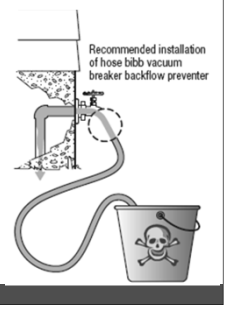
Backflow Case Study

Kool-Aid Laced with Chlordane

Exterminator submerged garden hoses in small buckets while mixing insecticide at the same time a water meter was being installed nearby

Chlordane was backsiphoned into water lines and became mixed with Kool-Aid

A dozen children and three adults became sick



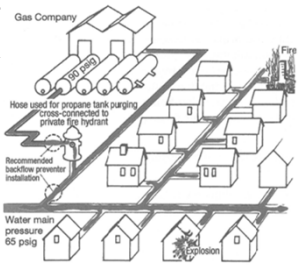
Backflow Case Study

Propane Gas in the Water Mains

Gas company initiated repairs on 30,000 gallon liquid propane tank by flushing with fire hydrant

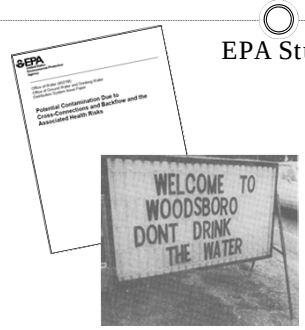
Vapor pressure of propane residual in the tank exceeded water main pressure

Hundreds evacuated, two homes caught fire, water supply contaminated



Backflow Case Study

EPA Study



EPA compiled backflow incident data from 1970 to 2001 and found:

459 incidents resulted in **12,093** illnesses

Backflow incidents can result in property damage, personal injury, and even death

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?

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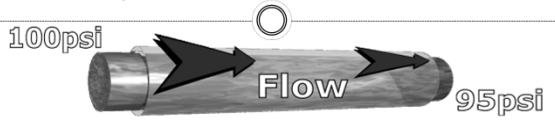
Hydraulics and Pressure



- Water can flow through a pipe in either direction
- The direction of flow will depend on the forces (pressures) acting on the water
- Water pressure naturally tends to equalize
- Therefore, water flows down a gradient from high pressure regions to low pressure regions

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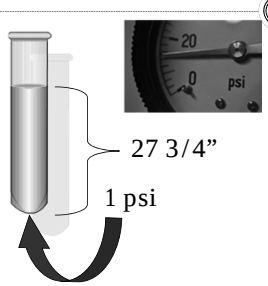
Head Pressure



27 ¾” = 2.31 Feet of Head

- 27 3/4” of water generates a pressure of one pound per square inch (psi)
- The pressure on the bottom of the container is generated by the weight of the water above it

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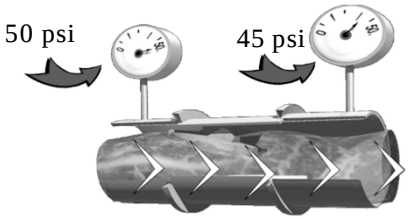
Normal Flow



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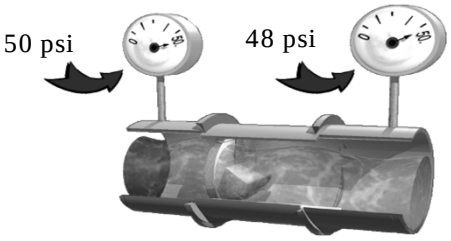
No Flow



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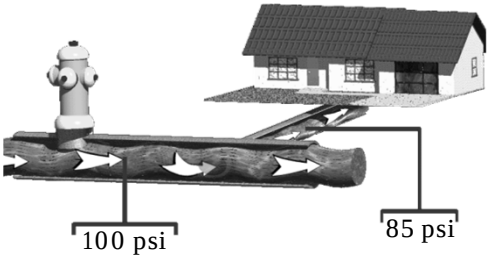
Normal Flow



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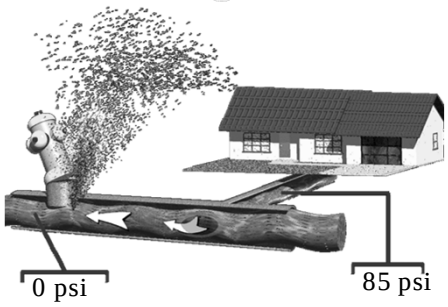
Reverse Flow - Backflow



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Backflow

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

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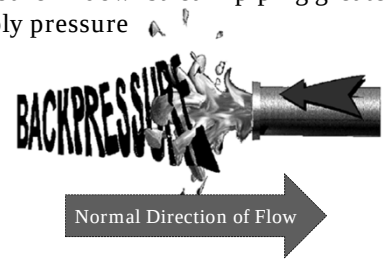
Backpressure

- Pressure in downstream piping greater than supply pressure



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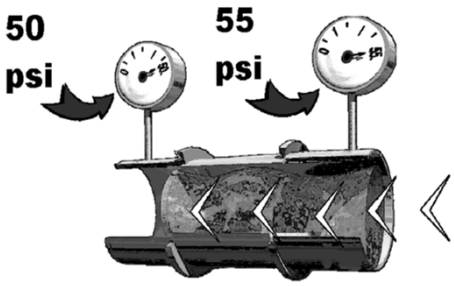
Backpressure



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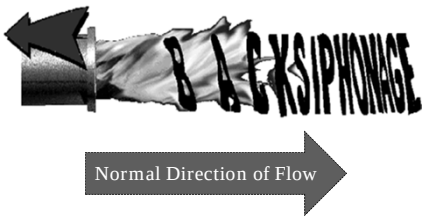
Backsiphonage

- Sub-atmospheric pressure in the water system



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Backsiphonage

What is drawn into the water pipes if backsiphonage occurs?

- As backsiphonage occurs air will be drawn up into the water pipes

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Backsiphonage

What is drawn into the water pipes if backsiphonage occurs?

- Whatever is in the barrel...

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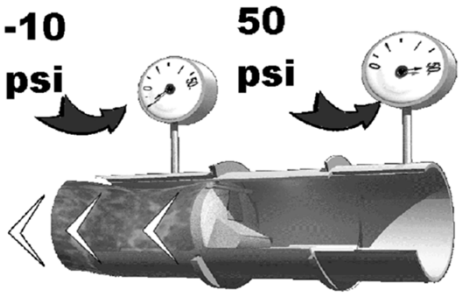
Backsiphonage



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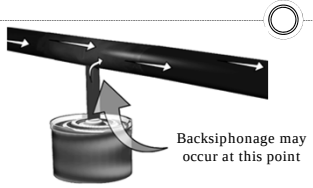
Aspirator Effect



- As water flows through a pipe, the pressure against the walls of the pipe decreases as the speed of the water increases
- If a second pipe is attached there could be a low pressure area created at the point of connection which could siphon water from the attached pipe into the flowing pipe - Backsiphonage

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Cross-Connection

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

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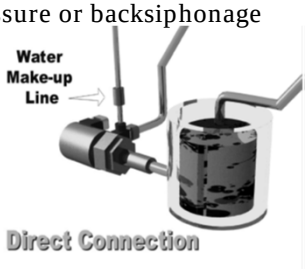
Direct Cross-Connection

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



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Indirect Cross-Connection

- An indirect cross-connection is subject to backsiphonage only

Submerged Inlet

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Indirect Cross Connection

Submerged Inlet	Low Inlet

Low Inlet

Direct Cross Connection?

Degree of Hazard

- Non-Health Hazard
  - Low hazard
  - Will not cause illness or death
  - **Pollutant**

- Health Hazard
  - High hazard
  - Causes illness or death
  - **Contaminant**

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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.

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Five Means of Preventing Backflow

- Air Gap Separation (AG)
- Reduced Pressure Principle Assembly (RPZ/RPBP/RP)
- Double Check Valve Assembly (DCVA)
- Pressure Vacuum Breaker (PVB)/ Spill-Resistant Vacuum Breaker
- Atmospheric Vacuum Breaker (AVB)

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Air Gap

- An air gap is the vertical separation between the water supply line outlet and the overflow rim of the non-pressurized receiving fixture or tank

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Air Gap

2 X ID,
not <1 inch

- An air gap is the *BEST* method of protection against backflow
- Approved air gap separation must have a vertical unobstructed distance of at least twice the internal diameter of the outlet pipe, but never less than 1 inch

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Air Gap Separation Limitations

- The air gap is the best method of backflow prevention, but it is easily defeated through modifications or being bypassed
- The air gap separation causes a loss of pressure in the system
- Sanitary control is lost - cannot be installed in an environment containing airborne contamination

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Approved Air Gap Separation

Backflow Protection Against:

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

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	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**

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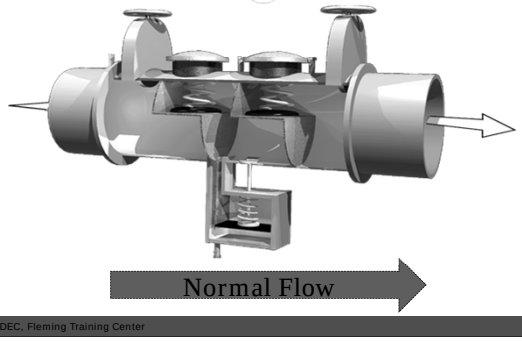
Reduced Pressure Principle Assembly



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Reduced Pressure Principle Assembly

- The reduced pressure principle backflow prevention assembly (RP) consists of two independently operating check valves together with a hydraulically operating, mechanically independent, pressure differential relief valve located between the check valves, all located between two resilient seated shutoff valves and four properly located test cocks.
- *BEST* device to protect against backflow

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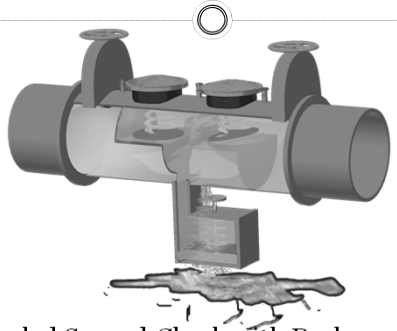
RP



Fouled Second Check with Backpressure

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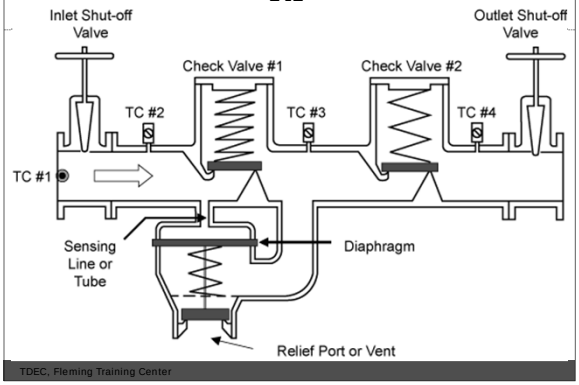
RP



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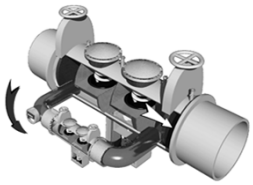
RP Detector Assembly

- Line sized RP
- Smaller detector RP installed on a bypass around large RP
- Water meter before smaller RP
- Purpose is to detect any unauthorized use of water



2 GPM and lower travels through bypass only and gets registered on water meter

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RP

<u>Backflow Protection Against</u>:

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

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	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**

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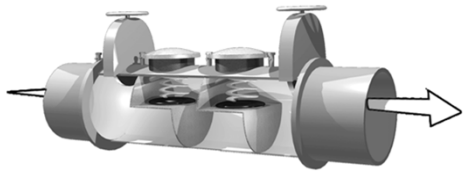
Double Check Valve Assembly (DC)



Normal Flow

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Double Check Valve Assembly (DC)

- The double check valve backflow prevention assembly (DC) consists of two independently operating check valves installed between two tightly closing resilient seated shutoff valves and fitted with four properly located test cocks
- Similar to the RP, but has no relief port and no where for the water to go during a backflow incident or failure

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Double Check Valve Assembly (DC)

- Since the water in a DC cannot leave the system during a backflow event or assembly failure then it is a higher risk and therefore cannot be used in a high hazard (contaminant) application
- If one check fails the other will continue to protect, but given enough time the second check will fail and backflow will occur

Second check fouled during backpressure

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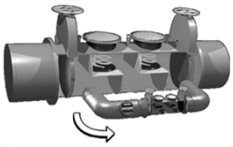
DC Detector Assembly



2 GPM and less through bypass only

- Line sized DC
- Smaller detector DC installed on a bypass around large DC
- Water meter before smaller DC registers low flow use
- Purpose is to detect any unauthorized use of water

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Double Check Valve Assembly (DC)

<u>Backflow Protection Against</u>:

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

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	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**

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Proper Installation for DC and RP

- Lowest part of the relief valve should be a minimum of 12 inches above either: the ground, the top of the opening of the enclosure wall, or the maximum flood level
  - Whichever is highest, in order to prevent any part of the assembly from becoming submerged
- Maximum 60” above grade to the center line of assembly, if higher then safe permanent access must be provided for testing and servicing

* Tennessee Cross-Connection Control Manual and Design Criteria for Cross-Connection Control Plans, Ordinances, and Policies (2008) – Appendix B

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Proper Installation for DC and RP

- Assemblies should be installed in accordance with manufacturer's installations otherwise it voids the approval for the assembly
- Protected from vandalism and weather (if needed)
- RP requires adequate drainage – ***cannot*** be installed in a pit or meter box
- Must be accessibile for testing and repair

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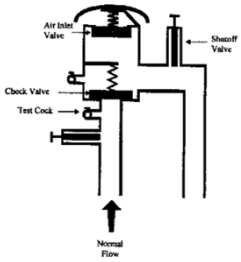
Pressure Vacuum Breaker (PVB)



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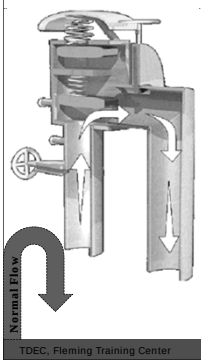
Pressure Vacuum Breaker (PVB)



- The pressure vacuum breaker or spill resistant vacuum breaker consists of an independently operating check valve and an independently operating spring loaded air inlet valve located on the discharge side of the check valve, with tightly closing shutoff valves on each side of the check valves, and properly located test cocks for valve testing

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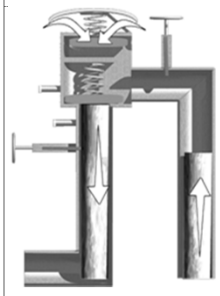
PVB Backsiphonage Condition



- In a backsiphonage condition there is a loss of supply pressure and the check valve is forced closed
- If the body loses pressure the air inlet valve is forced open allowing air into the body of the pressure vacuum breaker and breaking the siphon
- Only to be used to protect against backsiphonage

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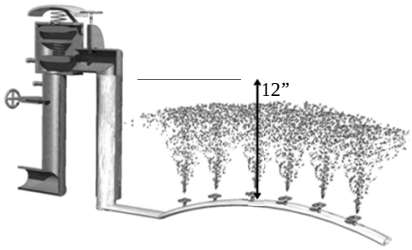
Installation of PVB

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



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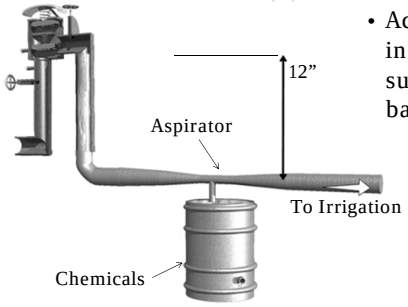
Pressure Vacuum Breaker



- Acceptable installation not subject to backpressure

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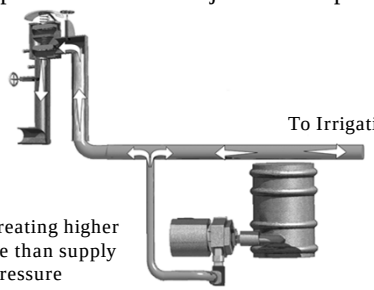
Pressure Vacuum Breaker

- Improper installation subject to backpressure



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Pressure Vacuum Breaker

Backflow Protection Against:

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

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	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**	

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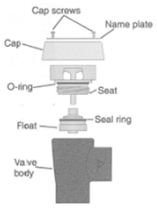
Atmospheric Vacuum Breaker (AVB)



