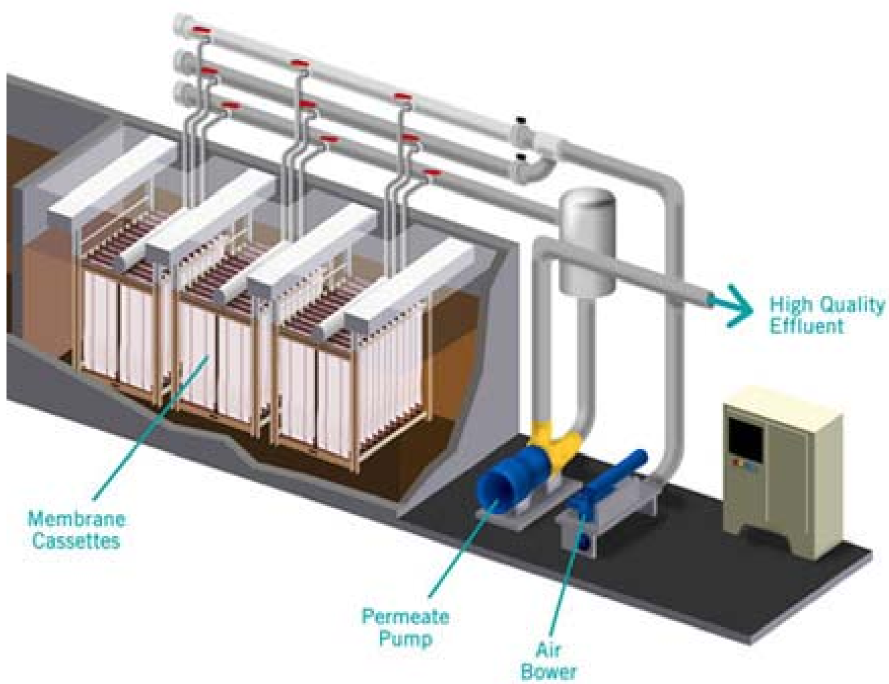
Advanced Water Treatment

Course # 3110



Fleming Training Center
February 13 - 17, 2017

Fleming Training Center

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Advanced Water Treatment

Course # 3110

February 13-17, 2017

Monday, February 13:

8:30	Pumps	Amanda Carter
11:00	LUNCH	
12:15	Equipment Maintenance	Amanda

Tuesday, February 14:

8:30	Iron & Manganese	Amanda
10:00	Softening	Amanda
11:00	LUNCH	
12:15	Water System Security	Amanda
1:30	Emergency Operation Plans	Amanda

Wednesday, February 15:

8:30	Membrane Filtration	Amanda
11:00	LUNCH	
12:15	Tour- Duck River WTP	

Thursday, February 16:

8:30	Fluoridation	Amanda
12:00	Lunch	
1:15	Filter Evaluation	Amanda

Friday, February 17:

8:30	Lab	Amanda
9:30	Review for Exam	Amanda
11:00	LUNCH	
12:15	Exam and Course Evaluation	Amanda

Advanced Water Treatment

Section 1

Pumps

PUMPS

California State University: Sacramento

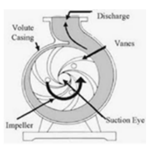
TENNESSEE DEPARTMENT OF ENVIRONMENT AND CONSERVATION

Necessity Of Pumps

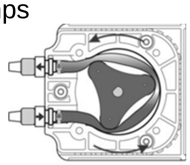
- Pumps are required when gravity cannot supply water with sufficient pressure to all parts of the distribution system
- Pumps account for the largest energy cost for a water supply operation

Types of Pumps

- Velocity Pumps



- Positive-Displacement Pumps

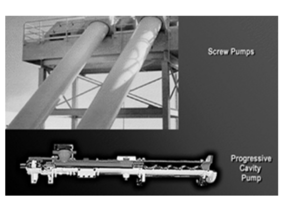


Types of Pumps

- Positive-Displacement Pumps
  - Metering pumps
    - sometimes used to feed chemicals
  - Piston pump
  - Screw pump
- Velocity Pumps
  - Vertical turbine
  - Centrifugal

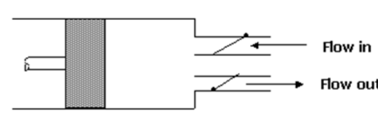
Positive-Displacement Pumps

- Chemical feed pumps
- Delivers a constant volume with each stroke
- Less efficient than centrifugal pumps
- **Cannot operate against a closed discharge valve**
- Types: piston, diaphragm, gear, or screw pump



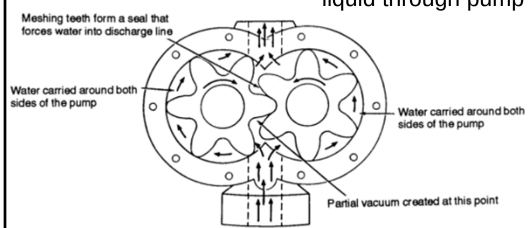
Positive-Displacement Pumps

- Reciprocating (piston) pump - piston moves back and forth in cylinder, liquid enters and leaves through check valves



Positive-Displacement Pumps

- Rotary pump - Use lobes or gears to move liquid through pump



Screw Pumps

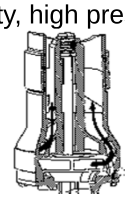
Incline screw pumps handle large solids without plugging

- Aka progressive cavity pumps
- Screw pumps are used to lift wastewater to a higher elevation
- This pump consists of a screw operating at a constant speed within a housing or trough
- The screw has a pitch and is set at a specific angle
- When revolving, it carries wastewater up the trough to a discharge point

Velocity Pumps

- Spinning impeller or propeller accelerates water to high velocity in pump casing (or volute)
- High velocity, low pressure water is converted to low velocity, high pressure water

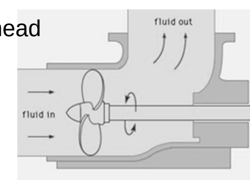
Volute



Diffuser

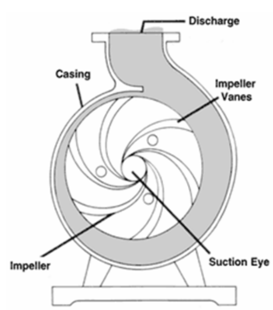
Velocity Pump Design Characteristics

- Axial - flow designs
  - Propeller shaped impeller adds head by lifting action on vanes
  - Water moves parallel to pump instead of being thrown outward
  - High volume, but limited head
  - Not self-priming



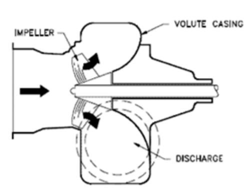
Velocity Pump Design Characteristics

- Radial flow designs
  - Water comes in through center (eye) of impeller
  - Water thrown outward from impeller to diffusers that convert velocity to pressure
  - The discharge is perpendicular to the pump shaft



Velocity Pump Design Characteristics

- Mixed - flow designs
  - Has features of axial and radial flow
  - Works well for water with solids



Centrifugal Pump

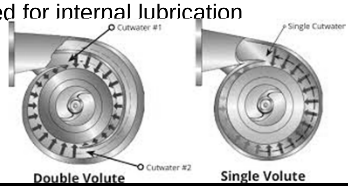
- Basically a very simple device: an impeller rotating in a casing
- The impeller is supported on a shaft, which in turn, is supported by bearings
- Liquid coming in at the center (eye) of the impeller is picked up by the vanes and by the rotation of the impeller and then is thrown out by centrifugal force into the discharge

Centrifugal Pumps

- Volute-casing type most commonly used in water utilities
- Impeller rotates in casing - radial flow
- Single or multi-stage
- By varying size, shape, and width of impeller, a wide range of flows and pressures can be achieved

Advantages of Centrifugal Pumps

- Wide range of capacities
- Uniform flow at a constant speed and head
- Low cost
- Ability to be adapted to various types of drivers
- Moderate to high efficiency
- No need for internal lubrication



Disadvantages of Centrifugal Pumps

- Efficiency is limited to very narrow ranges of flow and head
- Flow capacity greatly depends on discharge pressure
- Generally no self-priming ability
- Can run backwards if check valve fails and sticks open
- Potential impeller damage if pumping abrasive water

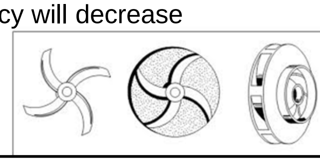
Let's Build a Centrifugal Pump

- First we need a device to spin liquid at high speeds – an impeller
  - As the impeller spins, liquid between the blades is impelled outward by centrifugal force
  - As liquid in the impeller moves outward, it will suck more liquid behind it through this eye

#1: If there is any danger that foreign material may be sucked into the pump, clogging or wearing of the impeller unduly, provide the intake end of the suction piping with a suitable screen

Impeller

- Bronze or stainless steel
- Closed; some single-suction have semi-open; open designs
- Inspect regularly
- As the impeller wears on a pump, the pump efficiency will decrease



Let's Build a Centrifugal Pump

- Now we need a shaft to support and turn the impeller
  - It must maintain the impeller in precisely the right place
  - But that ruggedness does not protect the shaft from the corrosive or abrasive effects of the liquid pumped, so we must protect it with sleeves slid on from either end

#2: Never pump a liquid for which the pump was not designed

Shaft and Sleeves

- Shaft
  - Connects impeller to pump; steel or stainless steel
  - Should be repaired/replaced if grooves or scores appear on the shaft
- Shaft Sleeves
  - Protect shaft from wear from packing rings
  - Generally they are bronze, but various other alloys, ceramics, glass or even rubber-coating are sometimes required.

Let's Build a Centrifugal Pump

- We mount the shaft on sleeve, ball or roller bearings
  - If bearings supporting the turning shaft and impeller are allowed to wear excessively and lower the turning units within a pump's closely fitted mechanism, the life and efficiency of that pump will be seriously threatened.

#3: Keep the right amount of the right lubricant in bearings at all times.

Bearings

- Anti-friction devices for supporting and guiding pump and motor shafts
- Get noisy as they wear out
- If pump bearings are over lubricated, the bearings will overheat and can be damaged or fail
  - Tiny indentations high on the shoulder of a bearing or race is called brinelling
  - When greasing a bearing on an electric motor, the relief plug should be removed and replaced after the motor has run for a few minutes. This prevents you from damaging the seals of the bearing.
- Types: ball, roller, sleeve

Let's Build a Centrifugal Pump

- To connect with the motor, we add a coupling flange
  - Our pump is driven by a separate motor, and we attach a flange to one end of the shaft through which bolts will connect with the motor flange
  - If shafts are met at an angle, every rotation throws tremendous extra load on bearings of both pump and the motor

#4: See that pump and motor flanges are parallel and vertical and that they stay that way.