Atmospheric Vacuum Breaker Exploded View

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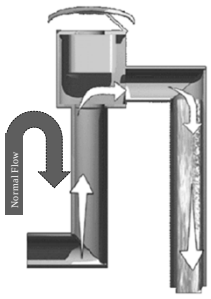
Atmospheric Vacuum Breaker (AVB)



- The atmospheric vacuum breaker is a device designed to prevent backsiphonage. It consists of a body, a single moving float that acts as a check valve when there is no flow and as a air-inlet valve when flow is present, and an air-inlet opening covered by a cap

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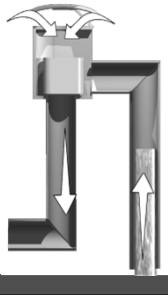
Atmospheric Vacuum Breaker (AVB)

- Backsiphonage condition



Loss of supply pressure

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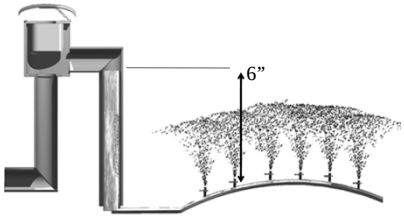
Installation of AVB

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



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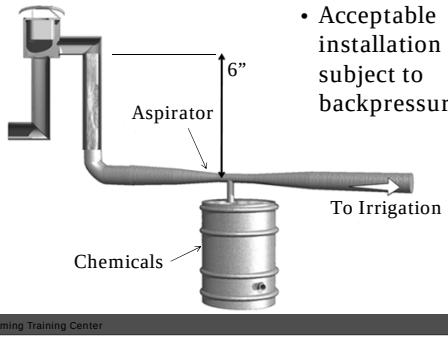
Atmospheric Vacuum Breaker

- Acceptable installation not subject to backpressure



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Atmospheric Vacuum Breaker

- Improper installation: downstream shutoff valves
- Shutoff valves downstream of an AVB can cause a continuous use situation
- The float of an AVB subjected to continuous use could begin to adhere to the air inlet and allow backflow

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Atmospheric Vacuum Breaker

<u>Backflow Protection Against</u>:

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

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	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	

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Testing of Assemblies

- Assemblies must be tested when installed, after repair, and at least annually
- Assembly testing must be conducted by certified personnel
- TDEC issues a certification for all assembly testers
- Backflow tester certification courses are offered through the Fleming Training Center

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Cross-Connection Control Manuals

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

http://www.tn.gov/assets/entities/environment/attachments/crossconnection.pdf

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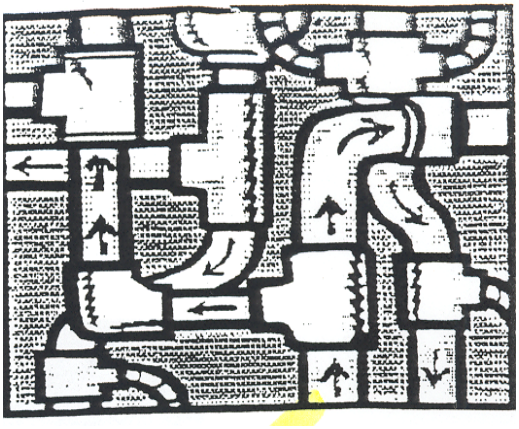


Vocabulary

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.

Chemical – A substance obtained by a chemical process or used for producing a chemical reaction.

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

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

Continuous Pressure – 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.

Cross Connection – (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.

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

Degree of Hazard – 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.

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

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

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

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

Indirect Connection – 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				0400-45-1-.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				0400-45-1-.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		0400-45-1-.33(12)
Miscellaneous				
Action regarding violations		3 years		0400-45-1-.20(1)(b)
Certified Letters to Fire Departments regarding Class C hydrants		5 years		0400-45-1-.17(18)
Complaint file		5 years		0400-45-1-.20(1)(h)
Consumer Confidence Reports		3 years		0400-45-1-.35(h)
Cross connection plans and inspection records		5 years		0400-45-1-.20(1)(h)
Daily worksheets, strip charts, shift logs		5 years		0400-45-1-.20(1)(g)
Disinfection Profile		10 years		
Disinfection SOP		Keep updated		
Distribution map		Keep updated, submit copy to DWS every 5 years		0400-45-1-.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		0400-45-1-.17(10)
MOR's		5 years		
MSDS		At least 30 years		29 CFR 1910.1020
New tap records		Survey to survey or 3 years		0400-45-1-.17(32)
Notice of Construction		Survey to survey or 3 years		
Plant SOP		Keep updated		
Public Notices		3 years		0400-45-1-.20(i)
Sanitary surveys		10 years		
Storage Tank Inspection Records		5 years		1200-1-5-.17(33), 0400-45-1-.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		0400-45-1-.20(1)(f)
Variances or Exemptions		5 years		0400-45-1-.20(1)(d)

Recordkeeping & Design Criteria

Introduction to Water Treatment
Grades 3 & 4
Course # 3101

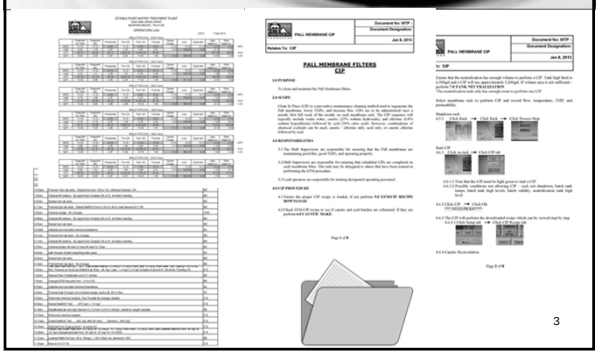
1

Agenda

- Recordkeeping.
  - Organization.
  - Records Maintenance.
  - Ethics.
- Design Criteria.
  - Part 1. Submission of Engineering Documents.
  - Part 2. General Design Considerations.
  - Part 3. Source Development.
  - Part 4. Treatment.
  - Part 5. Chemical Application.
  - Part 6. Laboratory Facilities.
  - Part 7. Pumping Facilities.

2

Recordkeeping



3

Recordkeeping – Organization General

- Sanitary Survey Manual is one tool to determine method to organize records.
- Other tools that address recordkeeping are:
  - Water Treatment Plant Operation, Vol. II, 5th Ed., Sacramento
  - WSO, Water Treatment, 4th Ed., AWWA
  - Water Treatment Operator Handbook, AWWA
- Records
  - Paper
  - Electronic

4

Recordkeeping – Organization Sanitary Survey Manual

A. Correspondence
B. Complaints
C. Construction Projects
D. Enforcement
E. Bacteriological Results
F. Turbidity/Treatment Technique Compliance
G. Disinfection/Disinfection By-Products Compliance
H. Chemical Analysis
I. Public Notification
J. Consumer Confidence Reports (CCR)
K. Operator Certification
L. Cross Connection Plan and Program
M. Emergency Operations Plan and Distribution Map

5

Recordkeeping – Organization Sanitary Survey Manual

N. Source Water Protection
O. Fluoridation
P. Monthly Operation Reports (MORs)
Q. Corrosion Control
R. Bacteriological Sampling Site Plan
S. Flushing Program
T. Capacity Development Plan (see Rule 0400-45-01-.04)
U. Filter Backwash Recycling

Added to List

V. Storage Tank Inspections and Maintenance Records
W. Facility/Equipment Maintenance Records
X. Daily Worksheets
Y. Operator Logs

6

0400-45-01-.20 Records Maintenance Public Water System Rules

- Many sections of 0400-45-01-…cover specifics regarding the rules and regulations.
- Section 0400-45-01-.20 details Records Maintenance.
  - Bacteriological analysis – *not less than five (5) years*.
  - Chemical analysis – *not less than ten (10) years*.
  - Action taken to correct violations or primary drinking water regulations – *not less than three (3) years after last action was taken regarding the violation*.
  - Copies of any written reports, summaries or communications relating to sanitary surveys of the system – not less than ten (10) years *after completion of sanitary survey involved*.
  - Variance or exemption granted – not less than five (5) years *following expiration of such variance or exemption*.

7

0400-45-01-.20 Records Maintenance Public Water System Rules

- Reports required by the Department *shall be available for inspection by the public* at the appropriate public water system office *during regular business hours*.
- Turbidity analysis – *not less than five (5) years*.
  - Daily worksheets.
  - Calibration data.
  - Strip charts/SCADA system data (date, time, place of collection, operating scale of the instrument, operator's initials (if strip chart)).
- Daily worksheets, strip charts and shift logs – *not less than five (5) years*.
- Cross-connection plans and inspection records – *not less than five (5) years*.
- Complaint logs records – *not less than five (5) years*.

8

0400-45-01-.20 Records Maintenance Public Water System Rules

- Facility maintenance records – *not less than five (5) years*.
- Storage tank inspection records – *not less than five (5) years*.
- Public notices issued and certifications made to the Department pursuant to Rule 0400-45-01-.19 – *must be kept for three (3) years after issuance*.
- Lead and copper – Any system subject to the requirements of Rule 0400-45-01-.33 – shall retain on its premises original records of all sampling data and analyses, reports, surveys, letters, evaluations, schedules, Department determinations, and any other information required by paragraphs (2) through (9) of Rule 0400-45-01-.33 – shall retain the records required by this rule for *no fewer than 12 years*.
- Monitoring plans – *shall be kept for the same period of time as the records of analyses taken under the plan are required to be kept except as specified elsewhere in this chapter*.

9

0400-45-01-.18 Reporting Requirements Public Water System Rules (Ethics)

- It shall be a violation of these regulations for any person, public water system, engineer, operator or certified laboratory to:
  - Record data or information and/or report any inaccurate, misleading, false or information known or that should be known to be false.
  - Report any data or information that is inaccurate, misleading or false because the person reporting has not used reasonable care, judgment or the application of his knowledge in the preparation of the report.
  - Provide inaccurate or false statements to the Department.

10

0400-49-01-.11 Summary and Revocation of Certificate (Ethics)

- An operator's certificate may be revoked when:
  - In accordance with paragraph (2) of this rule, an operator has not used reasonable care, judgment, or the application of his/her knowledge in the performance of his/her duties as a certified operator.
  - In accordance with paragraph (3) of this rule, an operator is incompetent to perform those duties properly.
  - In accordance with paragraph (4) of this rule, an operator has practiced fraud or deception.

11

0400-49-01-.11 Summary and Revocation of Certificate (Ethics)

- An operator shall be deemed to have not used reasonable care, judgment, or the application of his/her knowledge in the performance of his/her duties if he/she does not comply with the laws, rules, permit requirements, or orders of any governmental agency or court which govern the water supply system or the wastewater system he/she operates. Such acts of noncompliance include but are not limited to the following:
  - The intentional or the negligent failure by the operator or persons under his/her supervision to act that results in a water supply system facility or a wastewater system facility not operating in the manner in which it is capable of being operated for the performance of its designed function.
  - The intentional or the negligent failure by the operator or persons under his/her supervision to comply with the monitoring, sampling, analysis, or reporting requirements for a water supply system facility or a wastewater system facility.

12

0400-49-01-.11 Summary and Revocation of Certificate (Ethics)

- The intentional or the negligent unlawful discharge of wastes from a water supply system facility or a wastewater system facility.
- The intentional or the negligent failure by the operator or persons under his/her supervision to notify the Department of conditions: which may affect the quantity or quality of water being supplied to the customers of a water supply system; which cause the pollution of the waters of the State of Tennessee; or, which are violative of a standard of water quality promulgated by any governmental agency.

13

0400-49-01-.11 Summary and Revocation of Certificate (Ethics)

- An operator shall be deemed to be incompetent to perform his/her duties properly when he/she does not possess the basic skills and knowledge necessary to operate a water supply system facility or a wastewater system facility including laboratory functions or if he/she fails to have a system of verification and oversight of employees under his/her charge. Incompetency shall be determined by examining the technical skills of the operator in operating the type of facility of which he/she is in direct charge.
- An operator shall be deemed to have practiced fraud or deception as follows:
  - Obtained his/her certificate through fraud, deceit, or the submission of inaccurate data regarding his/her qualifications upon his/her application for a certificate.
  - Has practiced fraud or deception during the performance of his/her duties as a certified operator.

14

0400-49-01-.11 Summary and Revocation of Certificate (Ethics)

- Has prepared and/or signed reports of laboratory analysis results for the system that:
  - Contain inaccurate data and are known or should be known by the operator to be false.
  - Contain inaccurate data because the operator has not used reasonable care, judgment, or the application of his/her knowledge either in the performance of the laboratory analysis or in the preparation of the laboratory analytical reports.

15

0400-49-01-.12 Civil Penalties (Ethics)

- The Commissioner may assess the civil penalty authorized by law against a municipality, utility district, corporation, or any person operating a water supply system or a wastewater system if the competency of the person in direct charge of a system facility has not first been certified in accordance with these rules.
- A certified operator may be assessed the civil penalty authorized by law for the same acts and omissions that would constitute grounds for the revocation of his/her certificate by the Board.
- Prior to issuing an order that assess a civil penalty, in accordance with paragraphs (1) and (2) of this rule the Commissioner may hold a show cause meeting with the person or entity to whom the order is proposed to be issued.

16

Community Public Water Systems Design Criteria

17

Community Public Water Systems Design Criteria

- Sections applicable to water treatment facilities.
  - Part 1. Submission of Engineering Documents.
  - Part 2. General Design Considerations.
  - Part 3. Source Development.
  - Part 4. Treatment.
  - Part 5. Chemical Application.
  - Part 6. Laboratory Facilities.
  - Part 7. Pumping Facilities.
- Where the terms shall and must are used, it is intended to be a mandatory requirement. Other terms such as should, recommend, preferred, and the like, are intended to show desirable equipment, procedures, or methods.

18

Part 1. Submission of Engineering Documents

- All reports, final plans and specifications should be submitted at least 30 days prior to the date on which action by the Department is desired.
- Preliminary plans and the engineer's report should be submitted for review prior to the preparation of final plans when the project will significantly change the distribution system or alter the treatment plant.
- No approval for construction will be issued until final, complete, detailed plans and specifications have been submitted to the Department and found to be satisfactory.

19

Part 1. Submission of Engineering Documents

- General – Documents submitted for formal approval shall include but not be limited to:
  - Summary of the basis of design.
  - Hydraulic calculations and profiles.
  - Operation requirements, where applicable.
  - General layout.
  - Detailed plans.
  - Specifications.
- Engineer's Report - Where pertinent, the following information should be included in the report:
  - General information.
  - Extent of water works system.
  - Alternate plans.

20

Part 1. Submission of Engineering Documents

- Soil, ground water conditions, and foundation problems.
- Water consumption.
- Fire flow requirements.
- Wastewater system available.
- Sources of water supply – Describe the proposed source or sources of water supply to be developed, the reasons for their selection, and information as follows:
  - Summary of the basis of design.
    - Hydrological data, stream flow and weather records.
    - Safe yield, including all factors that may affect it, e.g. downstream flow necessary to assimilate wastewater.
    - Summarized quality of raw water with special references to fluctuations in quality, changing meteorological conditions, sources of contamination, etc.

21

Part 1. Submission of Engineering Documents

- Ground water sources.
  - Sites considered.
  - Advantages of site selected.
  - Elevations with respect to surroundings.
  - Probable character of formations through which source is to be developed.
  - Unusual geologic conditions affecting site.
  - Summary of source exploration, test well depth, and method of construction, placement of liners or screen, pumping test, hours, capacity, water levels and specific yield; water quality.
  - Possible sources of contamination.

22

Part 1. Submission of Engineering Documents

    - Data which document the expected available flow in spring such as the 3-day, 20-year minimum flow.
    - Evaluation of the ground water source for direct influence of surface water.
- Proposed treatment processes – Summarize and establish the adequacy of proposed processes for the treatment of the specific water under consideration. Pilot studies may be required. Provide design criteria of the treatment unit including, where applicable:
  - Treatment basin capacities.
  - Retention times of basins and clearwell.
  - Treatment unit loadings.
  - Filter area and proposed filtration rate.
  - Backwash rate.
  - Feeder capacities and ranges.

23

Part 1. Submission of Engineering Documents

- Waste disposal – Discuss the various wastes from the water treatment plant, their volumes, proposed treatment and points of discharge.
- Project sites – including:
  - Discussion on various sites considered and advantages of the recommended ones.
  - Proximity of residences, industries, and other establishments.
  - Presence of any potential sources of pollution that may influence the quality of the supply or interfere with the effective operation of the water works system, such as wastewater absorption systems, septic tanks, privies, cesspools, sink holes, refuse and garbage dumps, sanitary landfills, etc.

24

Part 1. Submission of Engineering Documents

- Distribution system.
- Financing.
- Future expansion – Summarize planning for future needs and service for the next 5-10 years.

- Plans
  - General layout.
  - Detailed plans – including:
    - Stream crossings, providing profiles with elevations of the stream bed and the normal and extreme high and low water levels, if this information is available.
    - Profiles, if needed, having a horizontal scale of not more than 100 feet to the inch and a vertical scale of not more than 10 feet to the inch, with both scales clearly indicated.

25

Part 1. Submission of Engineering Documents

- Location and size of the property to be used for the ground water development with respect to known references such as roads, streams, section lines, and streets.
- Topography and arrangement of present or planned wells or structures, with contour interval not greater than 2 feet.
- Elevation of highest known flood level, floor of structure, upper terminal of protective casing, and outside surrounding grade, using United States Coast and Geodetic Survey, United States Geological Survey or equivalent elevations where applicable as reference.
- Plat and profile drawings of well construction, showing diameter and depth of drill holes, casing and liner diameters and depths, grouting depths, elevations and designation of geological formations, water levels and other details to describe the proposed well completely.

26

Part 1. Submission of Engineering Documents

- Location of all sources of pollution within 250 feet of the source and 100 feet of underground treated water storage facilities.
- Size, length, identity, and location of wastewater lines, drains, water mains, and plant structures.
- Schematic flow diagrams and hydraulic profiles showing the flow through various plant units.
- Piping in sufficient detail to show flow through plant, including waste lines.
- Location of all chemical feeding equipment and points of chemical application (see Section 5.0.1).
- All appurtenances, specific structures, equipment, water treatment plant waste disposal units and points of discharge, having any relationship to the plans for water mains and/or water works structures.

27

Part 1. Submission of Engineering Documents

- Location of sanitary or other facilities, such as lavatories, showers, toilets, and lockers, when applicable.
- Location, dimensions and elevations of all proposed plant facilities.
- Adequate description of any features not otherwise covered by the specifications.

  – Detailed plans for distribution system.

- Specifications.
  - Complete detailed, technical specifications shall be supplied for the proposed project unless alternate specifications are referenced (see Section 1.3.2). These shall include, where pertinent:
    - Laboratory facilities and equipment, as well as sampling taps and their locations.

28

Part 1. Submission of Engineering Documents

- Number and design of chemical feeding equipment (see Section 5.0.1).
- Materials or proprietary equipment for sanitary or other facilities including any necessary backflow or backsiphonage protection.

  – The following alternate specifications may be referenced in lieu of submitting new specifications as long as these are applicable to the project:
    - Current, approved standard specifications for the water system on file in our {Department} office.
    - Local Government Public Works Standards and Specifications published by University of Tennessee Municipal Technical Advisory Service, if legally adopted by the water system and record of such adoption is on file in our {Department} office.

29

Part 1. Submission of Engineering Documents

- Revisions to Approved Plans – Any significant deviations from approved plans or specifications affecting capacity, hydraulic conditions, operating units, the functioning of water treatment processes, or the quality of water to be delivered, must be approved by the Department before such changes are made. Revised plans or specifications must be submitted in time to permit the review and approval of such plans or specifications before any construction work which will be affected by such changes is begun.
- As-Built Plans – As-built plans shall be submitted to the Department for new water treatment plants or any significant addition or modification to an existing water plant.

30

Part 2. General Design Considerations

- Plant Layout – System design shall consider:
  - Functional aspects of plant layout.
  - Provisions for future plant expansion.
  - Access roads.
  - Site grading.
  - Site drainage.
  - Walks.
  - Driveways and parking.
  - Chemical delivery.
  - Security.

31

Part 2. General Design Considerations

- Building Layout – Design shall provide:
  - Adequate ventilation, which is screened for insect protection.
  - Adequate lighting.
  - Adequate heating and air-conditioning.
  - Adequate drainage.
  - Dehumidification equipment as needed.
  - Accessibility of equipment for operation, servicing, and removal.
  - Flexibility of operation.
  - Operator safety, including safety railings.
  - Convenience of operation.
  - Consideration of chemical storage and feed equipment in separate rooms to reduce dust problems.
  - Separate facilities for laboratory procedures and office/lunch activities.

32

Part 2. General Design Considerations

- Standby Power – Standby power generation may be required by the Department so that water may be treated and/or pumped to the distribution system during periods when there is a power outage.
- Automatic Equipment – Adequate facilities must be provided for the maintenance and servicing of automatic equipment.
- Storage and Shop Space – Adequate facilities shall be included for shop space and storage consistent with the designed facilities.
- Provisions for Future Expansion – Consideration shall be given to providing extra wall castings built into the structure to facilitate expansion and unknown future uses whenever pipes pass through walls of concrete structures.
- Metering – All water systems shall have some means of metering the raw and finished water.

33

Part 3. Source Development

- General – In selecting the source of water to be developed, the designing engineer must show to the satisfaction of the Department that the water which is to be delivered to the consumers will meet the current requirements of the Department with respect to bacteriological, physical, chemical and radiological qualities. The Division of Water Supply Basin offices evaluate and approve proposed new sources.
- Surface Water – A surface water source includes all tributary streams and drainage basins, natural lakes and artificial reservoirs or impoundments above the point of water supply intake.
  - Quantity - The quantity of water at the source shall:
    - Be adequate to supply the water demand of the service area.
    - Provide a reasonable surplus for anticipated growth over a design period of 10 to 20 years.

34

Part 3. Source Development

    - Be adequate to compensate for all losses.
    - Be evaluated for dependable capacity during drought.
    - Be evaluated for impacts on downstream uses.
  - Quality - A sanitary survey and study should be made of the factors, both natural and man made, which will affect quality. Such survey and study shall include, but shall not be limited to:
    - Obtaining samples over a sufficient period of time to assess the biological, physical, chemical and radiological characteristics of the water.
    - Assessing degree of hazard to the supply from upstream discharges and by accidental spillage of materials that may be toxic, harmful or detrimental to treatment processes.

35

Part 3. Source Development

  - Structures - Intake structures design shall:
    - Provide withdrawal of water from more than one level.
    - Provide adequate protection against rupture by dragging anchors, ice, etc.
    - Have motors and electrical controls located above grade and 100-year flood level, except when submersible pumps are approved.
    - Be accessible.
    - Be designed against flotation.
    - Be equipped with removable or traveling screens before the pump suction well.
    - Provide chemical feed facilities for raw water transmission main if necessary for water quality control or prevention of infestation by clams, mussels etc.

36

Part 3. Source Developme

- Have intake valves and provisions for backflushing and testing for leaks, where practical.
- Have provisions for surges where necessary, Obtaining samples over a sufficient period of time to assess the biological, physical, chemical and radiological characteristics of the water.
- Have provisions for sand or gravel removal.

– Impoundments and Reservoirs.

- Ground Water – A ground water source includes all water obtained from drilled wells or springs. Drilled wells shall meet requirements for construction and development delineated in the latest AWWA A-100 Standards. Springs shall meet the requirements for protection established by the Department on a case-by-case basis. Ground water sources must be evaluated for direct influence of surface water.

37

Part 3. Source Developme

- Drilled Wells - Two important design questions are involved. One is the provision for the proper depth to which the well casing shall be installed as a watertight conduit. The other is provision for positive sealing of the annulus between the outside of the well casing to prevent seepage of water vertically along the outside of the pipe.
  – Water tight construction of the cased portion of a well shall be carried to such depth as may be required by the Department to prevent polluted or inferior quality water from entering the well.

38

Part 3. Source Developme

» Wells completed in an unconsolidated aquifer such as sand, gravel, or what is commonly referred to as overburden shall be designed with watertight casing extending from the land surface to a depth of at least 10 feet below the lowest expected pumping level. Where the pumping level is less than 25 feet from the surface, the casing shall extend no less than 20 feet below the lowest pumping level.

» Wells completed in consolidated rock formations having little or no primary permeability such as limestone, dolomite, sandstone, siltstone and shale shall be designed with watertight casing extending through all overburden material and firmly seated in the bedrock. Where applicable the casing shall extend below any crevices that would release water of inferior quality into the well.

39

Part 3. Source Developme

– Provisions shall be made in the construction of a well for grouting and sealing the annular space between the borehole and the outside of the well casing. This normally means planning an oversize borehole to the proper depth to provide an annulus into which suitable grouting material can be placed. To assure a proper seal, the grout must be placed by a positive displacement method such as pumping or pressure injection from the bottom of the annulus to the top in one continuous operation.

- Springs.
  – Use of springs as a source of supply shall be considered only when it is not feasible to develop an acceptable well or surface supply.

40

Part 3. Source Developme

– Spring supplies shall be protected from entry of surface water.
– Spring intakes shall be housed in permanent structures.
– Spring supplies must be evaluated for direct influence of surface water. If determined to be under the direct influence of surface water, treatment must be provided in accordance with Division of Water Supply Filtration and Disinfection rules.
– Spring supplies must be evaluated for dependable capacity during drought.
– Downstream impacts of water withdrawals from springs must be considered and appropriate environmental permits obtained.

- General Well Construction Requirement.

41

Part 4. Treatment

- 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. ***(Details of these topics are covered in other training segments).***
- Clarification - Plants designed for processing surface waters should:
  - Provide duplicate units for flocculation and sedimentation.
  - Be constructed to permit units to be taken out of service without disrupting operation.

42

Part 4. Treatment

- Pre-sedimentation - Waters containing high turbidity or silica particles may require pretreatment, usually sedimentation either with or without the addition of coagulation chemicals.
  - Basin Design - Pre-sedimentation basins should be designed to hold maximum 3-day usage.
  - Inlet - Incoming water shall be dispersed across the full width of the line of travel as quickly as possible; short circuiting must be prevented.
  - Bypass - Provisions for bypassing pre-sedimentation basins shall be included.
- Mixing (Flash or Quick):
  - Equipment - Basins should be equipped with mechanical mixing devices; other arrangements, such as baffling, and in-line mixers may be acceptable.

43

Part 4. Treatment

  - 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.
  - Velocity gradient - The minimum shall be 300 (ft/sec)/ft.
- Flocculation (Slow Mixing):
  - Basin Design - Inlet and outlet design shall prevent short circuiting and destruction of floc. A drain shall be provided.
  - Detention - The detention time for floc formation must be at least 30 minutes, with a detention time of 45 minutes being recommended.
  - 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.

44

Part 4. Treatment

  - 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.
  - 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.

45

Part 4. Treatment

- 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.
  - 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.
  - Depth - Should be based on an average depth of 8 ft. However, calculations using surface area, overflow rate and detention time should be used.
  - Rectangular tanks - A length to width ratio of 4:1 should be used.

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Part 4. Treatment

  - 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.
  - Plate Settlers – shall be designed, installed and loaded per the manufacturers recommendations.
  - 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.

47

Part 4. Treatment

  - Surface overflow Rate - Shall be between 0.25 - 0.38 gpm/sq. ft. for conventional sedimentation. When tube settlers are used, design of effluent weirs or pipes shall minimize carry over of floc from the tubes.
  - Velocity - The velocity through settling basins shall not exceed 0.5 feet per minute. The basins must be designed to minimize short circuiting. Baffles must be provided as necessary. Not applicable if tube settlers are used.
  - 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.

48

Part 4. Treatment

- 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.
- 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.

49

Part 4. Treatment

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

– 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.

50

Part 4. Treatment

- Installation of equipment - Supervision by a representative of the manufacturer should be provided with regard to all mechanical equipment at the time of:
  - Installation.
  - Initial operation.
- Operating equipment - The following should be provided for plant operation:
  - A complete outfit of tools and accessories.
  - Necessary laboratory equipment.
  - Adequate piping with suitable sampling taps so located as to permit the collection of samples of water from critical portions of the units.

51

Part 4. Treatment

- Chemical feed - Chemicals should be applied at such points and by such means as to insure satisfactory mixing of the chemicals with the water.
- Mixing - Mixing devices employed should be so constructed as to:
  - Provide good mixing of the raw water with previously formed sludge particles.
  - Prevent deposition of solids in the mixing zone.
- Flocculation - Flocculation equipment should:
  - Be adjustable.
  - Provide for coagulation to occur in a separate chamber or baffled zone within the unit.
  - Provide the flocculation and mixing period to be not less than 30 minutes.

52

Part 4. Treatment

- Sludge concentrators - The equipment should provide either internal or external concentrators in order to obtain a concentrated sludge with a minimum of waste water.
- Sludge removal - Sludge removal design should provide that:
  - Sludge pipes shall be not less than three inches in diameter and so arranged as to facilitate cleaning.
  - Entrance to sludge withdrawal piping shall prevent clogging.
  - Valves shall be located outside the tank for accessibility.
  - Operator may observe or sample sludge being withdrawn from the unit,
  - Backflow from sanitary sewer systems be impossible.

53

Part 4. Treatment

- Cross-connections:
  - Blow-off outlets and drains should terminate and discharge at places satisfactory to the Department.
  - Cross-connection control should be included for the potable water lines used to backflush sludge lines.
- 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/ft^2.
- Suspended slurry concentrate - Units should be designed so that continuous slurry concentrates of 1% or more, by weight, can be satisfactorily maintained.

54

Part 4. Treatment

- Water Losses.
  - Units should be provided with suitable controls for sludge withdrawal.
  - Total water losses should not exceed:
    - » 5% for clarifiers.
    - » 3% for softening units.
- Weirs or orifices - The units should be equipped with either overflow weirs or orifices. Weirs shall be:
  - Adjustable.
  - At least equivalent in length to the perimeter of the tank.

55

Part 4. Treatment

  - Constructed so that surface water does not travel over 10 feet horizontally to the collection trough.
- Weir loading - Should be same as conventional settling.

- Filtration - Acceptable filters include, at the discretion of the Department, the following types:
  - Gravity filters.
  - 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.

56

Part 4. Treatment

- Package Treatment Plants, Membranes And Other Technologies - Will be reviewed on a case-by-case basis based on demonstrated performance criteria.
  - 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.

57

Part 4. Treatment

  - 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.
  - 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.

58

Part 4. Treatment

- 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.
  - Equipment.
  - Contact Time and Point of Application.
  - Chlorinator Piping.
  - Housing.
  - Chlorine Dioxide.

59

Part 4. Treatment

  - UV Light.
  - Ozone.
  - Hydrogen Peroxide.
  - Permanganates.
  - Chloramines.
- 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.
  - Lime-Soda Process.
  - Cation Exchange Process.

60

Part 4. Treatment

- Aeration - Aeration treatment devices as described herein may be used for oxidation, separation of gases or for taste and odor control.
  - Natural Draft Aeration.
  - Forced or Induced Draft Aeration.
  - Other Methods of Aeration.
  - Wind Protection.
  - Protection from Contamination.
  - Bypass.
  - Corrosion Control.

61

Part 4. Treatment

- 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 35 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.

62

Part 4. Treatment

- 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.
- Corrosion Control - corrosion is caused by a reaction between the pipe material and the water in direct contact with each other.
- Taste and Odor Control – Chlorination, chlorine dioxide, powdered activated carbon (PAC), granular activated carbon adsorption units, copper sulfate and other copper compounds and aeration are methods for taste and odor control.

63

Part 4. Treatment

- 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.

64

Part 5. Chemical Applicati

- General - Plans and specifications describing water treatment plants (new, modified or expanded) shall include the chemicals and chemical feed equipment to be used in the treatment process.
  - These plans and specifications shall include:
    - Descriptions of feed equipment, including maximum and minimum feed ranges.
    - Location of feeders, piping layout and points of application.
    - Storage and handling facilities.
    - Specifications for chemicals to be used.
    - Operating and control procedures.
    - Descriptions of testing equipment and procedures.

65

Part 5. Chemical Applicati

  - Chemical shall be applied to the water at such points and by such means as to:
    - Provide maximum flexibility of operation through various points of application, when appropriate.
    - Prevent backflow at all points of feed.
- Feed Equipment.
  - Number of Feeders
    - Where chemical feed is essential to the production of safe drinking water or necessary for continuous operation.
      - A minimum of two feeders shall be provided.
      - A standby unit or combination of units of sufficient capacity should be available to replace the largest unit during shut-downs.
    - Spare parts shall be available for all feeders to replace parts which are subject to wear and damage.