Couplings

- Connect pump and motor shafts
- Lubricated require greasing at 6 month intervals
- Dry has rubber or elastomeric membrane
- Calipers and thickness gauges can be used to check alignment on flexible couplings

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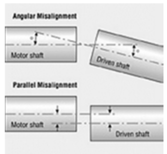
Misalignment of Pump & Motor



- Excessive bearing loading
- Shaft bending
- Premature bearing failure
- Shaft damage
- Checking alignment should be a regular procedure in pump maintenance.
  - Foundations can settle unevenly
  - Piping can change pump position
  - Bolts can loosen
  - Misalignment is a major cause of pump and coupling wear.

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Common Pump & Motor Connections

- Direct coupling
- Angle drive
- Belt or chain
- Flexible coupling
- Close-coupled

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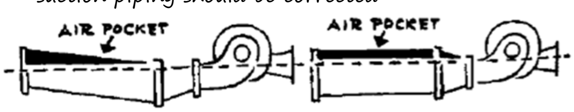
Let's Build a Centrifugal Pump

- Now we need a "straw" through which liquid can be sucked
  - The horizontal pipe slopes upward toward the pump so that air pockets won't be drawn into the pump and cause loss of suction

#5: Any down-sloping toward the pump in suction piping should be corrected



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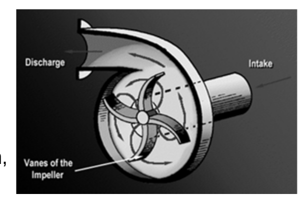
Let's Build a Centrifugal Pump

- We contain and direct the spinning liquid with a casing
  - Designed to minimize friction loss as water is thrown outward from impeller
  - Usually made of cast iron, spiral shape



#6: See that piping puts absolutely no strain on the pump casing.

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Mechanical Details of Centrifugal Pumps

- Casing
  - Housing surrounding the impeller; also called the volute
  - Designed to minimize friction loss as water is thrown outward from impeller
  - Usually made of cast iron, spiral shape

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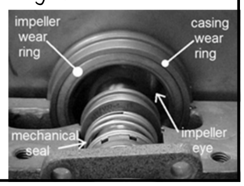
Let's Build a Centrifugal Pump

- Now our pump is almost complete, but it would leak like a sieve
  - As water is drawn into the spinning impeller, centrifugal force causes it to flow outward, building up high pressure at the outside of the pump (which will force water out) and creating low pressure at the center of the pump (which will draw water in)
    - Water tends to be drawn back from pressure to suction through the space between the impeller and casing – this needs to be plugged

Let's Build a Centrifugal Pump

- So we add wear rings to plug internal liquid leakage
  - Wear rings fill the gaps without having to move the parts of the pump closer together

#7: Never allow a pump to run dry. Water is a lubricant between the rings and impeller.



Wear Rings

- Restrict flow between impeller discharge and suction
- Leakage reduces pump efficiency
- Installed to protect the impeller and pump casing from excessive wear
- Provides a replaceable wearing surface
- Inspect regularly

Let's Build a Centrifugal Pump

- To keep air from being drawn in, we use stuffing boxes
  - We have two good reasons for wanting to keep air out of our pump
    - We want to pump water, not air
    - Air leakage is apt to cause our pump to lose suction
  - Each stuffing box we use consists of a casing, rings of packing and a gland at the outside end
    - A mechanical seal may be used instead

Stuffing Box

#9 – Packing should be replace periodically. Forcing in a ring or two of new packing instead of replacing worn packing is bad practice. It is apt to dislodge the seal cage.

#10 - Never tighten a gland more than necessary as excessive pressure will wear shaft sleeves unduly.

#11 – If shaft sleeves are badly scored, replace them immediately.

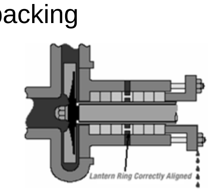
Let's Build a Centrifugal Pump

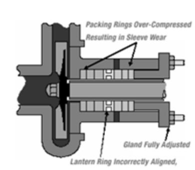
- To make packing more airtight, we add water seal piping
  - In the center of each stuffing box is a "seal cage"
  - This liquid acts both to block out air intake and to lubricate the packing
  - To control liquid flow, draw up the packing gland just tight enough to allow approximately one drop/second flow from the box

#12 – If the liquid being pumped contains grit, a separate source of sealing liquid should be obtained.

Lantern Rings

- Perforated ring placed in stuffing box
- A spacer ring in the packing gland that forms seal around shaft, helps keep air from entering the pump and lubricates packing





Packing Rings

- Asbestos or metal ring lubricated with Teflon or graphite
- Provides a seal where the shaft passes through the pump casing in order to keep air form being drawn or sucked into the pump and/or the water being pumped from coming out

Packing Rings

- If new packing leaks, stop the motor and repack the pump
- Pumps need new packing when the gland or follower is pulled all the way down
- The packing around the shaft should be tightened slowly, over a period of **several hours** to just enough to allow an occasional drop of liquid (**20-60 drops per minute** is desired)
  - Leakage acts as a lubricant
- Stagger joints 180º if only 2 rings are in stuffing box, space at 120º for 3 rings or **90º if 4 rings or more are in set**

Packing Rings

- If packing is not maintained properly, the following troubles can arise:
  - **Loss of suction** due to air being allowed to enter pump
  - **Shaft or shaft sleeve damage**
  - Water or wastewater **contaminating bearings**
  - **Flooding** of pump station
  - Rust corrosion and unsightliness of pump and area

Mechanical Seals

- Located in stuffing box
- Prevents water from leaking along shaft; keeps air out of pump
- **Should not leak**
- Consists of a rotating ring and stationary element
- The operating temperature on a mechanical seal should never exceed 160ºF (71ºC)
- Mechanical seals are always flushed in some manner to lubricate the seal faces and minimize wear
  - The flushing water pressure in a water-lubricated wastewater pump should be **3-5 psi higher** than the pump discharge pressure.

Mechanical Seals

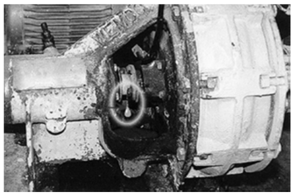
- Required instead of packing rings for suction head greater than 60 psi
- Prevents water from leaking along shaft, keeps air out of pump
  - Should not leak any water

Packing vs. Mechanical Seals

- If a pump has packing, water should drip slowly
- If it has a mechanical seal, no leakage should occur

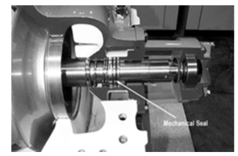
Packing Rings vs. Mechanical Seal

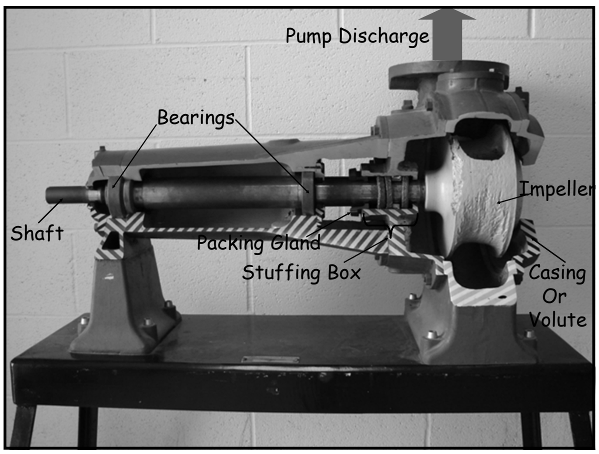
- Advantages
  - Less expensive, short term
  - Can accommodate some looseness
- Disadvantages
  - Increased wear on shaft or shaft sleeve
  - Increased labor required for adjustment and replacement

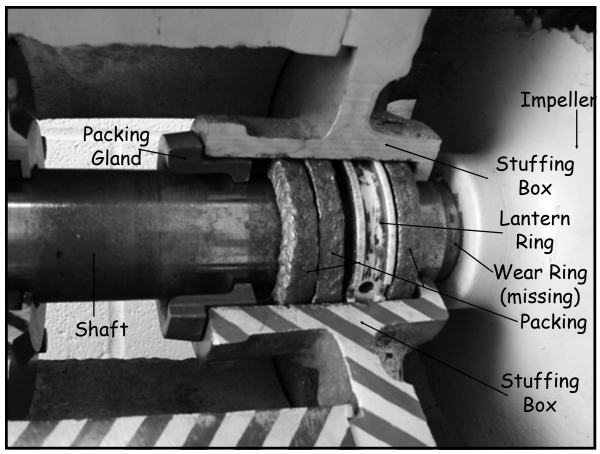


Mechanical Seal vs. Packing Rings

- Advantages
  - **Last 3-4 years**, which can be a savings in labor
  - Usually there is **no damage to shaft sleeve**
  - **Continual adjusting, cleaning or repacking is not required**
  - Possibility of flooding lift station because a pump has thrown its packing is eliminated; however mechanical seals can fail and lift stations can be flooded
- Disadvantages
  - **High initial cost**
  - **Great skill and care needed to replace**
  - When they fail, the pump must be shut down
  - **Pump must be dismantled to repair**







Centrifugal Pump Operation

- Pump Starting -
  - Impeller must be submerged for a pump to start
    - Should never be run empty, except momentarily, because parts lubricated by water would be damaged
  - Foot valve helps hold prime
  - Discharge valve should open slowly to control water hammer
  - In small pumps, a check valve closes immediately when pump stops to prevent flow reversal
  - In large pumps, discharge valve may close before pump stops

Centrifugal Pump Operation

- Pump shut down for extended period of time -
  - Close the valve in the suction line
  - Close the valve in the discharge line
  - Drain the pump casing

Flow Control

- Flow usually controlled by starting and stopping pumps
- Throttling flow should be avoided - wastes energy
- Variable speed drives or motor are best way to vary flow
  - Variable speed pumping equipment can be adjusted to match the inflow rate

Monitoring Operational Variables

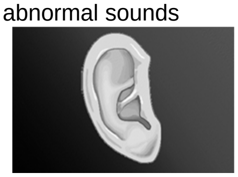
- Pump and motor should be tested and complete test results recorded as a baseline for the measurement of performance within the first 30 days of operation

Monitoring Operational Variables

- Suction and Discharge Heads
  - Pressure gauges
- Bearing and Motor Temperature
  - Temp indicators can shut down pump if temp gets too high
  - Check temp of motor by feel

Monitoring Operational Variables

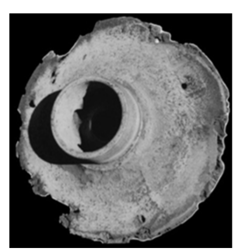
- Vibration
  - Detectors can sense malfunctions causing excess vibration
  - Operators can learn to distinguish between normal and abnormal sounds



Monitoring Operational Variables

- Likely causes of vibration
  - Bad bearings or bearing failure
  - Imbalance of rotating elements, damage to impeller
  - Misalignment from shifts in underlying foundation
  - Improper motor to pump alignment

Monitoring Operational Variables



- Speed
  - Cavitation can occur at low and high speeds
  - Creation of vapor bubbles due to partial vacuum created by incomplete filling of the pump

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Monitoring Operational Variables

- Cavitation is a noise coming from a centrifugal pump that sounds like marbles trapped in the volute
- A condition where small bubbles of vapor form and explode against the impeller, causing a pinging sound
- Best method to prevent it from occurring is to reduce the suction lift

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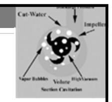
Suction Cavitation



- Suction Cavitation occurs when the pump suction is under a low pressure/high vacuum condition where the liquid turns into a vapor at the eye of the pump impeller.
- This vapor is carried over to the discharge side of the pump where it no longer sees vacuum and is compressed back into a liquid by the discharge pressure.
- This imploding action occurs violently and attacks the face of the impeller.
- An impeller that has been operating under a suction cavitation condition has large chunks of material removed from its face causing premature failure of the pump.