66

Part 5. Chemical Applicati

- Design and Capacity - Design and capacity shall be such that:
  - Feeders will be able to supply, at all times, the necessary amounts of chemical at an accurate rate, throughout the range of feed.
  - Feeders are adjustable to handle all plant flow rates.
  - Positive displacement type solution feed pumps shall be used to feed liquid chemicals, and shall not be used to feed chemical slurries.
  - Chemical solutions cannot be siphoned into the water supply.
  - Service water supply cannot be contaminated by chemical solutions by:
    - Equipping the supply line with backflow prevention devices (see Section 5.I.8.c).
    - Providing an air gap between supply line and solution tank.

67

Part 5. Chemical Applicati

- Chemical-contact materials and surfaces are resistant to the aggressiveness of the chemical solution.
- Dry chemical feeders will:
  - Measure chemicals volumetrically or gravimetrically.
  - Provide effective solution of the chemical in the solution pot.
  - Provide gravity feed from solution pots, in open troughs when feasible.
  - Completely enclose chemicals to prevent emission of dust to any of the operating areas (see Section 5.2.3d).
- No direct connection exists between any sewer and a drain or overflow from the feeder or solution chamber or tank.

68

Part 5. Chemical Applicati

- Location - chemical feed equipment.
  - Shall be conveniently located near points of application to minimize length of feed lines.
  - Shall be readily accessible for:
    - Servicing, repair and calibration, and
    - Observation of operation;
  - Shall be located and protective curbing provided, so that chemicals from equipment failure, spillage or accidental drainage shall not enter the water through conduits, treatment or storage basins, or result in hazardous discharge.

69

Part 5. Chemical Applicati

- Control.
  - Feeders may be manually or automatically controlled, with automatic control reverting to manual control as necessary.
  - Process must be manually started following shutdown, unless otherwise approved by the Department.
  - Feed rates proportional to flow must be provided.
  - Automatic chemical dose or residual analyzers may be approved for use and must provide:
    - Alarms for critical values.
    - Recording charts.
- Solution Tanks.
  - Means shall be provided in a solution tank to maintain uniform strength of solution, consistent with the nature of the chemical solution; continuous agitation is necessary to maintain slurries in suspension.

70

Part 5. Chemical Applicati

- Two solution tanks may be required for a chemical, of specific capacity, to assure continuity of supply in servicing a solution tank.
- Each tank shall be provided with a drain:
  - No direct connection between any tank or drain and a sewer shall be permitted.
  - Any drain must terminate at least two pipe diameters above the overflow rim of a receiving sump, conduit or waste receptacle.
- Means shall be provided to indicate the solution level in the tank.
- Make-up water shall enter the tank from above the maximum solution level, providing an air gap of two pipe diameters but not less than six inches, or shall be protected with an approved backflow prevention devices (see Section 5.1.8.c)

71

Part 5. Chemical Applicati

- Chemical solutions shall be kept covered. Large tanks with access openings shall have such openings curbed and fitted with tight covers.
- Subsurface locations for solution tanks shall:
  - Be free from sources of possible contamination.
  - Assure positive drainage for ground waters, accumulated water, chemical spills and overflows.
- Overflow pipes, when provided, should:
  - Be turned downward, with end screened.
  - Have free discharge.
  - Be located where noticeable.

72

Part 5. Chemical Applicati

- Weighing Scales.
  - Shall be provided for weighing cylinders, at all plants utilizing chlorine gas; for large plants, indicating and recording type are desirable.
  - Shall be provided to measure the amount of fluoride fed with the exception of the use of a saturator, which shall have a water meter.
  - Should be provided for volumetric dry chemical feeders.
  - Should be accurate to measure increments of 0.5% of load.

73

Part 5. Chemical Applicati

- Feed Lines
  - Should be as short as possible in length of run, and
    - Of durable, corrosion-resistant material.
    - Easily accessible throughout entire length.
    - Protected against freezing.
    - Easily cleaned.
    - Lime feed lines should be designed so they can be readily replaced.
    - Avoiding sharp bends when possible.
  - Should slope upward from chemical source to feeder, when conveying gases.
  - Should introduce corrosive chemicals in such manner as to minimize potential for corrosion.

74

Part 5. Chemical Applicati

  - Shall be designed consistent with scale-forming or solids depositing properties of the water, chemical, solution or mixture conveyed.
  - Shall not carry chlorine gas beyond chlorine storage and feeder room(s) except under vacuum.
  - Should be color coded.
- Service Water Supply
  - Water used for dissolving dry chemicals, diluting liquid chemicals or operating chemical feeders shall be:
    - Only from a safe, approved source.
    - Protected from contamination by appropriate means (see Section 5.1.8c).
    - Ample in supply and adequate in pressure.

75

Part 5. Chemical Applicati

    - Provided with means for measurement when preparing specific solution concentrations by dilution.
    - Properly treated for hardness, when necessary.
  - Where a booster pump is required, duplicate equipment should be provided and, when necessary, standby power.
  - Back-flow prevention shall be achieved by appropriate means such as:
    - An air gap between fill pipe and maximum flow line of solution or dissolving tank equivalent to 2 pipe diameters but not less than 6 inches.
    - An approved reduced pressure backflow preventer, consistent with the degree of hazard, aggressiveness of chemical solution, back pressure sustained, and available means for maintaining and testing the device.
    - A satisfactory vacuum relief device.

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Part 5. Chemical Applicati

- <u>Chemicals.</u>
  - Quality.
    - Chemical containers shall be fully labeled to include:
      - Chemical name, purity and concentration.
      - Supplier name and address.
      - Expiration date where applicable.
    - Chemicals shall be listed under ANSI/NSF Standard 60 (or equivalent) and meet American Water Works Association specifications, where applicable.
    - Provisions should be made for assay of chemicals delivered.
    - Chemicals shall not impart any toxic material to the water under recommended dosages.

77

Part 5. Chemical Applicati

- Storage.
  - Space should be provided for:
    - At least 30 days of chemical supply.
    - Convenient and efficient handling.
    - Dry storage conditions.
    - A minimum of 1-1/2 truck loads storage volume where purchase is by truck load lots.
    - Protection against excessive, damaging or dangerous extremes in temperature.
  - Cylinders of chlorine shall be:
    - Isolated from operating areas.
    - Restrained in position to prevent upset.

78

Part 5. Chemical Applicati

- Stored inside for sufficient time before being connected to chlorinator that temperature has been approximately equalized.
- Provided shade from direct sun and given physical security if stored outside of building.

- Liquid chemical storage tanks must:
  - Have a liquid level indicator.
  - Have an overflow and a receiving basin or drain capable of receiving accidental spills or overflows.
  - Provide for protection against freezing and/or loss from solution due to temperature drop.

79

Part 5. Chemical Applicati

- Special precautions must be taken with:
  - Sodium chlorite, to eliminate any danger of explosion.
  - Activated carbon, which is a potentially combustible material, requiring isolated, fireproof storage and explosion-proof electrical outlets, lights and motors in areas of dry handling.
  - Calcium hypochlorite and potassium permanganate, which may ignite spontaneously on contact with combustible substances.
  - Hydrofluosilicic acid, which is extremely corrosive. Fumes or spillage may damage equipment or structures.
  - Liquid caustic (50% sodium hydroxide solution) which is hazardous and may be lost from solution at low temperature.

80

Part 5. Chemical Applicati

- Gaseous chlorine (see Sections 5.3.4-5.4).
- On-site generation of sodium hypochlorite. Provisions must be included for dilution and venting of potentially explosive hydrogen gas.

- Chemicals shall be stored in covered or unopened shipping containers, unless the chemical is transferred into an approved covered storage unit.
- Solution storage or day tanks supplying feeders directly should have sufficient capacity for one day of operation.
- Acid storage tanks must be vented to the outside atmosphere, but not through vents in common with day tanks.

81

Part 5. Chemical Applicati

- Handling.
  - Provisions shall be made for:
    - Measuring quantities of chemicals used to prepare feed solutions.
    - For easy calibration of solution pumps measured from the suction side.
  - Storage tanks and pipelines for liquid chemicals shall be specific to the chemicals and not for alternates.
  - Chemicals that are incompatible shall not be fed, stored or handled together.

82

Part 5. Chemical Applicati

- Provisions must be made for the proper transfer of dry chemicals from shipping containers to storage bins or hoppers, in such a way as to minimize the quantity of dust which may enter the room in which the equipment is installed; control should be provided by use of:
  - Vacuum pneumatic equipment or closed conveyer systems.
  - Facilities for emptying shipping containers in special enclosures.
  - Exhaust fans and dust filters which put the hoppers or bins under negative pressure.
- Precautions shall be taken with electrical equipment to prevent explosions, particularly in the use of sodium chlorite and activated carbon.

83

Part 5. Chemical Applicati

- Acids shall:
  - Be kept in closed, acid-resistant shipping containers or storage units.
  - Not be handled in open vessels, but should be pumped in undiluted form from original containers, through suitable hose, to the point of treatment or to a covered day tank.
- Carts, elevators and other appropriate means shall be provided for lifting chemical containers to minimize excessive lifting by operators.
- Provisions shall be made for disposing of empty bags, drums or barrels, by approved procedures which will minimize exposure to dusts.

84

Part 5. Chemical Applicati

- Housing.
  - Structures, rooms and areas accommodating chemical feed equipment shall provide convenient access for:
    - Servicing and repair.
    - Observation of operation.
  - Floor surfaces shall be smooth and impervious, slip-proof and well-drained with 2.5% slope, minimum.
  - Open basins, tanks and conduits shall be protected from chemical spills or accidental drainage.
  - Chlorine gas feed and storage shall be:
    - Enclosed and separated from other operating areas in order to prevent injury to personnel and damage to equipment; separate chlorine feed and storage rooms may be required for large installations.

85

Part 5. Chemical Applicati

- Provided with an inspection window to permit viewing of the interior of the room and the equipment.
- Provided with doors opening outward with a crash bar, assuring ready means of exit; doors opening to the building exterior only shall be provided.
- Provided with locks to prevent general public access.

- Where chlorine gas is used, ventilation for each room shall be provided for one complete air change per minute:
  - The air outlet from the room shall be near the floor and the point of discharge shall be so located as not to contaminate air inlets to any rooms or structures, or adversely affect the surrounding environment.
  - Air inlets shall be through louvers near the ceiling, and temperature controlled to prevent adverse affect on chlorinator.

86

Part 5. Chemical Applicati

- Switches for fans and lights shall be outside of the room, at the entrance; signal light indicating fan operation shall be provided at each entrance when fan can be controlled from more than one point;
- Vents from feeders and storage shall discharge to the outside atmosphere, above grade.

- Chlorinator rooms should be heated to 60 degrees F, but should be protected from excess heat; cylinders and gas lines should be protected from temperatures above that of the feed equipment.
- Gaseous feed chlorine installations shall be equipped with a gas detection device connected to an audible alarm to prevent undetected, potentially dangerous leakage of chlorine gas.

87

Part 5. Chemical Applicati

- Operator Safety.
  - Gases from feeders, storage and equipment exhausts shall be conveyed to the outside atmosphere, above grade and remote from air intakes.
  - Special provisions shall be made for ventilation of chlorine feed and storage rooms (see Section 5.3.5).
  - A M-S-A air mask, Model 401, Catalog No. 01-95066 or equal, complete with storage cabinet and 30 minute air cylinder shall be provided along with a 30 minute backup cylinder to prevent loss of utility while the primary air cylinder is being refilled or tested. The air mask shall be cabinet-mounted close by but not inside the chlorine room, and shall be easily accessible to the operator.

88

Part 5. Chemical Applicati

- A bottle of ammonium hydroxide shall be available for chlorine leak detection during cylinder change.
- All gaseous feed chlorine installations shall be equipped with appropriate leak repair kits.
- At least one pair of rubber gloves with long gauntlets, a dust respirator of a type approved by the U.S. Bureau of Mines for toxic dusts, and an apron or other protective clothing shall be provided for each operator in any shift who will handle dry chemicals.
- Rubber gloves with long gauntlets, rubber roots, goggles, rubber apron or other suitable protective clothing shall be provided for each operator preparing chemical solutions, or cleaning up spills.

89

Part 5. Chemical Applicati

- Facilities shall be provided for washing of face, gloves and protective equipment.
- A safety shower shall be provided in areas where hazardous chemicals are handled.
- On-site generation of sodium hypochlorite must include dilution and venting of hydrogen gas.

90

Part 6. Laboratory Facilities

- General – Laboratory equipment and facilities shall be compatible with the raw water source, intended design of the treatment plant, and the complexity of the treatment process involved. Recognized laboratory procedures must be utilized. See Parts 4 and 5 for related criteria.
- Equipment – A list of testing equipment will be furnished by the Department.
- Laboratory Space and Facilities.
  - Laboratory facilities shall be located in a separate room from office/lunch activities and from the treatment units. Facilities shall be isolated by doors and not be located in the main traffic pattern.
  - Sufficient bench space, adequate ventilation, adequate lighting, storage room, laboratory sink, and auxiliary facilities shall be provided.

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Part 6. Laboratory Facilities

  - The bacteriological laboratory, if provided, shall have about 6-10 feet of counter space and shall be located in a separate room or area.
- Sample Taps – Sample taps shall be provided so that water samples can be obtained from each water source and from appropriate locations in each unit operation of treatment. Taps shall be consistent with sampling needs and not be of petcock type. Sample lines and pumps where applicable shall be sized to minimize time lag between point of sampling and point of sample collection.

92

Part 7. Pumping Facilities

- General – Pumping facilities shall be designed to maintain the sanitary quality of pumped water. Subsurface pits or pump rooms and inaccessible installations should be avoided. No pumping station shall be subject to flooding.
- Location – The pumping station shall be so located that the proposed site will meet the requirements of the sanitary protection of the water quality, hydraulics of the system and be protected against interruption of service by fire, flood or any other hazard.
- Ground Water Facilities – Where pumping facilities are used, wells and springs shall be vented by properly hooded and screened pipe extending at least 12 inches above the pump floor. Where necessary, provision shall be made for lubricating the pump from a point at least 6 inches above the top of the well cover, by means which will prevent contamination of the water supply.

93

Part 7. Pumping Facilities

- Surface Water Facilities – Pump stations normally associated with surface water sources, either as raw or finished water pump stations, shall:
  - Have adequate space for the installation of additional units if needed, and for the safe servicing of all equipment.
  - Be of durable character, fire and weather resistant and with outward opening doors.
  - Have floor elevation of at least 6 inches above finished grade.
  - Have underground structure waterproofed.
  - Have all floors drained without impairing the quality of water being handled and if equipment is contained on the floor, the floor shall have sufficient slope to drain adequately.
  - Provide suitable outlet for drainage from pump glands without discharging onto the floor.

94

Part 7. Pumping Facilities

- Booster Pumps – Booster pumps shall be located or controlled so that:
  - They will not produce negative pressure anywhere in the distribution system.
  - The pressure in the suction line shall be maintained at or above 20 psi by the use of a pressure sustaining valve or low pressure cutoff device.
  - Automatic or remote control devices shall have a range between the start and cutoff pressure which will prevent excessive cycling.
  - In-line Booster Pumps - In addition to the other requirements of this section, in-line booster pumps shall be accessible for servicing and repairs.
  - The criteria in this section also apply to fire pumps.

95

Part 7. Pumping Facilities

  - Booster pumps shall not serve more than 50 service connections unless gravity storage is provided or service pressure can be maintained above 20 psi without the pumps running.
- Automatic and Remote Controlled Stations – All automatic stations should be provided with automatic signaling apparatus which will report when the station is out of service. All remote controlled stations shall be electrically operated and controlled and shall have signaling apparatus of proven performance. Installation of electrical equipment shall conform with the National Electrical Code.

96

Part 7. Pumping Facilities

- Appurtenances.
  - Valves - Pumps shall be adequately valved to permit satisfactory operation, maintenance and repair of the equipment. If foot valves are necessary they shall have a net valve area of at least 2½ times the area of the suction pipe and they shall be screened. Each pump shall have a positive acting check valve on the discharge side between the pump and shutoff valve.
  - Piping - In general, piping shall:
    - Be designed so that the friction head will be minimized;
    - Not be subject to contamination;
    - Have watertight joints;
    - Be protected against surge or water hammer;
    - Be such that each pump has an individual suction line or the lines shall be so manifolded that they will insure similar hydraulic and operation conditions.