Information from http://www.pumpworld.com/Cavitation_discharge.htm

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Discharge Cavitation

- Discharge Cavitation occurs when the pump discharge is extremely high.
- It normally occurs in a pump that is running at less than 10% of its best efficiency point.
- The high discharge pressure causes the majority of the fluid to circulate inside the pump instead of being allowed to flow out the discharge.
- As the liquid flows around the impeller it must pass through the small clearance between the impeller and the pump cutwater at extremely high velocity.

Information from http://www.pumpworld.com/Cavitation_discharge.htm

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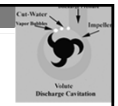
Discharge Cavitation



- This velocity causes a vacuum to develop at the cutwater similar to what occurs in a venturi and turns the liquid into a vapor.
- A pump that has been operating under these conditions shows premature wear of the impeller vane tips and the pump cutwater.
- In addition due to the high pressure condition premature failure of the pump mechanical seal and bearings can be expected and under extreme conditions will break the impeller shaft.

Information from http://www.pumpworld.com/Cavitation_discharge.htm

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Inspection and Maintenance

- Inspection and maintenance prolongs life of pumps
  - Checking operating temperature of bearings
  - Checking packing glands
  - Operating two or more pumps of the same size alternatively to equalize wear
  - Check parallel and angular alignment of the coupling on the pump and motor
    - A feeler gauge, dial indicator calipers are tools that can be used to check proper alignment
- Necessary for warranty
- Keep records of all maintenance on each pump
- Keep log of operating hours

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Inspection: Impellers

- Wear on impeller and volute
- Cavitation marks
- Chips, broken tips, corrosion, unusual wear
- Tightness on shaft
- Clearances
- Tears or bubbles (if rubber coated)

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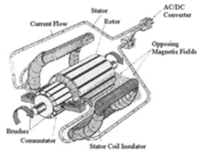
Pump Won't Start?



- Incorrect power supply
- No power supply
- Incorrectly connected
- Fuse out, loose or open connection
- Rotating parts of motor jammed mechanically
- Internal circuitry open

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Pump Safety

- Machinery should always be turned off and locked out/tagged out before any work is performed on it
- Make sure all moving parts are free to move and all guards in place before restarting
- Machinery creating excessive noise shall be equipped with mufflers.

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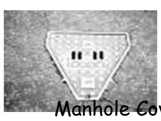
Pump Safety: Wet Wells

- Confined spaces
- Corrosion of ladder rungs
- Explosive atmospheres
- Hydrogen sulfide accumulation
- Slippery surfaces



Manhole Cover, London

Pump Vocabulary

1. Axial-Flow Pump – a pump in which a propeller-like impeller forces water out in the direction parallel to the shaft. Also called a propeller pump.
2. Bearing – anti-friction device used to support and guide a pump and motor shafts.
3. Casing – the enclosure surrounding a pump impeller, into which the suction and discharge ports are machined.
4. Cavitation – a condition that can occur when pumps are run too fast or water is forced to change direction quickly. A partial vacuum forms near the pipe wall or impeller blade causing potentially rapid pitting of the metal.
5. Centrifugal Pumps – a pump consisting of an impeller on a rotating shaft enclosed by a casing having suction and discharge connections. The spinning impeller throws water outward at high velocity, and the casing shape converts this velocity to pressure.
6. Closed-Coupled Pump – a pump assembly where the impeller is mounted on the shaft of the motor that drives the pump.
7. Diffuser Vanes – vanes installed within a pump casing on diffuser centrifugal pumps to change velocity head to pressure head.
8. Double-Suction Pump – a centrifugal pump in which the water enters from both sides of the impeller. Also called a split-case pump.
9. Foot Valve – a check valve placed in the bottom of the suction pipe of a pump, which opens to allow water to enter the suction pipe but closes to prevent water from passing out of it at the bottom end. Keeps prime.
10. Frame-Mounted Pump – a centrifugal pump in which the pump shaft is connected to the motor shaft with a coupling.
11. Impeller – the rotating set of vanes that forces water through the pump.
12. Jet Pump – a device that pumps fluid by converting the energy of a high-pressure fluid into that of a high-velocity fluid.
13. Lantern Ring – a perforated ring placed around the pump shaft in the stuffing box. Water from the pump discharge is piped to this ring. The water forms a liquid seal around the shaft and lubricates the packing.
14. Mechanical Seal – a seal placed on the pump shaft to prevent water from leaking from the pump along the shaft; the seal also prevents air from entering the pump.
15. Mixed-Flow Pump – a pump that imparts both radial and axial flow to the water.
16. Packing – rings of graphite-impregnated cotton, flax, or synthetic materials, used to control leakage along a valve stem or a pump shaft.
17. Packing Gland – a follower ring that compressed the packing in the stuffing box.
18. Positive Displacement Pump – a pump that delivers a precise volume of liquid for each stroke of the piston or rotation of the shaft.
19. Prime Mover – a source of power, such as an internal combustion engine or an electric motor, designed to supply force and motion to drive machinery, such as a pump.

20. Radial-Flow Pump – a pump that moves water by centrifugal force, spinning the water radially outward from the center of the impeller.
21. Reciprocating Pump – a type of positive-displacement pump consisting of a closed cylinder containing a piston or plunger to draw liquid into the cylinder through an inlet valve and forces it out through an outlet valve.
22. Rotary Pump – a type of positive-displacement pump consisting of elements resembling gears that rotate in a close-fitting pump case. The rotation of these elements alternately draws in and discharges the water being pumped.
23. Single-Suction Pump – a centrifugal pump in which the water enters from only one side of the impeller. Also called an end-suction pump.
24. Stuffing Box – a portion of the pump casing through which the shaft extends and in which packing or a mechanical seal is placed to prevent leakage.
25. Submersible Pump – a vertical-turbine pump with the motor placed below the impellers. The motor is designed to be submersed in water.
26. Suction Lift – the condition existing when the source of water supply is below the centerline of the pump.
27. Velocity Pump – the general class of pumps that use a rapidly turning impeller to impart kinetic energy or velocity to fluids. The pump casing then converts this velocity head, in part, to pressure head. Also known as kinetic pumps.
28. Vertical Turbine Pump – a centrifugal pump, commonly of the multistage, diffuser type, in which the pump shaft is mounted vertically.
29. Volute – the expanding section of pump casing (in a volute centrifugal pump), which converts velocity head to pressure head..
30. Water Hammer – the potentially damaging slam that occurs in a pipe when a sudden change in water velocity (usually as a result of too-rapidly starting a pump or operating a valve) creates a great increase in water pressure.
31. Wear Rings – rings made of brass or bronze placed on the impeller and/or casing of a centrifugal pump to control the amount of water that is allowed to leak from the discharge to the suction side of the pump.

Pump and Motor Facts

Pump Facts

High-service pump – discharges water under pressure to the distribution system.

Booster pump – used to increase pressure in the distribution system and to fill elevated storage tanks.

Impeller or centrifugal pump used to move water.

Likely causes of vibration in an existing pump/motor installation:

1. bad bearings
2. imbalance of rotating elements
3. misalignment from shifts in underlying foundation

Pump and motor should be tested and complete test results recorded as a baseline for the measurement of performance within the first 30 days of operations.

Calipers and thickness gauges can be used to check alignment on flexible couplings.

Packing/Seals Facts

If new packing leaks, stop the motor and repack the pump.

Pumps need new packing when the gland or follower is pulled all the way down.

The packing around the shaft should be tightened just enough to allow an occasional drop of liquid.

Joints of packing should be staggered at least 90°.

Mechanical seals consist of a rotating ring and stationary element.

The operating temperature on a mechanical seal should never exceed 160°F.

Motor Facts

Motors pull the most current on start up.

In order to prevent damage, turn the circuit off immediately if the fuse on one of the legs of a three-phase circuit blows.

An electric motor changes electrical energy into mechanical energy.

Power factors on motors can be improved by:
1. changing the motor loading
2. changing the motor type
3. using capacitors

Routing cleaning of pump motors includes:
1. checking alignment and balance
2. checking brushes
3. removing dirt and moisture
4. removal of obstructions that prevent air circulation

Cool air extends the useful life of motors.

A motor (electrical or internal combustion) used to drive a pump is called a prime mover.

The speed at which the magnetic field rotates is called the motor synchronous speed and is expressed in rpm.

If a variable speed belt drive is not to be used for 30 days or more, shift the unit to minimum speed setting.

Emory cloth should not be used on electric motor components because it is electrically conductive and may contaminate parts.

Ohmmeters used to test a fuse in a motor starter circuit.

The most likely cause of a three-phase motor not coming to speed after starting – the motor has lost power to one or more phases.

Transformer Facts

Transformers are used to convert high voltage to low voltage.

High voltage is 440 volts or higher.

Standby engines should be run weekly to ensure that it is working properly.

Relays are used to protect electric motors.

Pump and Motor Review Questions

1. Leakage of water around the packing on a centrifugal pump is important because it acts as a (n):
   a. Adhesive
   b. Lubricant
   c. Absorbent
   d. Backflow preventer

2. What is the purpose of wear rings in a pump?
   a. Hold the shaft in place
   b. Hold the impeller in place
   c. Control amount of water leaking from discharge to suction side
   d. Prevent oil from getting into the casing of the pump

3. Which of the following does a lantern ring accomplish?
   a. Lubricates the packing
   b. Helps keep air from entering the pump
   c. Both (a.) and (b.)

4. Closed, open and semi-open are types of what pump part?
   a. Impeller
   b. Shaft sleeve
   c. Casing
   d. Coupling

5. When tightening the packing on a centrifugal pump, which of the following applies?
   a. Tighten hand tight, never use a wrench
   b. Tighten to 20 foot pounds of pressure
   c. Tighten slowly, over a period of several hours
   d. Tighten until no leakage can be seen from the shaft

6. Excessive vibrations in a pump can be caused by:
   a. Bearing failure
   b. Damage to the impeller
   c. Misalignment of the pump shaft and motor
   d. All of the above

7. What component can be installed on a pump to hold the prime?
   a. Toe valve
   b. Foot valve
   c. Prime valve
   d. Casing valve

8. The operating temperature of a mechanical seal should not exceed:
   a. 60°C
   b. 150°F
   c. 160°F
   d. 71°C
   e. c and d

9. What is the term for the condition where small bubbles of vapor form and explode against the impeller, causing a pinging sound?
   a. Corrosion
   b. Cavitation
   c. Aeration
   d. Combustion

10. The first thing that should be done before any work is begun on a pump or electrical motor is:
    a. Notify the state
    b. Put on safety goggles
    c. Lock out the power source and tag it
    d. Have a competent person to supervise the work

11. Under what operating condition do electric motors pull the most current?
    a. At start up
    b. At full operating speed
    c. At shut down
    d. When locked out

12. Positive displacement pumps are rarely used for water distribution because:
    a. They require too much maintenance
    b. They are no longer manufactured
    c. They require constant observation
    d. Centrifugal pumps are much more efficient

13. Another name for double-suction pump is
    a. Double-jet pump
    b. Reciprocating pump
    c. Horizontal split-case pump
    d. Double-displacement pump

14. As the impeller on a pump becomes worn, the pump efficiency will:
    a. Decrease
    b. Increase
    c. Stay the same

15. How do the two basic parts of a velocity pump operate?

16. What are two designs used to change high velocity to high pressure in a pump?

17. In what type of pump are centrifugal force and the lifting action of the impeller vanes combined to develop the total dynamic head?

18. Identify one unique safety advantage that velocity pumps have over positive-displacement pumps.

19. What is the multistage centrifugal pump? What effects does the design have on discharge pressure and flow volume?

20. What are two types of vertical turbine pump, as distinguished by pump and motor arrangement, which are commonly used to pump ground water from wells?

21. What type of vertical turbine pump is commonly used as an inline booster pump?

22. Describe the two main parts of a jet pump.

23. What is the most common used of positive-displacement pumps in water plants today?

24. What is the purpose of the foot valve on a centrifugal pump?

25. How is the casing of a double-suction pump disassembled?

26. What is the function of wear rings in centrifugal pumps of the closed-impeller design? What is the function of the lantern rings?

27. Describe the two common types of seals used to control leakage between the pump shaft and the casing.

28. What feature distinguishes a close-coupled pump and motor?

29. What is the value of listening to a pump or laying a hand on the unit as it operates?

30. Define the term “racking” as applied to pump and motor control.

31. When do most electric motors take the most current?

32. What are three major ways of reducing power costs where electric motors are used?

33. What effect could over lubrication of motor bearings have?

34. Why should emery cloth not be used around electrical machines?

35. What are the most likely causes of vibration in an existing pump installation?

36. What can happen when a fuse blows on a single leg of a three-phase circuit?

37. Name at least three common fuels for internal-combustion engines.

38. List the type of information that should be recorded on a basic data card for pumping equipment.

39. What is the first rule of safety when repairing electrical devices?

Answers:

1. B	6. D	11. A
2. C	7. B	12. D
3. C	8. E	13. C
4. A	9. B	14. A
5. C	10. C	

15. A spinning impeller accelerates water to a high velocity within a casing, which changes the high-velocity, low-pressure water to a low-velocity, high-pressure discharge.
16. Volute casing and diffuser vanes.
17. Mixed-flow pump (the design used for most vertical turbine pumps)
18. If a valve is closed in the discharge line, the pump impeller can continue to rotate for a time without pumping water or damaging the pump.
19. A multistage centrifugal pump is made up of a series of impellers and casings (housings) arranged in layers, or stages. This increases the pressure at the discharge outlet, but does not increase flow volume.
20. Shaft-type and submersible-type vertical turbines.
21. A close-coupled vertical turbine with an integral sump or pot.
22. The jet pump consists of a centrifugal pump at the ground surface and an ejector nozzle below the water level.
23. Positive-displacement pumps are generally used in water plants to feed chemical into the water supply.
24. The foot valve prevents water from draining when the pump is stopped, so the pump will be primed when restarted.
25. The bolts holding the two halves of the casing together are removed and the top half is lifted off.
26. Wear rings prevent excessive circulation of water between the impeller discharge and suction area. Lantern rings allow sealing water to be fed into the stuffing box.
27. (1) Packing rings are made of graphite-impregnated cotton, flax, or synthetic materials. They are inserted in the stuffing box and held snuggly against the shaft by an adjustable packing gland. (2) Mechanical seals consist of two machined and polished surfaces. One is attached to the shaft, the other to the casing. Spring pressure maintains contact between the two surfaces.
28. The pump impeller is mounted directly on the shaft of the motor.
29. An experienced operator can often detect unusual vibration by simply listening or touching. Vibration, especially changes in vibration level, are viewed as symptoms or indicators of other underlying problems in foundation, alignment and/or pump wear.
30. Racking refers to erratic operation that may result from pressure surges when the pump starts; it is often a problem when the pressure sensor for the pump control is located too close to the pump station.
31. During start-up.
32. (1) Increase system efficiency; (2) spread the pumping load more evenly throughout the day; (3) reduce power-factor charges
33. The bearings may run hot, and excess grease or oil could run out and reach the motor windings, causing the insulation to deteriorate.
34. The abrasive material on emery cloth is electrically conductive and could contaminate electrical components.
35. Imbalance of the rotating elements, bad bearings and misalignment
36. A condition called single-phasing can occur, causing the motor windings to overheat and eventually fail.

37. gasoline, propane, methane, natural gas and diesel oil (diesel fuel)
38. make, model, capacity, type, date and location installed, and other information for both the driver (motor) and the driven unit (pump)
39. Make sure the power to the device is disconnected. This is critical since rubber gloves, insulated tools and other protective gear are not guarantees against electrical shock.

Section 2

Equipment Maintenance

Maintenance

California State University, Sacramento

Water Treatment Plant Operations Vol. II

TDEC - Fleming Training Center

Treatment Plant Maintenance

- A good maintenance program is a must in order to maintain successful operation of a water plant
- Should include everything from mechanical equipment to the care of the plant grounds, buildings and structures
- Mechanical maintenance is of prime importance as the equipment must be kept in good operating condition in order for the plant to maintain peak performance

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Preventive Maintenance Records

- Preventive maintenance programs keep equipment in good working condition and correct small malfunctions before they turn into big problems
- A good record keeping system tells when maintenance is due and shows equipment performance
- Equipment service cards and service record cards should be filled out for each piece of equipment in the plant

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Equipment Service Card

- Tells what should be done and when
- Should include equipment name
  - e.g. raw water intake pump No. 1
- List each required maintenance service with an item number
- List maintenance services in order of frequency of performance
- Describe each type of service under work to be done

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EQUIPMENT SERVICE CARD
Equipment: #1 Raw Water Intake Pump

Item No.	Work to be done	Frequency	Time
1	Check water seal and packing gland	Daily	
2	Listen for unusual noises	Daily	
3	Operate pump alternately	Weekly	Monday
4	Inspect pump assembly	Weekly	Wednesday
5	Inspect and lube bearings	Quarterly	1, 4, 7, 10
6	Check operating temperature of bearings	Quarterly	1, 4, 7, 10
7	Check alignment of pump and motor	Semi-annually	4, 10
8	Inspect and service pump	Semi-annually	4, 10
9	Drain pump before shutdown		

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Service Record Card

- Tells what was done and when it was done
- Should have date and work done, listed by item number and signed by the operator who performed the service

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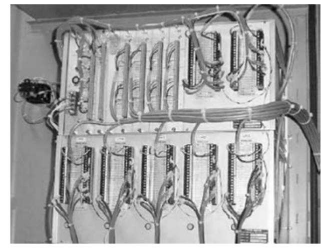
SERVICE RECORD CARD
Equipment: #1 Raw Water Intake Pump

Date	Work Done (Item No.)	Signed
1-6-13	1-2-3	J.D.
1-7-13	1-2	J.D.
1-8-13	1-2-4-5-6	P. K.

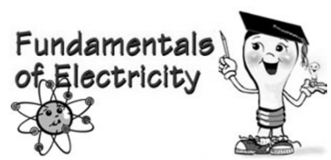
Date	Work Done (Item No.)	Signed



Electrical Equipment

Beware of Electricity

- Do not attempt to install, troubleshoot, maintain, repair, or replace electrical equipment, panels, controls, wiring, or circuits unless
  - You know what you are doing
  - You are qualified
  - You are authorized

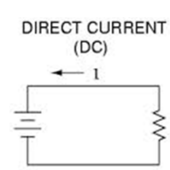


Volts

- Also known as electromotive force (EMF)
- The electrical pressure available to cause a flow of current (amperage) when a circuit is closed
- Voltage (E) is the force that is necessary to push electricity or electric current through a wire
- Two types:
  - Direct current (DC)
  - Alternating current (AC)

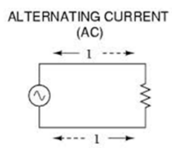
Direct Current (DC)

- Flow in one direction and is essentially free from pulsation
- Used exclusively in automotive equipment, certain types of welding equipment, and a variety of portable equipment
- Found in various voltages
  - 6, 12, 24, 48, and 110 volts
- All batteries are DC



Alternating Current (AC)

- Voltage and current periodically change direction and amplitude
- Current goes from zero to maximum strength, back to zero, and to the same strength in the opposite direction
- Hertz describes the frequency of cycles completed per second
- Classified as
  - Single phase
  - Two phase
  - Three phase or polyphase



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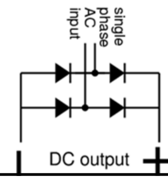
Alternating Current – Single Phase

- Found in lighting systems, small pump motors, various portable tools, and throughout homes
- Usually 120 volts and sometimes 240 volts
- Only one phase of power is supplied to the main electrical panel



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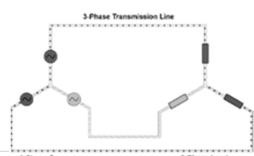
Alternating Current – Three Phase

- Generally used with motors and transformers
- Usually is 208, 220, 240 volts, or 440, 460, 480, and 550 volts
- Used when high power requirements or larger motors are used
- Efficiency is higher and less maintenance is required
- Generally, all motors with > 2 HP are three phase



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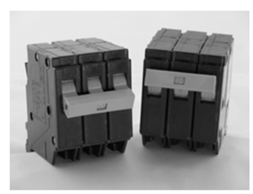
Alternating Current – Circuit Breakers

- Used to protect electric circuits from overloads
- Metal conductors that de-energize the main circuit is overheated by too much current passing through



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Amps

- The measurement of current or electron flow and is an indication of work being done or "how hard the electricity is working"
- The practical unit of electrical current

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Watts (W) and Kilowatts(kW)

- The units of measurement of the rate at which power is being used or generated
- In DC circuits, watts equal the voltage times the current
  - Watts = (volts)(amps)
- In AC polyphase circuits, you have to include the power factor and the √3
  - Watts = (volts)(amps)(power factor)(1.73)
- Power factor is the ratio of actual power passing through a circuit to the apparent power
  - Usually somewhere near 0.9

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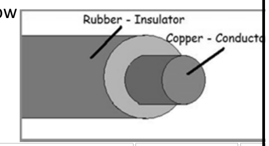
Conductors and Insulators

- Conductor - a material that allows the flow of electric current e.g. copper
- Insulator - a material that will not allow the flow of electricity e.g. rubber
  - Insulation commonly used to prevent the loss of electrical flow by two conductors coming into contact with each other



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Tools, Meters and Testers

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Voltage Testing

- Multimeter used for checking voltage
- Use meter that has sufficient range to measure voltage you would expect to find
- Tells if AC or DC and intensity or voltage
- Used to test for open circuits, blown fuses, single phasing of motors, grounds, etc.