97

Part 7. Pumping Facilities

- Gauges and Meters - Each pump shall:
  - Shall have a standard pressure gauge on its discharge line.
  - Shall have a compound gauge on its suction line.
  - Shall have recording gauges in larger stations.
  - Should have a means for measuring the discharge.

  The larger stations should have indicating, totalizing and recording metering of the total water pumped.
- Water Seals - Water seals shall not be supplied with water of a lesser sanitary quality than that of the water being pumped.

98

Part 7. Pumping Facilities

- Controls - Pumps, their prime movers and accessories, shall be controlled in such a manner that they will operate at rated capacity without dangerous overload. Where two or more pumps are installed, provision shall be made for proper alternation. Provision shall be made to prevent operation of the pump during the backspin cycle. Electrical controls should be located above grade.
- Power - When power failure would result in cessation of minimum essential service, power supply shall be provided from at least two independent sources or standby or auxiliary source shall be provided.
- Auxiliary Power Supply - When automatic pre-lubrication of pump bearings is necessary, and an auxiliary power supply is provided, the pre-lubrication line shall be provided with a valved by-pass around the automatic control.

99

Resources

- *Sanitary Survey Manual,* Community and Non-Community Public Water Supplies. Tennessee Department of Environment and Conservation. June 2013.
- *Chapter 0400-45-01 Public Water Systems*, Rules of Tennessee Department of Environment and Conservation. October 2012.
- *Chapter 0400-49-01*, Rules Governing Water and Wastewater Operator Certification. August 2014.
- *Community Public Water Systems Design Criteria,* Division of Water Supply, Tennessee Department of Environment and Conservation. 2008.
- *Water Treatment*, Principles and Practices of Water Supply Operations. 4th ed. 2010. American Water Works Association.
- *Water Treatment Plant Operation*, A Field Study Guide, Vol II, 5th ed. 2006. California State University.

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Questions

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Section 11

Lab

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.

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Chlorine, Free

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:

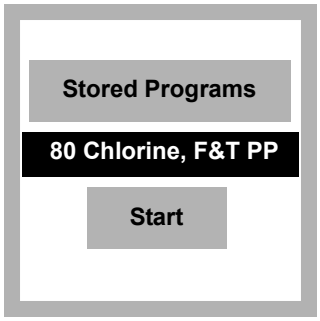
If the test over-ranges, dilute the sample with a known volume of high quality, chlorine demand-free water and repeat the test. Some loss of chlorine may occur due to the dilution. Multiply the result by the dilution factor. Alternatively, samples with high chlorine concentrations may be analyzed directly 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.

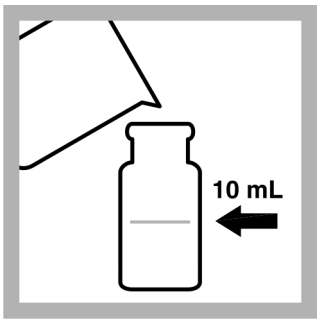
Powder pillow procedure



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.

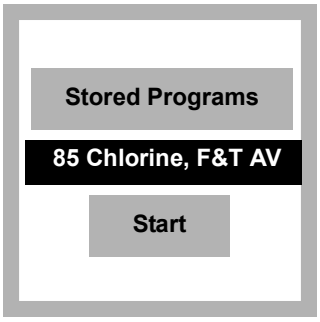
5. Swirl the sample cell for 20 seconds to mix.

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.

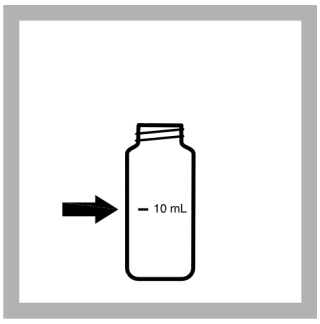
Results are in mg/L Cl_2.

AccuVac Ampuls procedure



1. Select the test.

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



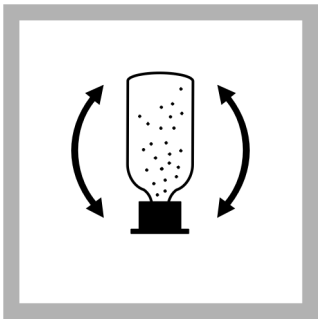
2. Blank Preparation: Fill a sample cell with 10-mL of sample.

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

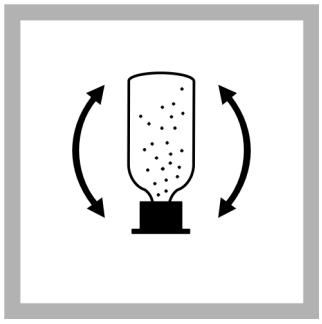
ZERO the instrument. The display will show: 0.00 mg/L Cl_2

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

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Fluoride

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:

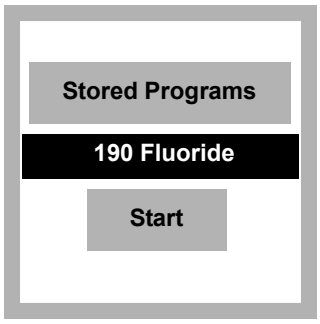
The sample and deionized water should be at the same temperature (± 1 °C). Temperature adjustments may be made before or after reagent addition.
SPADNS 2 Reagent is corrosive. Use care while handling the reagent.
For best results, measure the volume of SPADNS 2 Reagent as accurately as possible.
If the 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.

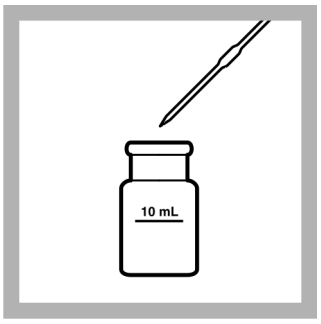
SPADNS 2 reagent solution



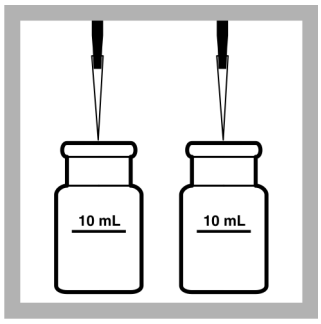
1. Select the test.

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.



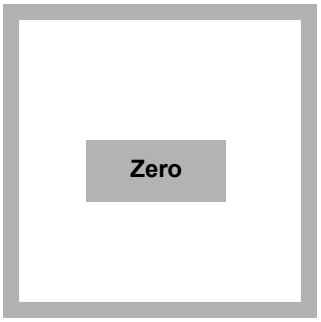
4. Carefully pipet 2.0 mL of SPADNS 2 Reagent into each cell. Swirl to mix.

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.

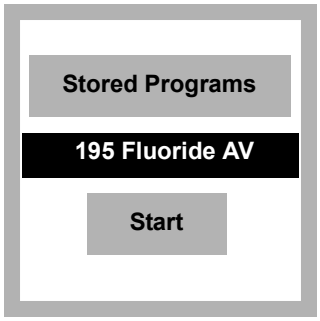
The display will show:

0.00 mg/L F^-

8. Insert the prepared sample cell.

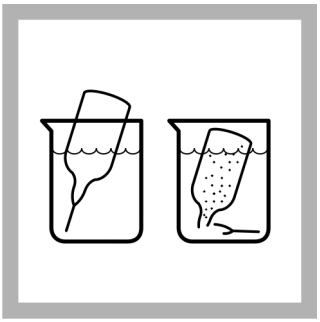
READ the results in mg/L F^-.

SPADNS 2 AccuVac® Ampuls



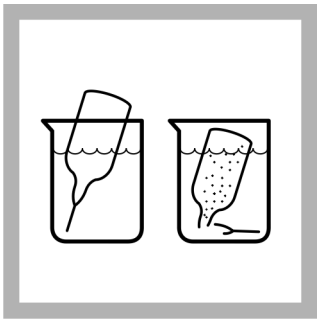
1. Select the test.

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

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Manganese

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:

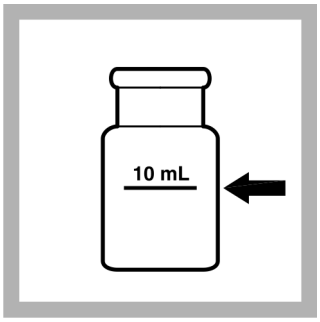
Description	Quantity
Alkaline Cyanide Reagent	12 drops
Ascorbic Acid Powder Pillows	2
PAN Indicator Solution, 0.1%	12 drops
Deionized Water	10 mL
Sample Cells (see *Instrument-specific information*)	2
Stoppers for 18 mm tube	2

See *Consumables and replacement items* for reorder information.

PAN method for powder pillows

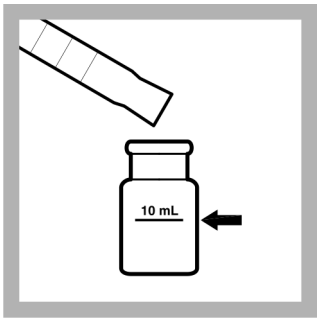
1. Select the test.

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

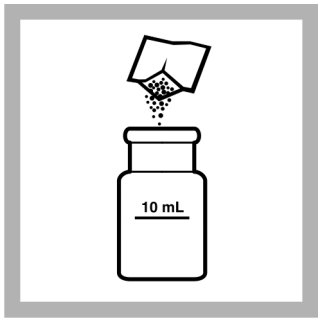


2. Blank Preparation: Pour 10.0 mL of deionized water into a sample cell.

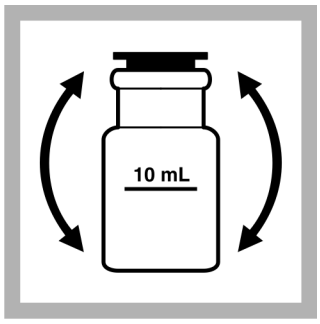
Total manganese determination requires prior digestion.



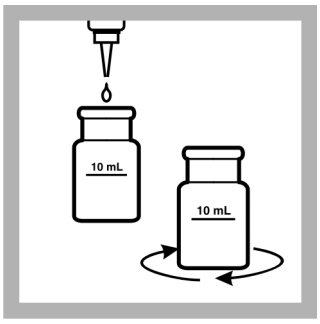
3. Prepared Sample: Pour 10.0 mL of sample into another sample cell.



4. Add the contents of one Ascorbic Acid Powder Pillow to each cell.

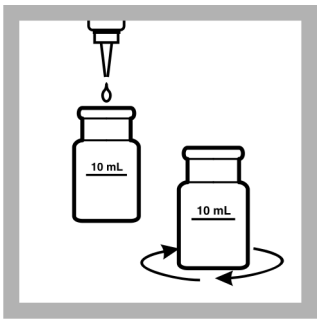


5. Stopper and invert to dissolve the powder.



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.



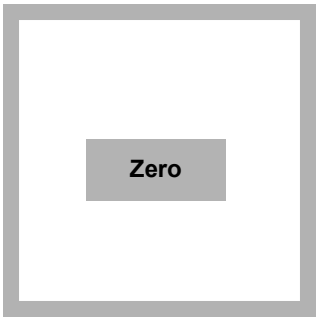
7. Add 12 drops of PAN Indicator Solution, 0.1%, to each sample cell. Swirl gently to mix.

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.

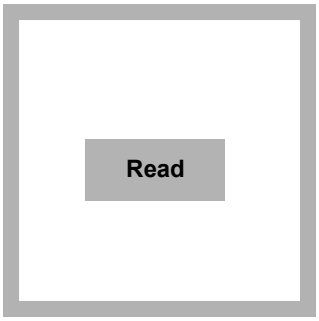


10. ZERO the instrument.

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

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Iron, Total

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:

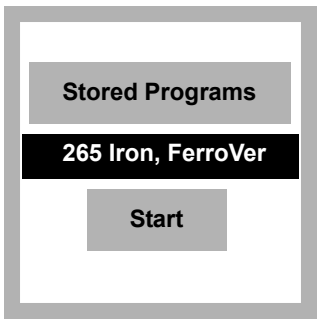
Description	Quantity
Powder Pillow Test:	
FerroVer® Iron Reagent Powder Pillow	1
Sample Cells (see *Instrument-specific information*)	2

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.

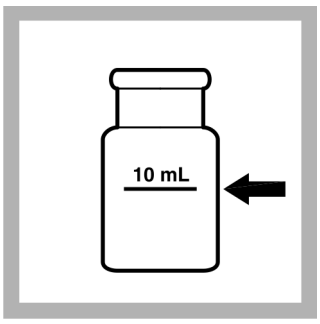
FerroVer method for powder pillows



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

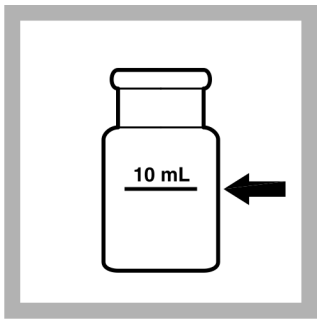
3. Add the contents of one FerroVer Iron Reagent Powder Pillow to the sample cell. Swirl to mix.

Accuracy is not affected by undissolved powder.

4. Start the instrument timer.

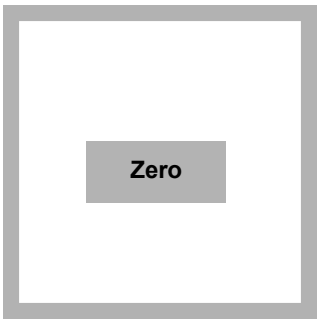
A three-minute reaction period will begin. An orange color will form, if iron is present.

(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.

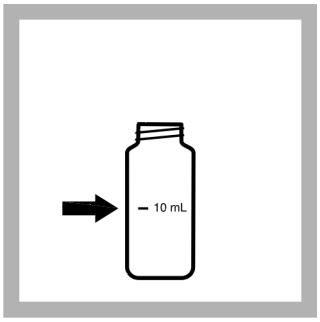
READ the results in mg/L Fe.

FerroVer method for AccuVac® Ampuls

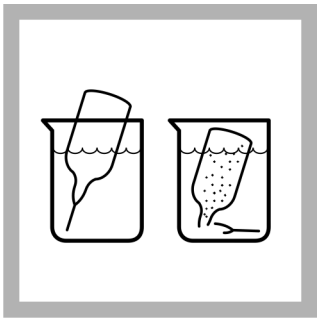
1. Select the test.

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.

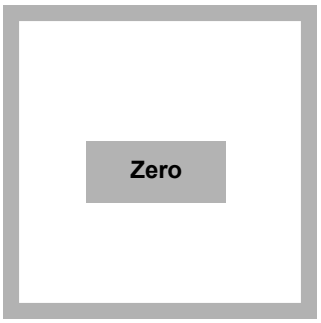
4. Quickly invert the Ampul several times to mix.

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

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Alkalinity

DOC316.53.01151

USEPA[1] Buret Titration Method[2]

Method 8221

(0 to 5,000 mg/L as $CaCO_3$)

Buret Titration

Scope and Application: For water, wastewater and seawater

[1] USEPA Accepted

[2] Adapted from *Standard Methods for the Examination of Water and Wastewater, 2320 B*

Test preparation

Before starting the test:

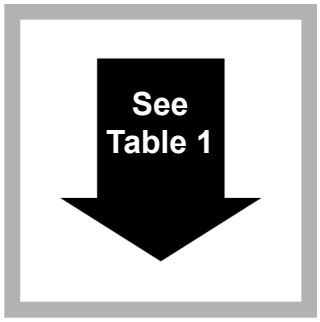
Read the entire procedure before starting the test.
A pH meter is required for NPDES reporting and is recommended for best results.
Substitute six drops of Phenolphthalein Indicator Solution for the Phenolphthalein Indicator Powder Pillow if necessary
Substitute six drops of Bromcresol Green-Methyl Red Indicator Solution for the Bromcresol Green-Methyl Red Powder Pillow if necessary.
Results in mg/L as $CaCO_3$ Ó 17.12 = grains per gallon

Collect the following items:

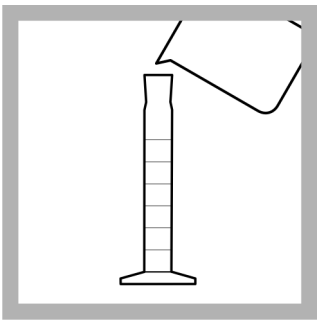
Description	Quantity
Bromcresol Green-Methyl Red indicator powder pillow	1
Phenolphthalein indicator powder pillow	1
Sulfuric acid standard solution, 0.020 N	varies[1]
Buret clamp, double	1
Buret, Class A, 25-mL	1
Graduated cylinder	varies[1]
Erlenmeyer flask, 250-mL	1
Funnel, Micro	1
Support Stand	1

[1] See *Consumables and replacement items* on page 6.