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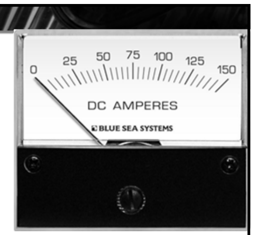
Ammeter



- Records the current or "amps" flowing in the circuit
- Two common types:
  - Clamp-on type – used for testing
    - Clamped around a wire supplying a motor
  - In-line type – installed in a panel or piece of equipment
    - Connected in line with the power lead or leads

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Megger

- Used for checking the insulation resistance on motors, feeders, bus bar systems, grounds, and branch circuit wiring
- Connected to a motor terminal at the starter
- Test results show if the insulation is deteriorating or cut
- Three types
  - Crank operated
  - Battery operated
  - Instrument

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Ohmmeters

- Used to measure the resistance in a circuit
- Also called circuit testers
- Electrical circuit must be OFF to use ohmmeter
- Ohmmeter supplies own power

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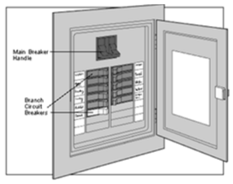

Equipment Protective Devices

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Fuses

- A protective device having a strip or wire of fusible metal that will melt and break the electrical circuit when subjected to excessive temperature
- Common types:
  - Current-limiting fuses – used to protect power distribution circuits
  - Dual-element fuses – used for motor protection circuits
- Be sure to replace fuses with proper size and type indicated for that circuit

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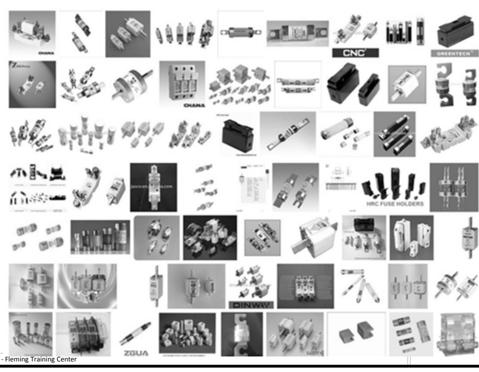
Fuses



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Circuit Breakers

- A protective device consisting of a switch that opens automatically when the current of the voltage exceeds or falls below a certain limit
- Can be reset unlike a fuse
- Can be visually inspected to find out if it has been tripped

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Overload Relays

- Heater strips open on current rise (overheating) and open the control circuit
  - This opens the power control circuit which de-energizes the start and stops power to the motor
- Also known as heaters or “thermal overloads”
- Range form 100-110 of the motor nameplate ratings
- Should never exceed 125% of the motor rating
- Never increase the rating of the overload relay
  - Find the problem that is causing it to trip and repair it
- Ground – an electrical connection to earth or a large conductor that is at the earth’s potential or neutral voltage

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Overload Relays

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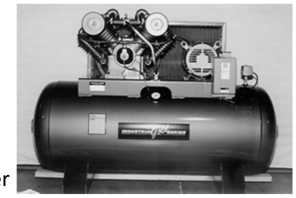
Auxiliary Electrical Power

- Standby power generation – three types
  - Engine driven generator
  - Batteries
  - Alternate power source
- Emergency lighting
- Batteries

Compressors

- A device used to increase the pressure of air or gas
- Consists of a suction pipe with a filter and a discharge pipe that connects to an air receiver



- Can be simple diaphragm type or complex rotary, piston, or sliding vane type

Compressor Maintenance

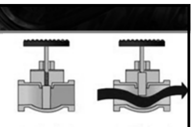
- Inspect the suction filter of the compressor monthly
  - Clean or replace filter every 3-6 months
- Lubrication must be inspected daily
  - Oil should be replaced every 3 months
- Cylinder or casing fins should be cleaned weekly
- Inspect unloader
  - If not working properly, compressor will not start, stall, or burn off belts if belt driven
- Test the safety valves weekly

Compressor Maintenance

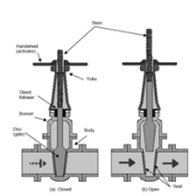
- Drain the condensate from air receiver daily
  - If has automatic drain, inspect periodically
- Inspect belt tension on compressor
  - Should be able to press the belt down, in the center, with your hand approximately ¾ inch
- Examine operating controls
  - Make sure compressor is starting and stopping at the proper settings
- Ensure portable compressors have oil in tool oiler reservoir
- Clean thoroughly each month

Valves

Gate Valves



- Basic parts: operator (handle), shaft packing assembly, bonnet, valve body with seats, stem, and disc
- Valve disc is raised/lowered by a threaded shaft
- Disc is screwed down until it wedges itself between two machined valve seats
- Not used to control flows
- Either rising stem or non-rising stem type



Gate Valves – O & M

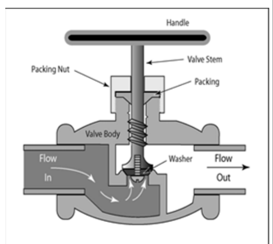
- 1. Open valve fully
- 2. Operate all large valves at least yearly to ensure proper operation
- 3. Inspect valve stem packing for leaks
- 4. If the valve has a rising stem, keep stem threads clean and lubricated
- 5. Close valves slowly in pressure lines to prevent water hammer
- 6. If a valve will not close by using the handwheel, check for the cause; Using a “cheater” bar will only aggravate the problem

Gate Valves - Maintenance

Frequency	Service
Annually	**Replace packing:** Remove all old packing from stuffing box. Insert new split ring packing while staggering the ring splits.
Semi-annually	**Operate valve:** Operate inactive gate valves to prevent sticking
Annually	**Lubricate gearing:** Lubricate gate valves as recommended by manufacturer
Semi-annually	**Lubricate rising stem threads:** Clean threads on rising stem gate valves and lubricate with grease
Annually	**Reface leaky gate valve seats:** Remove bonnet and clean examine disc body thoroughly. Check and service all parts of valve completely. Remove all old packing a clean out stiffing box. Do not salvage old gasket. After cleaning and examining all parts, determine whether valve can be repaired or must be replaced. Test repaired valve before putting back in line.

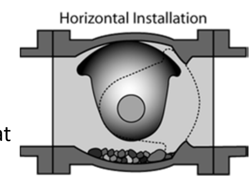
Globe Valves

- Use a circular disc to make a flat surface contact with a ground-fitted valve seat
- Internal design enables valve to be used in a controlling /throttling mode
- Can be of rising or nonrising stem type
- O & M similar to gate valve



Eccentric Valves

- Uses a cam shaped plug to match an eccentric valve seat
- As the valve is closed, the plug throttles the flow yet maintains a smooth flow rate
- Excellent for controlling the flows of slurries and sludges



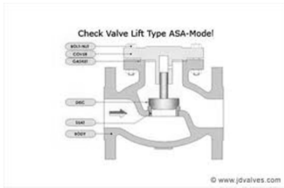
Butterfly Valves

- Used primarily as a control valve
- Uses a machined disc that can be opened to 90º to allow full flow through valve
- Closed valve is forced against the continuous rubber seat

Check Valves

- Allows water to flow in only one direction
- Three types:
  - Swing check – a movable disc (clapper) rests at a right angle to the flow an seats against a ground seat
  - Wafer check – a circular disc that hinges in the center of the disc. Flow collapses the disc and flow stoppage allows the disc to return to its circular form
  - Lift check – uses a vertical lift disc or ball. Flow lifts the disc/ball and allows water to flow through.
    - Foot valves are nearly always vertical lift valves

Lift Check Valve



Swing Check Valve

Wafer Check Valve

Check Valves - Maintenance

Frequency	Service
Annually	**Inspect disc facing**: Open valves to observe condition of facing on swing check valves
Annually	**Check pin wear:** Check pin wear on balanced check valve, since disc must be accurately positioned in seat to prevent leakage

Chemical Storage and Feeders

Chemical Storage

- Hydroscopic chemicals absorb or attract moisture from the air
  - e.g. quicklime will generate tremendous heat when in contact with water
- Some liquid chemicals will form a solid or “freeze” if exposed to air
  - e.g. caustic soda will form calcium carbonate and sodium hydroxide will crystalize below 55ºF

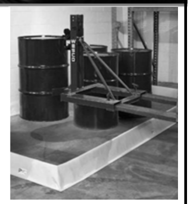
Chemical Storage

- Potassium permanganate can be stored for extended times in a cool, dry area in closed containers
  - Store in fire resistant building with concrete floors
  - Do not store near greases/oils or a heat source
  - Clean spill immediately by flushing away with water

Chemical Storage

- Carbon should be stored in a clean, dry place
  - Single or double rows with access around every stack
  - Storage area should be fire proof with self closing fire doors
  - Should be protected from contact with flammable materials
  - Keep oily rags and chlorine compounds away from area

Chemical Storage



- Polymer solutions will lose their strength when exposed to biological contamination
  - Clean tanks before a new shipment is delivered
- Liquid chemical storage tanks should have a berm around the tanks to hold the amount stored (secondary containment)
- Continual surveillance and maintenance of storage and feeding systems are required

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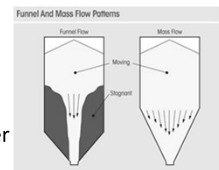
Chemical Storage

- Keep liquid feeders clean to prevent plugging or corrosion of the mechanism
- Single drain pit that can accept both acid and alkali chemicals is not allowed
- Solid chemical feeders should be kept clean and dry to prevent bridging of the chemical the hopper and clogging in the feeder
  - Bridging is a hardened layer that can form an arch and prevent flow



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Calibrating Large Volume Metering Pumps

- Fill sight tube from the chemical solution tank
- Set valve so tube is only source of liquid chemical entering the pump
- Run the pump for set time at each representative setting of the pump control scale
- Use this info to develop curves of pump setting vs chemical dose in mg/L or gal/day
  - Called a calibration curve

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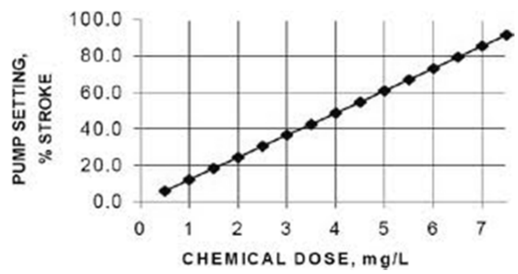
Calibrating Large Volume Metering Pumps



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Calibrating Dry Chemical Systems

- Two common types:
  - Rocker-dump type – uses a scraper moving back and forth on a platform
  - Helex-feed type – uses a rotating screw (helix)
- To calibrate, catch the chemical fed at several representative settings during a measured time interval
- Weigh each volume and convert into lbs/day

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Chlorinators

- Chlorine gas leaks will cause equipment to corrode
  - A green or reddish deposit on metal indicates corrosion
- Ammonia vapor will detect any chlorine leak
  - Cloth soaked with diluted ammonia works as a leak detector
  - Wave cloth on a stick in general area of leak (do **not** touch equipment with it)
  - If there is a leak, a white cloud of ammonium chloride will form
- This should be done at all gas pipe joints, both inside and outside the chlorinators, at regular intervals

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Chlorinators

- New gaskets should be used for each new connection
- Water strainers may be cleaned by flushing with water
  - If badly fouled, clean with hydrochloric acid then rinse with water
- Atmosphere vent lines must be open and free
  - Should evacuate chlorine to outside when chlorinator is being shut down

Maintenance Vocabulary

A. Air Gap
B. Alternating Current
C. Amperage
D. Ampere
E. Circuit
F. Circuit Breaker
G. Conductor
H. Coulomb
I. Current
J. Cycle
K. Direct Current
L. Electrolyte
M. Electromotive Force
N. Electron
O. Fuse
P. Ground
Q. Hertz
R. Hygroscopic
S. Lead
T. Megger
U. Ohm
V. Power Factor
W. Prussian Blue
X. Resistance
Y. Voltage
Z. Water Hammer

_____ 1. A complete alteration of voltage or current in an alternating current circuit.

_____ 2. A safety device in an electric circuit that automatically shuts off the circuit when it becomes overloaded.

_____ 3. The ratio of true power passing through an electric current to the product of the voltage and amperage in the circuit.

_____ 4. An expression representing an electrical connection to earth or a large conductor that is at the earth's potential or neutral voltage.

_____ 5.The electrical pressure available to cause a flow of current when an electric circuit is closed.

_____ 6. The strength of an electric current measured in amperes.

_____ 7. That property of a conductor or wire that opposes the passage of a current, thus causing electric energy to be transformed into heat.

_____ 8. A wire or conductor that can carry electric current.

_____ 9. A blue paste or liquid used to show a contact area. Used to determine if gate valve seats fit properly.

_____ 10. The electrical pressure available to cause a flow of current when an electric circuit is dead.

_____ 11. Electric current flowing in only one direction and essentially free from pulsation.

_____ 12. The unit used to measure current strength.

_____ 13. A substance that dissociates (separates) into tow or more ions when it is dissolved in water.

_____ 14. The condition that occurs when a valve is opened or closed very rapidly.

_____ 15. In electricity, a substance, body, device, or wire that readily conducts or carries electric current.

_____ 16. The unit of electrical resistance. The resistance of a conductor in which one volt produces a current of one ampere.

_____ 17. A protective device having a strip or wire of fusible metal that, when placed in a circuit, will melt and break the electric circuit if heated too much.

_____ 18. A very small, negatively charged particle that is practically weightless. The part of an atom that determines its chemical properties.

_____ 19. A measurement of the amount of electrical charge carried by an electric current of 1 amp/second. Equal to 6.25×10^{18} electrons.

_____ 20. Absorbing or attracting moisture from the air.

_____ 21. The complete path of an electric current including the generating apparatus or other source.

_____ 22. An open, vertical empty space between a drinking water supply and potentially contaminated water.

_____ 23. The number of complete electromagnetic cycles or waves in one second of an electric or electronic circuit. Also called the frequency of the current.

_____ 24. An instrument used for checking the insulation resistance on motors, feeders, etc.

_____ 25. A movement or flow of electricity. Measured by the number of coulombs per second.

_____ 26. A electric current that reverses its direction (positive/negative values) at regular intervals.

Answers

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

Section 3

Membrane Filtration

Membrane Treatment Processes

California State University, Sacramento

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

2

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

3

Flux

- A flow or flowing
- Term used to describe the rate of water flow through the semipermeable membrane
- Expressed in gal/day/ft^2 of membrane surface area or gram/second/cm^2
- There will always be a decline in flux with time due to membrane compaction
- "Flux decline" is a loss of water flow through a membrane due to compaction plus fouling

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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

5

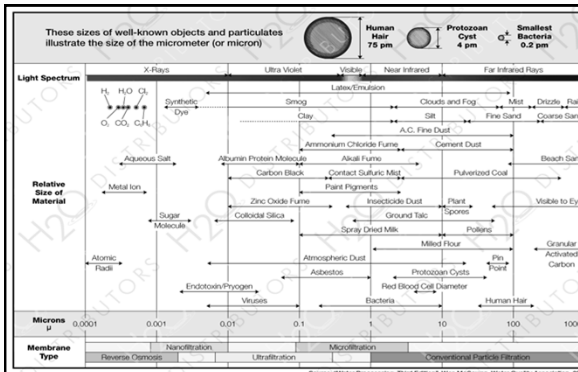
Seasonal Effects

- 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

6

Membrane Treatment Technologies

- Contain very fine pore openings that allow water to pass through and block contaminants
- Types:
  - Microfiltration (MF)
  - Ultrafiltration (UF)
  - Nanofiltration (NF)
  - Reverse Osmosis (RO)
- Type of membrane depends on constituents to be removed



TYPICAL REMOVAL RATES FOR THIN-FILM COMPOSITE MEMBRANES
At 65 PSI Feed Pressure and 77° Temperature

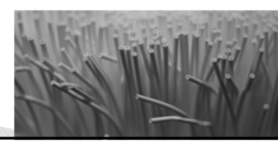
Arsenic	94%	Barium	99%	Flouride	93%	Nitrates	87%	Nitrites	87%
Asbestos	99%	Cadmium	98%	Lead	99%	Radium	80%	Hexavalent Chromium	86%
Cyanide	86%	Copper	99%	Mercury	91%	Selenium	96%	Trivalent Chromium	88%

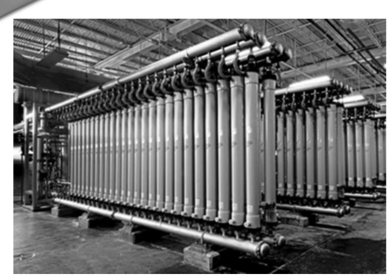
Membrane Treatment Technologies

- Microfiltration and ultrafiltration used in water treatment
  - Particles, sediments, algae, bacteria, and viruses
  - *Giardia* and *Cryptosporidium*
- Reverse osmosis used for desalination or demineralization and for home treatment units while nanofiltration can be used to reduce natural organic matter (DBP precursor)
  - Dissolved organic matter and dissolved contaminants such as arsenic, nitrate, pesticides, and radionuclides
  - Ions such as calcium, magnesium, sodium and chloride

Membrane Filtration Units

- Membranes are hollow fibers
- Outside diameter of 0.5-2.0 mm
- Pressure vessels
  - Arranged in racks 4-12 inches in diameter and 3-18 ft long
  - May flow from outside in or from inside out
- Submerged flow
  - Modules suspended in basins of water to be treated
  - Flows from outside in

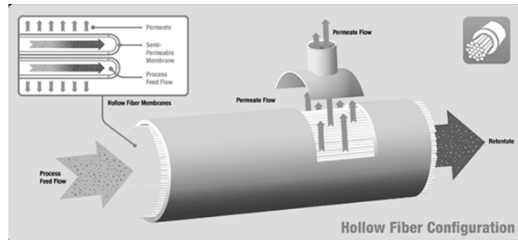




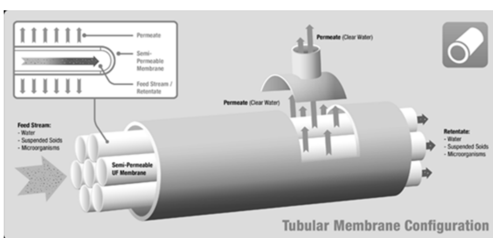
Membranes

- Spiral wound
- Hollow fine fiber
- Tubular

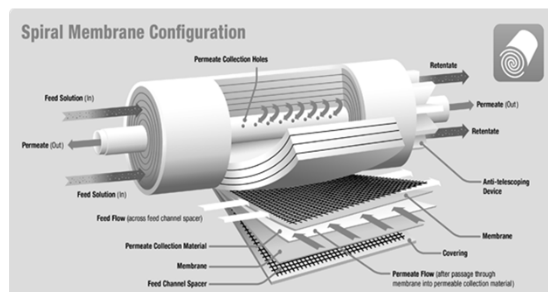
Hollow Fiber Membrane



Tubular Membrane

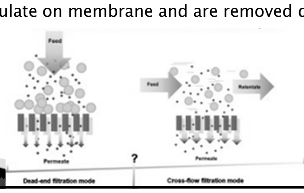


Spiral Wound Membrane



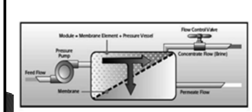
Membrane Flow Types

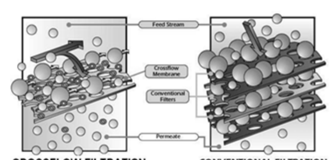
- Cross flow filtration
  - Water flows from inside fiber through the membrane and out of system
  - What does not flow through, flows out end of fiber as a waste stream
- Dead end filtration
  - Water may flow from inside out or outside in
  - Solids accumulate on membrane and are removed during backwash



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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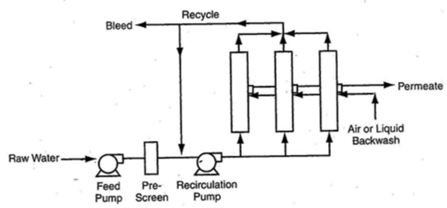
System Configurations



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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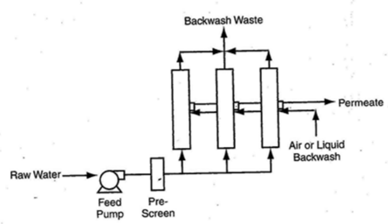
System Configuration