Buret titration (Method 8221)

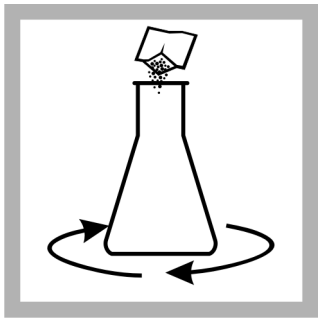


1. Select a sample volume from the *Sample volume selection for expected concentration* table that corresponds to the expected alkalinity concentration in mg/L as calcium carbonate ($CaCO_3$).

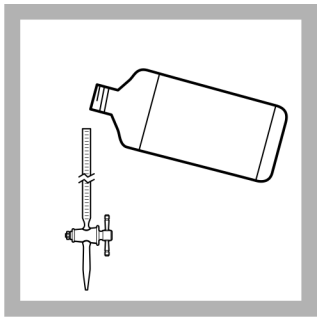


2. Use a graduated cylinder or pipet to measure the sample volume.

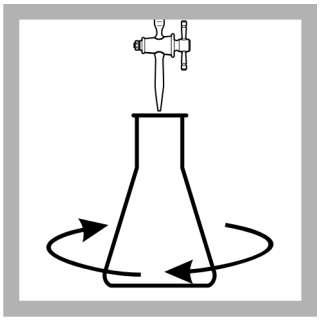
3. Transfer the sample into a 250-mL Erlenmeyer flask. Dilute to about 50-mL with deionized water if necessary.



4. Add the contents of one Phenolphthalein Indicator Powder Pillow. Swirl to mix. (Omit this step when using a pH meter.)

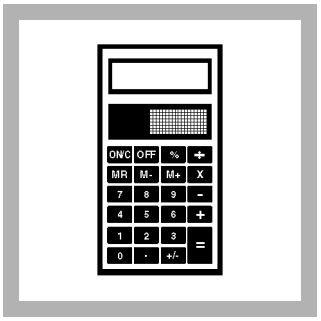


5. Fill a 25-mL buret to the zero mark with 0.020 N Sulfuric Acid standard solution.



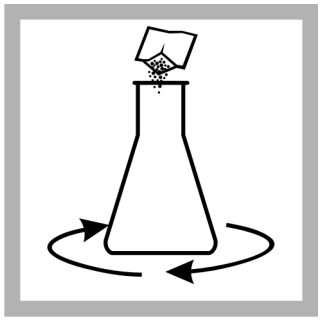
6. While swirling the flask, titrate the sample until the solution color changes from pink to colorless (pH 8.3).

If the solution is colorless before titrating with sulfuric acid, the phenolphthalein alkalinity is zero.



7. Calculate:

mL Titrant ì multiplier used = mg/L phenolphthalein alkalinity as $CaCO_3$.

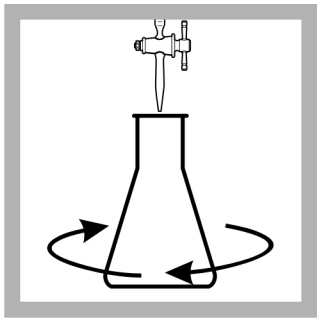


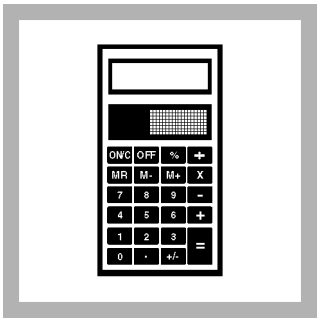
8. Add the contents of one Bromcresol Green-Methyl Red Indicator Powder Pillow to the titrated sample. Swirl to mix.

Do not add indicator if a pH meter is used.

Specific sample composition may require titration to a specific pH (see the *Alkalinity relationship* table).

Buret titration (Method 8221)





9. Continue the titration until a light pink end point is reached.

10. Calculate:

mL Titrant Ì multiplier used = mg/L total alkalinity as $CaCO_3$.

Table 1 Sample volume selection for expected concentration

Range (mg/L as $CaCO_3$)	Sample Volume (mL)	Sulfuric Acid	Multiplier
0–500	50	20353	20
400–1000	25	20353	40
1000–2500	10	20353	100
2000–5000	5	20353	200

The end points in the *Alkalinity endpoints* table are recommended for determining total alkalinity in water samples of various compositions and alkalinity concentrations.

Table 2 Alkalinity endpoints

Sample composition	End point pH	
	Total Alkalinity	Phenolphthalein Alkalinity
Alkalinity about 30 mg/L	pH 4.9	pH 8.3
Alkalinity about 150 mg/L	pH 4.6	pH 8.3
Alkalinity about 500 mg/L	pH 4.3	pH 8.3
Silicates or phosphates present	pH 4.5	pH 8.3
Industrial wastes or complex system	pH 4.5	pH 8.3
Routine or Automated Analyses	pH 4.5	pH 8.3

Total alkalinity primarily includes hydroxide, carbonate, and bicarbonate alkalinities. The concentration of these types in a sample may be determined when the phenolphthalein and total alkalinities are known (*Alkalinity relationship* table).

Table 3 Alkalinity relationship

Row	Result of Titration	Hydroxide Alkalinity Equals:	Carbonate Alkalinity Equals:	Bicarbonate Alkalinity Equals:
1	Phenolphthalein Alkalinity equal to 0	0	0	Total Alkalinity
2	Phenolphthalein Alkalinity equal to Total Alkalinity	Total Alkalinity	0	0
3	Phenolphthalein Alkalinity less than one-half of Total Alkalinity	0	Phenolphthalein Alkalinity times 2	Total Alkalinity minus two times Phenolphthalein Alkalinity
4	Phenolphthalein Alkalinity equal to one-half of Total Alkalinity	0	Total Alkalinity	0
5	Phenolphthalein Alkalinity greater than one-half of Total Alkalinity	2 times Phenolphthalein Alkalinity minus Total Alkalinity	2 times the difference between Total and Phenolphthalein Alkalinity	0

Use the *Alkalinity relationship* table with the following procedure:

1. Does the phenolphthalein alkalinity equal zero? If yes, use Row 1.
2. Does the phenolphthalein alkalinity equal total alkalinity? If yes, use Row 2.
3. Divide the total alkalinity by 2 to calculate one-half the total alkalinity.
4. Select Row 3, 4 or 5 based on comparing the result of step c (one-half total alkalinity) with the phenolphthalein alkalinity.
5. Perform the required calculations if any.
6. Check your results. The sum of the three alkalinity types will equal the total alkalinity.

Example:
A sample has 170 mg/L as $CaCO_3$ phenolphthalein alkalinity and 250 mg/L as CaCO3 total alkalinity. What is the concentration of hydroxide, carbonate, and bicarbonate alkalinities?

a. The phenolphthalein alkalinity does not equal zero but 170 mg/L.
b. The phenolphthalein alkalinity does not equal total alkalinity (170 mg/L vs. 250 mg/L).
c. One-half of the total alkalinity equals 125 mg/L.
d. Because the phenolphthalein alkalinity of 170 mg/L is greater than one-half the total alkalinity of 125 mg/L, select Row 5.

The hydroxide alkalinity is equal to:

$$2 \times 170 = 340$$

$$340 - 250 = 90 \text{ mg/L hydroxide alkalinity}$$

The carbonate alkalinity is equal to:

$$250 - 170 = 80$$

$$80 \div 2 = 160 \text{ mg/L carbonate alkalinity}$$

The bicarbonate alkalinity is equal to zero mg/L.

Check:

90 mg/L hydroxide alkalinity + 160 mg/L carbonate alkalinity + 0 mg/L bicarbonate alkalinity = 250 mg/L

The answer is correct.

The sum of each type equals the total alkalinity (250 mg/L).

Interferences

Chlorine at levels above 3.5 mg/L cause a yellow-brown color upon the addition of the Bromcresol Green-Methyl Red Indicator Powder Pillow. Residual chlorine interference with the indicator may be removed by adding a drop of 0.1 N Sodium Thiosulfate Standard Solution* before adding the indicator.

Highly colored or turbid samples may mask the color change at the end point. Use a pH meter for these samples, titrating to pH 8.3 for phenolphthalein alkalinity and the appropriate pH (see the *Alkalinity endpoints* table) for total alkalinity.

Sampling and storage

Collect samples in plastic or glass bottles. Fill completely and cap tightly. Avoid excessive agitation and prolonged exposure to air. Samples should be analyzed as soon as possible after collection but can be stored at least 24 hours by cooling to 4 °C (39 °F) or below. Warm to room temperature before analyzing.

Accuracy check

End point confirmation

- To accurately determine the phenolphthalein alkalinity end point, mix the contents of one Phenolphthalein Indicator Powder Pillow and the contents of one pH 8.3 Buffer Powder Pillow with 50 mL of deionized water in a 250-mL Erlenmeyer flask. The resulting color is the end point.
- To accurately determine the total alkalinity end point, mix the contents of one pH 4.5 Buffer Powder Pillow and the contents of one Bromcresol Green-Methyl Red Indicator Powder Pillow with 50 mL of deionized water in a 250-mL Erlenmeyer flask. Titrate to a light pink color change.

Standard additions method (Sample Spike)

Perform the standard additions method check as follows:

1. Break the top off an Alkalinity Voluette® Ampule Standard Solution, 0.500 N.
2. Use the TenSette Pipet* to add 0.1 mL of standard to the sample titrated in step 6 or step 9. Resume titration back to the same end point. Record the volume of titrant needed.
3. Repeat, using two more additions of 0.1 mL. Titrate to the end point after each addition.
4. The mL of titrant required should increase by 2.5 mL for each 0.1 mL increment of standard added.

Summary of method

Alkalinity is expressed as P (phenolphthalein) alkalinity or as T (total) alkalinity. Both types are determined by titration with a Sulfuric Acid Standard Solution to an end point evidenced by the color change of an indicator solution or determined with a pH meter. The P alkalinity is determined by titration to a pH of 8.3 and registers the total hydroxide and one half the carbonate present. The T alkalinity is determined by titration to a pH of 4.5. The total alkalinity includes all carbonate, bicarbonate and hydroxide alkalinity. Alternatively, total alkalinity end points may be determined by using a pH meter and titrating to the specific pH required for the sample composition.

* See *Consumables and replacement items* on page 6.

Consumables and replacement items

Required reagents

Description	Quantity/test	Unit	Catalog number
Bromcresol Green-Methyl Red Indicator Powder Pillows	1 pillow	100/pkg	94399
Phenolphthalein Indicator Powder Pillows	1 pillow	100/pkg	94299
Sulfuric Acid Standard Solution, 0.020 N	varies	1 L	20353

Required apparatus

Description	Quantity/test	Unit	Catalog number
Buret Clamp, double	1	each	32800
Buret, Class A, 25-mL	1	each	2636540
Select one or more based on sample volume:			
Cylinder, graduated, 5-mL	—	each	50837
Cylinder, graduated, 10-mL	—	each	50838
Cylinder, graduated, 25-mL	—	each	50840
Cylinder, graduated, 50-mL	—	each	50841
Flask, Erlenmeyer, 250-mL	1	each	50546
Pipet, volumetric, Class A, 5-mL,	—	each	1451537
Pipet, volumetric, Class A, 10-mL	—	each	1451537
Pipet Filler, Safety Bulb	—	each	1465100
Ampule Breaker	—	each	2196800
Funnel, Micro	1	each	2584335
Support Stand	1	each	56300

Required standards

Description	Unit	Catalog number
Alkalinity Standard Solution, Voluette® Ampules, 0.500 N, 10-mL	16/pkg	1427810
Buffer Powder Pillows, pH 4.5	25/pkg	89568
Buffer Powder Pillows, pH 8.3	25/pkg	89868
Water, deionized	4 L	27256

Optional items

Description	Unit	Catalog number
Sodium Thiosulfate Standard Solution, 0.1 N	—	32332
TenSette Pipet, 0.1–1.0 mL	—	1970001
Tips for Tensette Pipet	50/pkg	2185696

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Hardness, Calcium

USEPA[1] Buret Titration Method[2]

Method 8222

0 to 25,000 mg/L as $CaCO_3$

Buret Titration

Scope and Application: For water, wastewater and seawater.

[1] USEPA accepted when 0.020 N titrant is used.

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

Test preparation

Before starting the test:

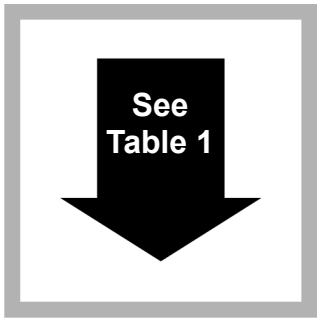
A 0.1-g scoop of CalVer® 2 Calcium Indicator Powder can be used in place of the CalVer 2 Calcium Indicator Powder Pillow.
Magnesium is not included in the results but must be present for a sharp end point. If magnesium is not present, add one to two drops of Magnesium Standard Solution, 10-g/L as $CaCO_3$ to the sample before the test is started.

Collect the following items:

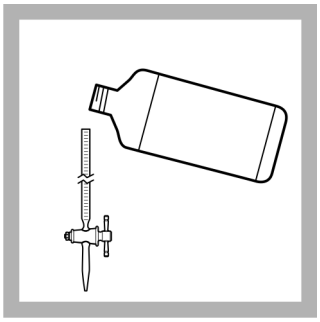
Description	Quantity
CalVer 2 Calcium Indicator Powder Pillow	1
Potassium Hydroxide Standard Solution, 8 N	1 mL
TitraVer Hardness Titrant (see *Range-specific information*)	1 bottle
Buret, Class A, 25-mL, with support stand	1
Erlenmeyer flask, 250 mL	1
Graduated cylinder	1

See *Consumables and replacement items* for reorder information.

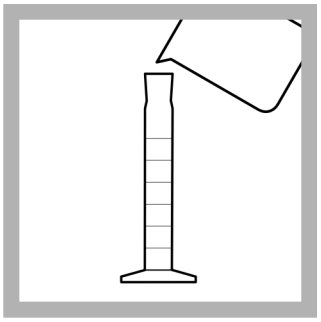
Buret titration



1. Select the sample volume and titrant concentration from the *Range-specific information* table.

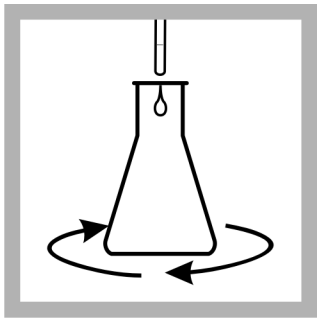


2. Fill a 25-mL buret to the zero mark with the TitraVer Hardness Titrant.

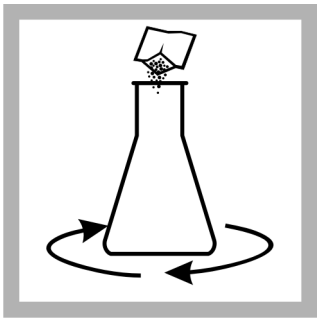


3. Use a graduated cylinder or pipet to measure the sample volume from the *Range-specific information* table.

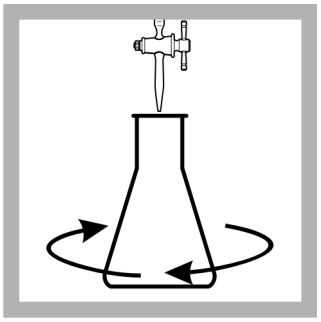
4. Transfer the sample into a 250-mL Erlenmeyer flask. If the sample volume is less than 50 mL, dilute to approximately 50 mL with deionized water. If magnesium is known to be absent, add one or two drops of Magnesium Standard Solution, 10-g/L as $CaCO_3$.



5. Add 1 mL of 8 N Potassium Hydroxide Standard Solution using the 1-mL dropper. Swirl to mix.

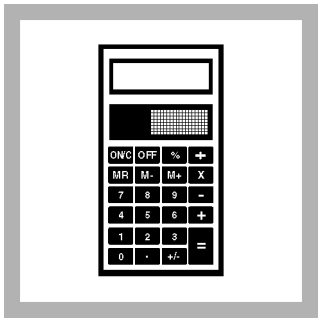


6. Add the contents of one CalVer 2 Calcium Indicator Powder Pillow. Swirl to mix.



7. Titrate the sample while swirling the flask until the color changes from red to pure blue.

Magnesium must be present (and usually is in natural waters) for a sharp end point, although it is not measured in the titration.