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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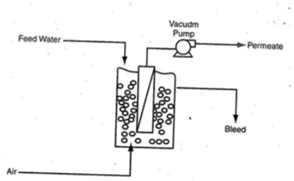
System Configuration



Direct flow submersible

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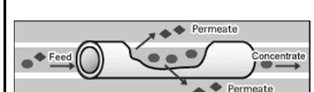
Inside-Out Filtration



- 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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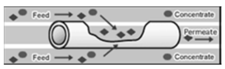
Outside-In Filtration



- 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

Components of Membrane Plant

1. Raw water source
   - Most are surface water
2. Raw water pump
   - Diverts water from the source into the treatment units
3. Pretreatment facility
   - Consists of chemical pretreatment processes to remove turbidity
4. Membrane filters
   - Remove particles, sediment, algae, bacteria and viruses
5. Backwashing
   - Based on three possible conditions:
     - time, flow, TMP

Components of Membrane Plant

6. Backwash water treatment
   - Water from backwash requires treatment prior to discharge
7. Clean-in-place membrane regeneration system
   - Uses aggressive chemicals to regenerate membranes
8. Chemical feed systems
   - Disinfectants, CIP, corrosion control
9. CT chamber
   - Provides required contact time for disinfection
10. Clear well
   - Provides storage prior to distribution

Components of Membrane Plant

11. Treated water pump station
    - Pumps treated water to distribution system
12. Standby engine generator
    - To provide power in the event of a power failure

Troubleshooting

Problem	Cause	Corrective Action
Air compressor failure	• Mechanical failure inside unit • Belt failure • Oil pump leak	• Rebuild failed compressor • Replace belt • Repair leak • Use portable air compressor
Raw water pump station failure	• Electronic failure of the uninterrupted power supply (UPS)	• Bypass UPS • Conduct routine monthly checks of all plant UPS units
Computer lockup	• Central SCADA computer failure	• Operate plant with only local control over plant operation • Hire an outside contractor to bring computer back to normal operating conditions

Recordkeeping

- Water quality monitoring data
  - Turbidity and chlorine residual monitored continuously
- Water production data
  - Water levels, flow rates, hours of operations, and quality of water produced
- Maintenance information & tasks performed
- Calibration dates & procedures
- Cleaning dates & procedures
- Testing methods
- SDSs

Recordkeeping

- Membrane filter maintenance and inspection
  - Transmembrane pressure
  - Filtration production by skid
  - Backwash occurrence
  - Membrane integrity testing using pressure decay testing
  - Membrane sonic testing
  - Membrane repair testing and fiber repairs

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Reductions in Membrane Productivity

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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

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- 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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Membrane Fouling

- The cause of a loss of flow as a result of material being retained on the surface of the membrane or within its pores
- Reversible or irreversible
  - If reversible, flow may be recovered by backwashing and cleaning
- Material causing the fouling
  - Inorganic matter
  - Dissolved organic matter
  - Natural organic matter (most common)
- Means of the fouling
  - Pore adsorption, pore blocking or cake formation

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Inorganic Fouling

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- 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

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- 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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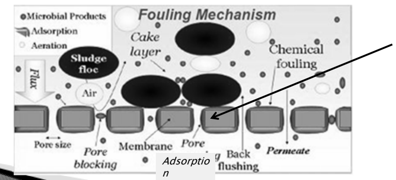
Fouling

- **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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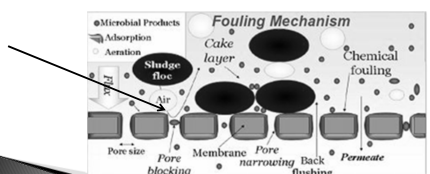
Fouling

- **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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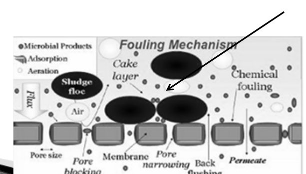
Fouling

- **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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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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RO Plant Operation

- Check cartridge filters
  - Should be replaced when head loss gets too high or effluent turbidity exceeds 1NTU
- Start up and check scale inhibitor feeding equipment
  - Use **sodium hexametaphosphate** as scale inhibitor
- Start chlorine feed if used to prevent biological fouling
- Start up and adjust acid feed system to keep feed water pH between 5 & 6
  - Protects membranes from damage due to hydrolysis

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RO Plant Operation

- Ensure system's automatic controls are set to proper parameters
- Adjust permeate and concentrate flow
- Check differential pressure across membrane unit
- Monitor performance
  - Flow measurements, product water quality, and various pressure indications

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Operations

Membrane Filtration	Conventional 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	• 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	Conventional 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.	• 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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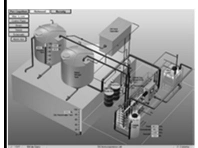
Operations



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

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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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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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Post Treatment

- Disinfection: required by State and Federal Regulations
- Optional additions:
  - Fluoridation
  - Corrosion Control

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 35-40ºC can enhance cleaning effectiveness

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

Integrity Testing

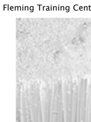
There are several methods that can be used to monitor membrane integrity including:

- 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

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

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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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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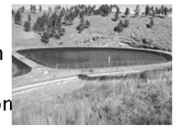
Process Residuals

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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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.

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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.

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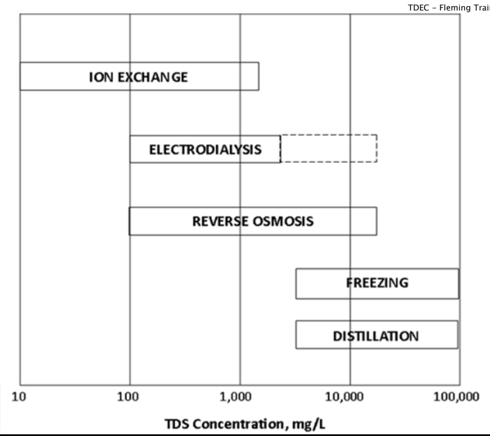
Troubleshooting

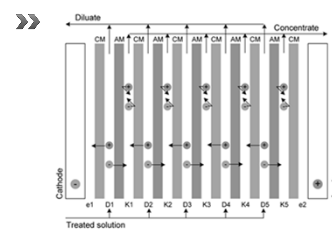
Condition	Ideas to consider
CIP does not return unit to baseline	Check normalized clean water resistance and permeability values
	Evaluate CIP procedure, more aggressive cleaning may be needed (higher temp, stronger chemical concentration if compatible with membrane)
	Consider changing the order of chemicals (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

Demineralization

- Process that removes dissolved minerals (salts) from water
  - Primarily used to remove dissolved inorganic materials (TDS)
- Two classes
  - Phase change, i.e. freezing or distillation
  - Non-phase change, i.e. reverse osmosis, electrodialysis, and ion exchange
- Water industry mainly uses non-phase change method



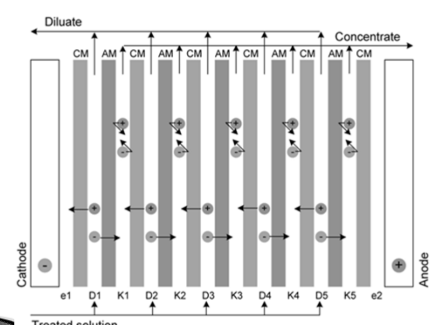
Electrodialysis



Electrodialysis (ED)

- Water flows between alternating cation-permeable and anion-permeable membranes
- Membranes assembled into stacks
- Spacers contain the water streams and direct the flow across the membranes faces
- Several hundred membranes and their spacers between a set of electrodes form a membrane stack

Electrodialysis (ED)



Electrodialysis (ED)

- Occurs in 10-20 seconds
- Percent mineral removal depends on
  - Water temperature
  - Type and amount of ions present
  - Water flow rate
  - Stack design
- 25-40% removal
- 1-6 stacks/stages
- Operates at temperatures up to 110ºF
  - Efficiency increases as temperature increases

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Electrodialysis (ED)

- Advantages
  - Well developed technology
  - Efficient removal of most inorganics
  - Waste brine contains only salts plus a small amount of acid used for pH control
- Most common problem is scaling (fouling) by organic and inorganic material damaging or destroying membranes
  - Feed acid to the concentrate to keep the Langelier Index negative

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Electrodialysis Reversal (EDR)

- System reverses DC current direction and flow path of dilution and concentrating streams every 15 minutes
- Electrodes reverse by switching polarity of cathodes and anodes
- Stream flow paths exchange source every 15 minutes
- This makes it possible to prevent scale formation on membranes without additional chemicals

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Principles of Electrodialysis

- Ion – charged molecule
- Anion – negatively charged ion
- Cation – positively charged ion
- Anode – positive electrode
- Cathode – negative electrode

Remember:	Opposites attract Likes repel

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Principles of Electrodialysis

- Using the properties of ions to purify water
  - Cations will move toward cathode and anions will move toward anode
  - Install proper barriers and isolate a purified zone
- Place these "barriers" into a solution to form three compartments to demineralize the central compartment
- Two types of membranes
  - Cation-permeable membranes
    - Permit only the passage of cations
  - Anion-permeable membranes
    - Permit only the passage of anions

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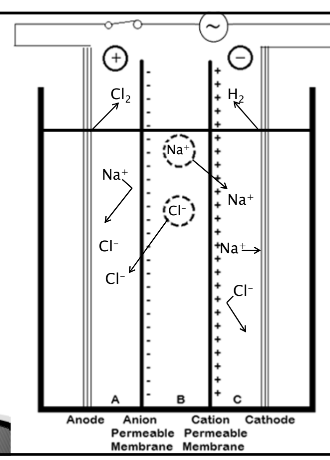

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Process

- 1. Na^+ from compartment A cannot pass through anion-permeable membrane (2) into compartment (B)
- 2. Cl^- from compartment A reacts at the anode (1) to give off chlorine gas
- 3. Na^+ from compartment B passes through cation-permeable membrane (3) into compartment C
- 4. Cl^- from compartment B passes through anion-permeable membrane (2) into compartment A

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Process

- 5. Na^+ from compartment C reacts at the cathode to give off hydrogen gas and hydroxyl ions (OH^-)
- 6. Cl^- from compartment C cannot pass through the cation-permeable membrane (3) into compartment B
- End result: demineralized central compartment