8. Use the multiplier in *Range-specific information* to calculate the concentration:

mL titrant used x multiplier = mg/L calcium as $CaCO_3$

Example: 50 mL of sample was titrated with the 0.020 N titrant solution and 15 mL of titrant was used to reach the endpoint.
The calcium concentration is: 15 x 20 = 300 mg/L as $CaCO_3$

Table 1 Range-specific information

Range (mg/L as $CaCO_3$)	Sample volume (mL)	Hardness titrant concentration	Multiplier
0–500	50	0.020 N	20
400–1000	25	0.020 N	40
1000–2500	10	0.020 N	100
2000–5000	5	0.020 N	200
1000–5000	50	0.200 N	200
4000–10,000	25	0.200 N	400
10,000–25,000	10	0.200 N	1000

Table 2 Hardness conversions

To convert from	To	Multiply by
mg/L as $CaCO_3$	mg/L as Ca	0.400
	grains per gallon (gpg)	0.058
	German degrees hardness (Gdh)	0.056

Interferences

WARNING
Chemical hazard. Potassium cyanide is toxic. Always add it after the potassium hydroxide. Dispose of all cyanide containing wastes according to local regulations.

An interfering substance can prevent the color change at the titration end point. A dilution can reduce the interference to a level at which the substance does not interfere. If an interference is suspected, decrease the sample volume, dilute to 50 mL and repeat the test. *Interfering substances* lists substances that can interfere with this test.

Table 3 Interfering substances

Interfering substance	Interference level
Acidity	The test can tolerate 10,000 mg/L acidity.
Alkalinity	The test can tolerate 10,000 mg/L alkalinity.
Aluminum	Interferes by causing a slow end point but up to 200 mg/L aluminum can be tolerated by allowing sufficient time for the color change.
Barium	Barium is titrated along with calcium but is seldom found in natural waters in significant amounts.
Chloride	Saturated solutions do not give a distinct end point, but the test can be run directly under sea water.
Cobalt	Interferes at all levels. 0.5 grams of potassium cyanide can be added after the potassium hydroxide solution to remove interference from up to 20 mg/L cobalt.
Copper	Interferes at 0.1 mg/L copper. 0.5 grams of potassium cyanide can be added after the potassium hydroxide solution to remove interference from up to 100 mg/L copper.
Iron	Interferes above 8 mg/L by causing an orange-red to green end point. Accurate results can still be obtained up to approximately 20 mg/L iron with this end point.
Magnesium	Interference from magnesium is prevented up to 200 mg/L by the formation of magnesium hydroxide at the high test pH but higher levels prevent a distinct end point.
Manganese	Interferes above 5 mg/L.
Nickel	Interferes at 0.5 mg/L nickel. 0.5 grams of potassium cyanide can be added after the potassium hydroxide solution to remove interference from up to 200 mg/L nickel.

Table 3 Interfering substances (continued)

Interfering substance	Interference level
Orthophosphate	Causes a slow end point but does not interfere if the calcium phosphate that forms is allowed to redissolve during the titration.
Polyphosphates	Interfere directly and must be absent.
Strontium	Strontium is titrated along with calcium but is seldom found in natural waters in significant amounts.
Temperature	Samples at about 20 °C (68 °F) or colder should be titrated slowly near the end point to allow sufficient time for the color change.
Zinc	Interferes at 5 mg/L zinc. 0.5 grams of potassium cyanide can be added after the potassium hydroxide solution to remove interference from up to 100 mg/L zinc.
Highly buffered samples or extreme sample pH	May exceed the buffering capacity of the reagents. Adjust the pH before starting the test (see *Sample collection, preservation and storage*).

Sample collection, preservation and storage

Collect samples in plastic or glass bottles that have been washed with a detergent and rinsed with tap water. Then rinse the bottles in 1:1 nitric acid solution and deionized water.

The following storage instructions are necessary only when immediate analysis is not possible. To preserve the sample, add 1.5 mL of nitric acid per liter (or quart) of sample. Mix. Measure the sample pH to make sure that the pH is 2 or less. Add more nitric acid in 0.5-mL increments if necessary. Mix thoroughly and check the pH after each addition until the pH is 2 or less. Preserved samples can be stored at least six months at room temperature.

Before running the test, adjust the sample to pH 7 by adding potassium hydroxide standard solution and mixing thoroughly. Correct the test result for volume additions.

Accuracy check

Use the standard additions method to find if the sample has an interference. Use the standard solution method to confirm anaytical technique and reagent performance.

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

- Hardness Voluette Ampule Standard Solution, 10,000-mg/L as $CaCO_3$
- Ampule breaker
- TenSette Pipet, 0.1–1.0 mL or 1.0–10.0 mL and Pipet Tips.

Procedure for use with the **0.020 N** titrant:

1. Open the standard solution ampule.
2. Use the TenSette Pipet to add 0.1 mL of the standard to the titrated sample. Swirl to mix.
3. Titrate the spiked sample to the end point. Write down the amount of titrant that was used to reach the end point.
4. Use the TenSette Pipet to add 0.2 mL of standard to the titrated sample. Swirl to mix.
5. Titrate the spiked sample to the end point. Write down the amount of titrant that was used to reach the end point.
6. Use the TenSette Pipet to add 0.3 mL of standard to the titrated sample. Swirl to mix.
7. Titrate the spiked sample to the end point. Write down the amount of titrant that was used to reach the end point.

8. Each 0.1 mL of standard that was added should use 1.0 mL of titrant to reach the endpoint. If more or less titrant was used, there can be an interference (see *Interferences*) or the concentration of the titrant has changed (see *Accuracy check*).

Procedure for use with the **0.200 N** titrant:

1. Open the standard solution ampule.
2. Use the TenSette Pipet to add 1.0 mL of the standard to the titrated sample. Swirl to mix.
3. Titrate the spiked sample to the end point. Write down the amount of titrant that was used to reach the end point.
4. Use the TenSette Pipet to add 2.0 mL of standard to the titrated sample. Swirl to mix.
5. Titrate the spiked sample to the end point. Write down the amount of titrant that was used to reach the end point.
6. Use the TenSette Pipet to add 3.0 mL of standard to the titrated sample. Swirl to mix.
7. Titrate the spiked sample to the end point. Write down the amount of titrant that was used to reach the end point.
8. Each 1.0 mL of standard that was added should use 1.0 mL of titrant to reach the endpoint. If more or less titrant was used, there can be an interference (see *Interferences*) or the concentration of the titrant has changed (see *Standard solution method*).

Standard solution method
Complete the following test to confirm analytical technique and reagent performance.

Procedure for use with the **0.020 N** titrant:

1. Add 25.0 mL of a calcium chloride standard solution, 1000-mg/L as $CaCO_3$, to an Erlenmeyer flask. Dilute to 50 mL with deionized water and mix fully.
2. Add the potassium hydroxide and CalVer 2 indicator. Swirl to mix.
3. Titrate the standard to the end point with the 0.020 N hardness titrant and calculate the result. The titration should use 25 mL of titrant.

Procedure for use with the **0.200 N** titrant:

1. Add 10.0 mL of a Hardness Voluette Ampule Standard Solution, 10,000-mg/L as $CaCO_3$, to an Erlenmeyer flask. Dilute to 50 mL with deionized water and mix fully.
2. Add the potassium hydroxide and CalVer 2 indicator. Swirl to mix.
3. Titrate the standard to the end point with the 0.200 N hardness titrant and calculate the result. The titration should use 10 mL of titrant.

Summary of method

The sample is made alkaline (pH 12 to 13) with potassium hydroxide to precipitate magnesium as magnesium hydroxide. CalVer 2 Calcium Indicator is added as an indicator and combines with any calcium to form a red color. As the TitraVer (EDTA) is added, it will react with all the free calcium ions present. At the end point of the titration, when no free calcium ions are present, the EDTA will remove the calcium complexed with the indicator. The indicator will then change from red to blue.

Consumables and replacement items

Required reagents

Description	Quantity/Test	Unit	Catalog number
Hardness (Calcium) Reagent Set (approximately 100 tests), includes:			2447000
CalVer 2 Calcium Indicator Powder Pillows	1	100/pkg	85299
Potassium Hydroxide Standard Solution, 8 N	1 mL	100 mL MDB	28232H
TitraVer® Hardness Titrant, 0.020 N	varies	1 L	20553
TitraVer Hardness Titrant, 0.200 N	varies	500 mL	102149

Required apparatus

Description	Quantity/Test	Unit	Catalog number
Buret, Class A, 25-mL	1	each	2636540
Buret Clamp, double	1	each	32800
Flask, Erlenmeyer, graduated, 250-mL	1	each	50546
Graduated cylinder—select one or more based on range:			
Cylinder, graduated, 5-mL	1	each	50837
Cylinder, graduated, 10-mL	1	each	50838
Cylinder, graduated, 25-mL	1	each	50840
Cylinder, graduated, 50-mL	1	each	50841
Support Stand	1	each	56300

Recommended standards and apparatus

Description	Unit	Catalog number
Calcium Chloride Standard Solution, 1000-mg/L as $CaCO_3$	1 L	12153
Hardness Standard Solution, Voluette ampule, 10,000-mg/L as $CaCO_3$, 10-mL	16/pkg	218710
Pipet, Class A volumetric, 10 mL	each	1451538
Pipet, Class A volumetric, 25 mL	each	1451540
Safety bulb	each	1465100

Optional reagents and apparatus

Description	Unit	Catalog number
CalVer® 2 Calcium Indicator Powder	113 g	28114H
Magnesium Standard Solution, 10-g/L as $CaCO_3$	29 mL	102233
Nitric Acid Solution, ACS	500 mL	15249
Nitric Acid Solution, 1:1	500 mL	254049
Potassium cyanide	125 g	76714
Potassium Hydroxide Standard Solution, 8 N	500 mL	28249
TenSette Pipet, 0.1 to 1.0 mL	each	1970001
Water, deionized	500 mL	27249
Spoon, measuring, 1 g	each	51000
Spoon, measuring, 0.5 g	each	90700
Spoon, measuring, 0.1 g	each	51100
Pipet Tips, for TenSette Pipet 1970001[1]	50/pkg	2185696
Voluette Ampule breaker 10 mL	each	2196800
Pipet, TenSette®, Pipet, 1.0–10.0 mL	each	1970010
Pipet Tips, for TenSette Pipet 1970010[1]	50/pkg	2199796
Sampling Bottle with cap, low density polyethylene, 250 mL	12/pkg	2087076

[1] Other sizes are available

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Hardness, Total

USEPA[1] ManVer 2 Buret Titration Method[2]

Method 8226

0 to 25,000 mg/L as $CaCO_3$

Buret Titration

Scope and Application: For water, wastewater and seawater.

[1] USEPA accepted when 0.020 N titrant is used.

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

Test preparation

Before starting the test:

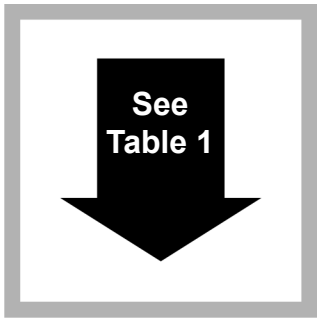
Four drops of Hardness 2 Indicator Solution or a 0.1-g scoop of ManVer 2 Hardness Indicator Powder can be added in place of the ManVer 2 Hardness Indicator Powder Pillow.
Hardness conversions: grains per gallon (gpg) as $CaCO_3$ = mg/L x 0.058; German degrees hardness (Gdh) = mg/L x 0.056

Collect the following items:

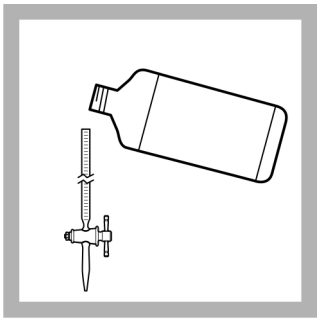
Description	Quantity
ManVer 2 Hardness Indicator Powder Pillow	1
Hardness 1 Buffer Solution	1 mL
TitraVer Hardness Titrant (see *Range-specific information*)	1 bottle
Buret, Class A, 25-mL, with support stand	1
Erlenmeyer flask, 250 mL	1
Graduated cylinder	1

See *Consumables and replacement items* for reorder information.

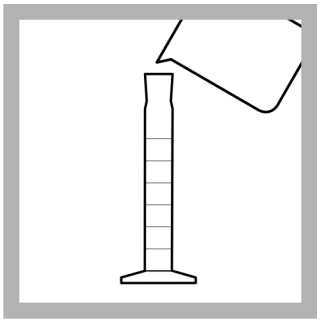
Buret titration



1. Select the sample volume and titrant concentration from *Range-specific information*.



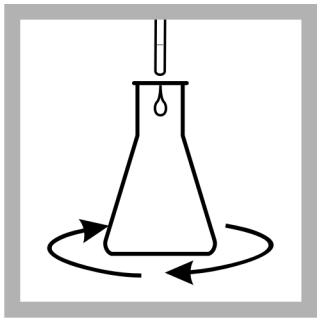
2. Fill a 25-mL buret to the zero mark with the TitraVer Hardness Titrant.



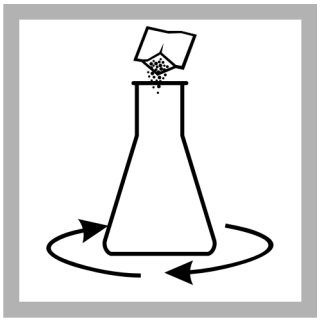
3. Use a graduated cylinder or pipet to measure the sample volume from the *Range-specific information* table.

4. Transfer the sample into a 250-mL Erlenmeyer flask. If the sample volume is less than 50 mL, dilute to approximately 50 mL with deionized water.

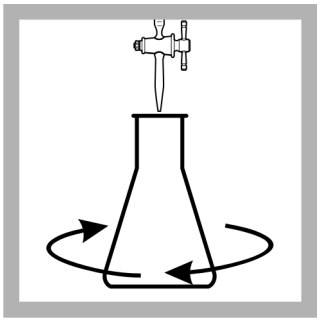
Buret titration (continued)



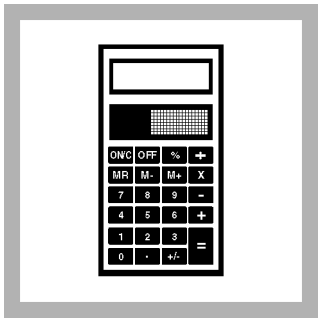
5. Add 1 mL of Hardness 1 Buffer Solution using the 1-mL dropper. Swirl to mix.



6. Add the contents of one ManVer 2 Hardness Indicator Powder Pillow. Swirl to mix.



7. Titrate the sample while swirling the flask until the color changes from red to pure blue.



8. Use the multiplier in the *Range-specific information* to calculate the concentration:

mL titrant used x multiplier = mg/L total hardness as $CaCO_3$

Example: 50 mL of sample was titrated with the 0.020 N titrant and 15 mL of titrant was used to reach the endpoint. The hardness concentration is: 15 x 20 = 300 mg/L as $CaCO_3$

Table 1 Range-specific information

Range (mg/L as $CaCO_3$)	Sample volume (mL)	Hardness titrant concentration	Multiplier
0–500	50	0.020 N	20
400–1000	25	0.020 N	40
1000–2500	10	0.020 N	100
1000–5000	50	0.200 N	200
4000–10,000	25	0.200 N	400
10,000–25,000	10	0.200 N	1000

Interferences

WARNING
Chemical hazard. Potassium cyanide is toxic. Always add it after the buffer solution. Dispose of all cyanide containing wastes according to local regulations

An interfering substance can prevent the color change at the titration end point. A dilution can reduce the interference to a level at which the substance does not interfere. If an interference is suspected, decrease the sample volume, dilute to 50 mL and repeat the test.

Interfering substances lists substances that can interfere with this test.

Table 2 Interfering substances

Interfering substance	Interference level
Acidity	Acidity at 10,000 mg/L as $CaCO_3$ does not interfere.
Alkalinity	Alkalinity at 10,000 mg/L as $CaCO_3$ does not interfere.
Aluminum	Aluminum interferes above 0.20 mg/L aluminum. 0.5 grams of potassium cyanide can be added after the buffer solution to remove interference from up to 1 mg/L aluminum.
Barium	Barium is titrated directly but is seldom found in natural waters in significant amounts.
Chloride	Saturated solutions do not give a distinct end point. The test can be run directly in sea water.
Cobalt	Interferes at all levels and must be absent or masked. 0.5 grams of potassium cyanide can be added after the buffer solution to remove interference from up to 100 mg/L cobalt.
Copper	Copper interferes above 0.10 mg/L copper. 0.5 grams of potassium cyanide can be added after the buffer solution to remove interference from up to 100 mg/L copper.
Iron	Interferes above 15 mg/L by causing an orange-red to green end point. Accurate results can still be obtained up to approximately 30 mg/L iron with this end point. For slightly sharper end points in solutions containing higher levels of iron, HexaVer Hardness Titrant (CDTA) can be used in place of the TitraVer Hardness Titrant (EDTA).
Manganese	Interferes above 20 mg/L. Adding a 0.10-gram scoop of Hydroxylamine Hydrochloride Monohydrate raises this level to 200 mg/L manganese.
Nickel	Interferes at all levels and must be absent or masked. 0.5 grams of potassium cyanide can be added after the buffer solution to remove interference from up to 100 mg/L nickel.
Orthophosphate	Causes a slow end point but does not interfere if the calcium phosphate that forms is allowed to redissolve during the titration.
Polyphosphates	Interfere directly and must be absent.
Polyvalent metal ions	Although less common than calcium and magnesium, other polyvalent metal ions cause the same hardness effects and will be included in the results.
Strontium	Strontium is titrated directly but is seldom found in natural waters in significant amounts.
Zinc	Titrates directly. 0.5 grams of potassium cyanide can be added after the buffer solution to remove interference from up to 100 mg/L zinc.
Highly buffered samples or extreme sample pH	May exceed the buffering capacity of the reagents. Adjust the pH before starting the test (see *Sample collection, preservation and storage*).

The addition of one CDTA Magnesium Salt Powder Pillow will remove metals interferences at or below the levels shown in the *Interference level with CDTA pillow* table. If more than one metal is present at or above the concentrations in the *Interference level with CDTA pillow* table, an additional CDTA Magnesium Salt Powder Pillow may be necessary.

Table 3 Interference level with CDTA pillow

Interfering substance	Interference level, mg/L
Aluminum	50
Cobalt	200
Copper	100
Iron	100
Manganese	200
Nickel	400
Zinc	300

The results obtained with CDTA Magnesium Salt will include the hardness contributed by those soluble metal ions present. If the concentration of soluble metal ion is known, a correction can be made to obtain the hardness contributed by calcium and magnesium only. The hardness

contributed per mg/L metal ion is listed in *Hardness equivalence factors* for the individual metals. The mg/L of metal present multiplied by its calcium carbonate hardness equivalent factor should be subtracted for each metal present from the total hardness determined in step 8 of the procedure to obtain the hardness contributed by calcium and magnesium only.

Table 4 Hardness equivalence factors

Interfering substance	Hardness equivalence factors, mg/L as $CaCO_3$
Aluminum	3.710
Barium	0.729
Cobalt	1.698
Copper	1.575
Iron	1.792
Manganese	1.822
Nickel	1.705
Strontium	1.142
Zinc	1.531

Sample collection, preservation and storage

Collect samples in plastic or glass bottles that have been washed with a detergent and rinsed with tap water. Then rinse the bottles in 1:1 nitric acid solution and deionized water.

The following storage instructions are necessary only when immediate analysis is not possible. To preserve the sample, add 1.5 mL of nitric acid per liter (or quart) of sample. Mix. Measure the sample pH to make sure that the pH is 2 or less. Add more nitric acid in 0.5-mL increments if necessary. Mix thoroughly and check the pH after each addition until the pH is 2 or less. Store samples at 4 °C (39 °F) or below. Preserved samples can be stored for at least seven days.

Before starting the test, warm the sample to room temperature and adjust the pH to approximately pH 7 with 5.0 N sodium hydroxide. Mix thoroughly. If a significant amount of nitric acid was added, make a volume correction for the extra acid and hydroxide. Divide the total volume (sample + acid + hydroxide) by the volume of the sample and multiply the result from the test by this value.

Accuracy check

Use the standard additions method to find if the sample has an interference. Use the standard solution method to confirm analytical technique and reagent performance.

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

- Hardness Voluette Ampule Standard Solution, 10,000-mg/L as $CaCO_3$
- Ampule breaker
- TenSette Pipet, 0.1–1.0 mL or 1.0–10.0 mL and Pipet Tips

Procedure for use with the **0.020 N** titrant:

1. Open the standard solution ampule.
2. Use the TenSette Pipet to add 0.1 mL of the standard to the titrated sample. Swirl to mix.
3. Titrate the spiked sample to the end point. Write down the amount of titrant that was used to reach the end point.
4. Use the TenSette Pipet to add 0.2 mL of standard to the titrated sample. Swirl to mix.

5. Titrate the spiked sample to the end point. Write down the amount of titrant that was used to reach the end point.
6. Use the TenSette Pipet to add 0.3 mL of standard to the titrated sample. Swirl to mix.
7. Titrate the spiked sample to the end point. Write down the amount of titrant that was used to reach the end point.
8. Each 0.1 mL of standard that was added should use 1.0 mL of titrant to reach the endpoint. If more or less titrant was used, there can be an interference (see *Interferences*) or the concentration of the titrant has changed (see *Standard solution method*).

Procedure for use with the **0.200 N** titrant:

1. Open the standard solution ampule.
2. Use the TenSette Pipet to add 1.0 mL of the standard to the titrated sample. Swirl to mix.
3. Titrate the spiked sample to the end point. Write down the amount of titrant that was used to reach the end point.
4. Use the TenSette Pipet to add 2.0 mL of standard to the titrated sample. Swirl to mix.
5. Titrate the spiked sample to the end point. Write down the amount of titrant that was used to reach the end point.
6. Use the TenSette Pipet to add 3.0 mL of standard to the titrated sample. Swirl to mix.
7. Titrate the spiked sample to the end point. Write down the amount of titrant that was used to reach the end point.
8. Each 1.0 mL of standard that was added should use 1.0 mL of titrant to reach the endpoint. If more or less titrant was used, there can be an interference (see *Interferences*) or the concentration of the titrant has changed (see *Standard solution method*).

Standard solution method

Complete the following test to confirm the analytical technique and reagent performance.

Procedure for use with the **0.020 N** titrant:

1. Add 25.0 mL of a calcium chloride standard solution, 1000-mg/L as $CaCO_3$, to an Erlenmeyer flask. Dilute to 50 mL with deionized water and mix fully.
2. Add the Hardness 1 Buffer Solution and ManVer 2 indicator. Swirl to mix.
3. Titrate the standard to the end point with the 0.020 N hardness titrant and calculate the result. The titration should use 25 (± 0.3) mL of titrant.

Procedure for use with the **0.200 N** titrant:

1. Add 10.0 mL of a Hardness Voluette Ampule Standard Solution, 10,000-mg/L as $CaCO_3$, to an Erlenmeyer flask. Dilute to 50 mL with deionized water and mix fully.
2. Add the Hardness 1 Buffer Solution and ManVer 2 indicator. Swirl to mix.
3. Titrate the standard to the end point with the 0.200 N hardness titrant and calculate the result. The titration should use 10 (± 0.2) mL of titrant.

Summary of method

In the total hardness test, the water sample is first buffered (using an organic amine and one of its salts) to a pH of 10.1. An organic dye, calmagite, is added as the indicator for the test. This dye reacts with calcium and magnesium ions to give a red-colored complex.

EDTA (ethylenediaminetetraacetic acid) is added as a titrant. The EDTA will react with all free calcium and magnesium ions present in the sample. At the end point of the titration, when free magnesium ions are no longer available, EDTA will remove magnesium ions from the indicator, causing a color change from red to blue.

Consumables and replacement items

Required reagents

Description	Quantity/Test	Unit	Catalog number
Hardness (Total) Reagent Set (approximately 100 tests), includes;			2447600
(1) ManVer 2 Hardness Indicator Powder Pillows	1	100/pkg	85199
(1) Buffer Solution, Hardness 1	1 mL	100 mL MDB	42432
(1) TitraVer® Hardness Titrant, 0.020 N	varies	1 L	20553
Hardness (Total) Reagent Set (approximately 100 tests), includes:			2447700
(1) ManVer 2 Hardness Indicator Powder Pillows	1	100/pkg	85199
(1) Buffer Solution, Hardness 1	1 mL	100 mL MDB	42432
(1) TitraVer® Hardness Titrant, 0.200 N	varies	500 mL	102149

Required apparatus

Description	Quantity/Test	Unit	Catalog number
Buret, Class A, 25-mL	1	each	2636540
Buret Clamp, double	1	each	32800
Flask, Erlenmeyer, graduated, 250-mL	1	each	50546
Graduated cylinder—select one or more based on range:			
Cylinder, graduated, 10-mL	1	each	50838
Cylinder, graduated, 25-mL	1	each	50840
Cylinder, graduated, 50-mL	1	each	50841
Support Stand	1	each	56300

Recommended standards and apparatus

Description	Unit	Catalog number
Calcium Chloride Standard Solution, 1000-mg/L as $CaCO_3$	1 L	12153
Hardness Standard Solution, Voluette ampule, 10,000-mg/L as $CaCO_3$, 10-mL	16/pkg	218710
Pipet, Class A volumetric, 10 mL	each	1451538
Pipet, Class A volumetric, 25 mL	each	1451540
Safety bulb	each	1465100

Optional reagents and apparatus

Description	Unit	Catalog number
CDTA Magnesium Salt Powder Pillow	100/pkg	1408099
Magnesium Standard Solution, 10-g/L as $CaCO_3$	29 mL	102233
Hardness 2 Indicator Solution	100 mL	42532
HexaVer Hardness Titrant, 0.020 N	1 L	74053
ManVer 2 Hardness Indicator Powder	113 g	28014
Nitric Acid Solution, ACS	500 mL	15249
Nitric Acid Solution, 1:1	500 mL	254049
Potassium cyanide	125 g	76714
Sodium Hydroxide Standard Solution, 5 N	50 mL	245026
TenSette Pipet, 0.1 to 1.0 mL	each	1970001
Water, deionized	500 mL	27249
Spoon, measuring, 1 g	each	51000
Spoon, measuring, 0.5 g	each	90700
Spoon, measuring, 0.1 g	each	51100
Pipet Tips, for TenSette Pipet 1970001	50/pkg	2185696
Voluette Ampule breaker 10 mL	each	2196800
Pipet, TenSette®, Pipet, 1.0–10.0 mL	each	1970010
Pipet Tips, for TenSette Pipet 1970010[1]	50/pkg	2199796
Sampling Bottle with cap, low density polyethylene, 250 mL	12/pkg	2087076

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Section 12

Solids Handling & Disposal

Handling and Disposal of Process Wastes

California State University - Sacramento

Need for Handling and Disposal of Process Wastes

- Water Pollution Control Act Amendments of 1972 restricts discharge of process wastes
- National Pollutant Discharge Elimination System (NPDES) requires a permit to discharge to a body of water
- Three categories of water treatment plants
  - *Category 1* – Plants that use coagulation, oxidative Fe and Mn removal, OR direct filtration
  - *Category 2* – Plants that use only chemical softening process
  - *Category 3* – Plants that are a combination of 1 & 2

Process Sludge Volumes

- Sludge accumulation based on
  - Type & amount of suspended matter in source water
  - Level & type of coagulant used
- Organic polymers produce less sludge than alum
- Polymers are denser and easier to dewater
- Sedimentation tanks should be drained and cleaned at least twice a year
  - More often if sludge buildup interferes with treatment process

Methods of Handling and Disposal

- Remove sludge regularly during day
  - Send to drying bed
  - Regular removal of water on top of bed will speed drying
- Drain tank and remove sludge semi-annually
- Backwash recovery ponds or lagoons separate water from solids
  - Also used to concentrate or thicken sludges
- Thickening, conditioning, and dewatering
- Discharge to wastewater collection system
- Spreading on land or dumping in landfill

Methods of Handling and Disposal

- Thickening – treatment to remove water from the sludge mass to reduce the volume that must be handled
- Conditioning – pretreatment of sludge to facilitate removal of water in subsequent treatment processes
  - Polymers can be added to condition sludge
- Dewater – to dry sludge so it can be handled and disposed of
  - Belt filter presses, centrifuges, filter presses, vacuum filters, solar lagoons, and sand drying beds

Draining and Cleaning of Tanks

- Should be done twice a year
  - Before and after peak demand months
- Determine water table level before draining underground storage tank
  - If table is high, tank can float
- Hose down all surfaces as tank is draining
  - Dried sludge is very difficult to remove
- Drain should be located in the headworks area
  - Sludge is denser near the entrance to tank

Sludge Dewatering

Solar Drying Lagoons

- Shallow, small-volume storage ponds
- Sludge settles to bottom and supernatant is skimmed off top
- Sludge is dried to concentration of 30-50% solids by evaporation and solar drying
- Sludge then disposed of on site or at landfill
- Due to process taking a long time, several lagoons should be provided

Sludge Dewatering

Sand Drying Beds

- Consists of layer of sand, support gravel layer, underdrain, system, sludge removal method
- Drying can vary from days to weeks
  - Precondition sludge with coagulant to improve dewatering process
- Sludge will not expand once even partially dried
  - Layer of layer of wet sludge can be added over a period of time
  - Sludge must be at least 2-3% solids

Sludge Dewatering

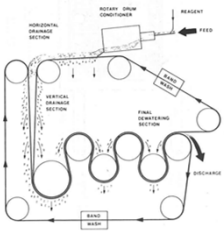
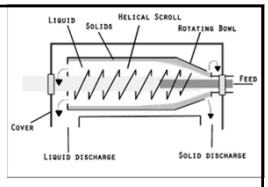


Fig. 17.9 Flow diagram of Winkipress (a continuous belt filter press)
(Permission of Ashbrook-Simon-Hartley)

Belt Filter Presses

- Two primary mechanisms:
  - Gravity drainage
  - Pressure dewatering
- Dries to 35-40% solids
- Sludge is conveyed and dewatered between two endless belts
- Three distinct zones
  - Horizontal zone for gravity drainage
  - Vertical sandwich draining zone
  - Final dewatering zone containing arrangement of staggered rollers to squeeze out remaining free water

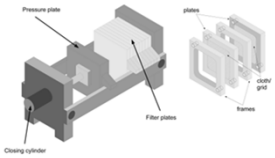
Sludge Dewatering



Centrifuges

- Two types
  - Scroll centrifuge
    - Solids introduced horizontally into center of unit
    - Spinning action forces solids against outer wall
    - Solids transported to discharge end by rotating screw
  - Basket centrifuge
    - Sludge introduced vertically bottom of bowl and supernatant is discharged over weir at top
    - When solids in supernatant gets too high, operation is stopped and the dense solids cake is removed by a knife unloader

Sludge Dewatering



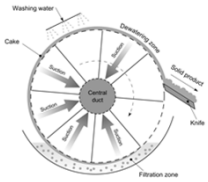
Filter Presses

- Best suited for sludges with high specific resistance
  - the internal resistance of a sludge cake to the passage of water
- Consists of a series of vertical plates covered with cloth
  - Sludge fed into press
  - Plates pressed together at pressures as high as 225 psi
  - Water passes through cloth; solids retained on cloth
  - Cake is formed that is removed when press is depressurized

Sludge Dewatering

Vacuum Filters

- Cylindrical drum rotates in a tank of sludge
- Vacuum applied under belt to form cake on surface
- Belt separates from drum as goes over top
- Belt is then washed before it re-enters the vat
- Precoat of diatomaceous earth required to dewater alum sludge



Disposal of Sludge

- Lime sludge is excellent for agricultural purposes
- Alum sludge must not be applied to agricultural land
  - Causes soils to harden and does not provide any beneficial value
  - Can be sent to landfill or land applied and plowed into soil
- Slow sand filter for iron treatment has top layer removed instead of backwashing
  - Must be disposed of in sanitary landfill
- Ion exchange softener regeneration wastewater may be very slowly and carefully discharged into sewer
- Filter backwash water must be recycled through water treatment plant or placed in storage pond