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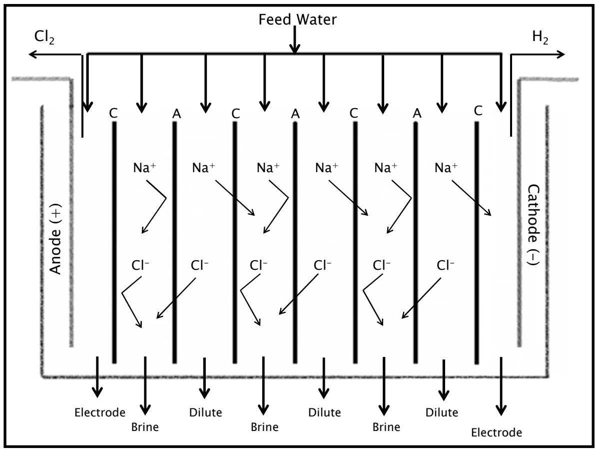

Multicompartment Unit

- A = anion-permeable principle
- C = cation-permeable principle
- Ions will move from compartments bounded by an anion-permeable membrane on the left and a cation-permeable membrane on the right into the adjacent compartment
- Compartments losing salt are "dilute"
- Compartments receiving salt are "brine"
- Chlorine gas is evolved at the cathode
- Hydrogen gas is evolved at the anode

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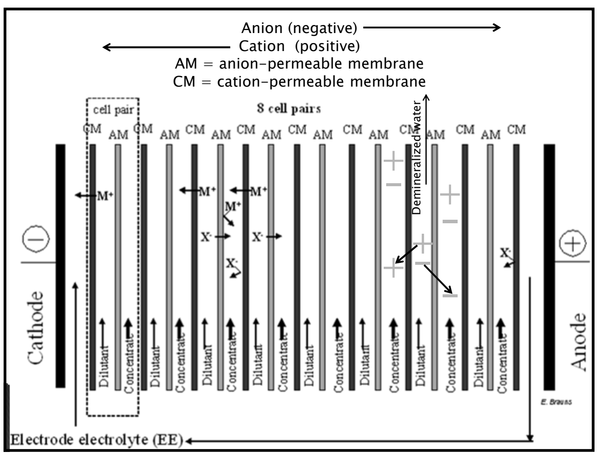

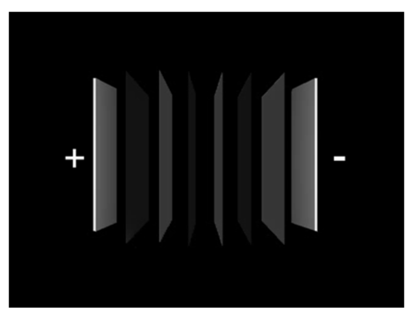

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Parts of an ED Unit

- Pretreatment
  - Includes removal of suspended or dissolved solids, iron, manganese, or chlorine residual
  - Can be accomplished with cartridge filter
- Pumping equipment
  - Use only for circulation through stack
  - 50-75 psi
- DC power supply
  - AC is converted by rectifier to DC which is applied to electrodes
  - Control module reverses current every 15-30 minutes

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Parts of an ED Unit

- Membrane stack
  - Comprised of many stacked pieces: half are membranes, half are spacers that alternate
  - 2 membranes or 2 spacers should never occur together
  - 1 stack = 1 demineralization stage
  - Cell pairs consist of one anion-permeable membrane, one cation-permeable membrane, and two intermembrane spacers
- Chemical flush system
  - 5% HCl (hydrochloric acid) and 5% salt solution that has caustic soda added are used to periodically flush membrane stack in a CIP process

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Feedwater

- If iron concentration > 0.3 mg/L, needs to be removed by pretreatment
- Should be free of bacteria to prevent biological membrane fouling
- Control of pH important due to corrosion control in piping and plumbing equipment
- Cannot contain <u>any</u> chlorine residual
  - If prechlorinate, water must be dechlorinated before ED unit

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Feedwater

- Do not operate ED unit if feed water contains any of the following:
  - Chlorine residual of any concentration
  - Hydrogen sulfide of any concentration
  - Calgon or other hexametaphosphates in excess of 10 mg/L
  - Manganese in excess of 0.1 mg/L
  - Iron in excess of 0.3 mg/L

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Maintenance

- Daily
  - Fill out log sheet
  - Verify that electrodes are bumping and flowing properly
  - Inspect stacks for excess external leakage
    - Greater than 10 gal/hr/stack
  - Check pressure drop across the cartridge filter and change the cartridges whenever the pressure drop reaches 10 psi
- Weekly
  - Voltage probe the membrane stacks
  - Check the oil level on pumps fitted with automatic oilers
  - Inspect all piping and skid components for leaks
  - Twice per week, measure all electrode waste flows

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Membrane Filtration Vocabulary

Asymmetric – Having a varying consistency throughout (e.g. a membrane that varies in density or porosity across its structure).

Backpulse – A very short-duration backwash.

Backwash – The intermittent waste stream from a microfiltration or ultrafiltration membrane system; also, a term for a cleaning operation that typically involves periodic reverse flow of clean water and/or air from the filtrate aide to the feed side to remove foulants accumulated at the membrane surface.

Bank – A group of pressure vessels that share common valving and that can be isolated as a group for testing, cleaning, or repair; synonymous with the terms train, skid, rack and membrane unit.

Biofouling – Membrane fouling that is attributed to the deposition and growth of microorganisms on the membrane surface and/or the adsorptive fouling of secretions of microorganisms.

Bleed – The continuous waste stream from a microfiltration or ultrafiltration system operated in a crossflow mode (synonymous with the terms reject and concentrate).

Cartridge – A type of module consisting of a disposable backwashable or nonbackwashable filter element contained in an external casing.

Chemical Cleaning (also, Clean-In-Place or CIP) – The periodic application of a chemical solution (or series of solutions) to a membrane unit for the intended purpose of removing accumulated foulants and thus restoring permeability and resistance to baseline levels; a commonly used term for in situ chemical cleaning.

Crossflow – The application of water at high velocity tangential to the surface of a membrane to maintain contaminants in suspension.

Differential Pressure – A pressure drop across a membrane module or unit form the feed inlet to concentrate outlet.

Fiber – A single hollow fiber or hollow fine fiber.

Filtrate – The water produced from a filtration process.

Flux – The throughput of a pressure-driven membrane filtration system, expressed as flow per unit of membrane area.

Foulant – Any substance that causes fouling.

Fouling – The gradual accumulation of contaminants on a membrane surface or within a porous membrane structure that inhibits the passage of water, therefore decreasing productivity.

Hydrophilic – The water-attracting property of membrane material.

Hydrophobic – The water-repelling property of membrane material.

Inside-out – A flow pattern associated with hollow fiber membranes in which the feedwater enters the inside of the fiber and is filtered as it passes through the lumen wall to the outside of the fiber.

Log Removal – The filtration removal efficiency for a target organisms, particulate, or surrogate expresses as $\log_{10}$.

Lumen – The center or bore of a hollow fiber membrane.

Microfiltration (MF) – A pressure-driven membrane filtration process that typically employs hollow fiber membranes with a pore size range of approximately 0.10 – 0.5 µm.

Nanofiltration (NF) – A pressure-driven membrane separation process that employs the principles of reverse osmosis to remove dissolved contaminants from water; typically applied for membrane softening or the removal of dissolved organic contaminants.

Outside-In – A flow pattern associated with hollow fiber membranes in which the feedwater is filtered through the lumen wall as it passes from the outside of the fiber to the inside where the filtrate is collected.

Reverse Osmosis (RO) – The reverse of the natural osmosis process, i.e. the passage of a solvent (e.g. water) through a semipermeable membrane from a solution of higher concentration to a solution of lower concentration against the concentration gradient, achieved by applying pressure greater than the osmotic pressure to the more concentrated solution; also, the pressure-driven membrane separation process that employs the principles of RO to remove dissolved contaminants from water.

Scaling – The precipitation or crystallization of salts on a surface (e.g. on the feed side of a membrane).

Ultrafiltration (UF) – A pressure-driven membrane filtration process that typically employs hollow fiber membranes with a pore size range of approximately 0.01-0.05 µm.

Membrane Vocabulary

A. atm
B. Colloids
C. Conductance
D. Cross-flow filtration
E. Dead-end filtration
F. Demineralization
G. Disinfection by-product
H. Dissolved organic carbon
I. Dissolved organic matter
J. Enzymes
K. Feedwater
L. Flux
M. Fulvic acid
N. Humic substances
O. Hydrolysis
P. Material Safety Data Sheets
Q. Membrane fouling
R. Microfiltration
S. Nanofiltration
T. Natural organic matter
U. Osmosis
V. Permeate
W. Reverse osmosis
X. SCADA
Y. Salinity
Z. Sequestration
AA. Total dissolved solids
BB. Ultrafiltration

_____ 1. Natural organic matter resulting from partial decomposition of plant or animal matter and forming the organic portion of soil.

_____ 2. Humic substances composed of humic and fulvic acids that come from decayed vegetation.

_____ 3. A type of membrane filtration where the water being filtered flows across the surface of the membrane to keep the particle buildup and fouling to a minimum.

_____ 4. The relative concentration of dissolved salts, usually sodium chloride, in water.

_____ 5. That portion of the organic matter in water that passes through a 0.45 μm pore-diameter filter.

_____ 6. A chemical complexing of metallic cations with certain inorganic compounds.

_____ 7. A pressure-driven membrane filtration process that separates particles down to approximately 0.1 μm diameter from influent water using a sieving process.

_____ 8. A flowing or flow.

_____ 9. A contaminant formed by the reaction of disinfection chemicals with other substances in the water being disinfected.

_____ 10. A rapid method of estimating the dissolved solids content of a water supply. Indicates capacity of sample to carry an electric current.

_____ 11. A pressure-driven membrane filtration process that separates particles down to approximately 0.01 μm diameter from influent water using a sieving process.

_____ 12. A type of membrane filtration where the water being filtered flows through the membrane, but there is no wastestream from the system.

_____ 13. Very small, finely divided solids that remain dispersed in a liquid for a long time due to their small size and electrical charge.

_____ 14. All of the dissolved solids in water.

_____ 15. To penetrate and pass through, as water penetrates and passes through soil and other porous materials.

_____ 16. A complex organic compound that can be derived from either soil or water.

_____ 17. The application of pressure to a concentrated solution, which causes the passage of a liquid from the concentrated solution to a weaker solution across a semipermeable membrane.

_____ 18. Organic or biochemical substances that cause or speed up chemical reactions.

_____ 19. A treatment process that removes dissolved minerals (salts) from water.

_____ 20. Supervisory Control And Data Acquisition system.

_____ 21. The cause of a loss of flow through a membrane as a result of material being retained on the surface of the membrane or within the membrane pores.

_____ 22. The water that is fed to a treatment process; the water that is going to be treated.

_____ 23. That portion of the organic carbon in water that passes through a 0.45 µm pore-diameter filter.

_____ 24. The passage of a liquid from a weak solution to a more concentrated solution across a semipermeable membrane.

_____ 25. A chemical reaction in which a compound is converted into another compound by taking up water.

_____ 26. The abbreviate for atmosphere. One atmosphere is equal to 14.7 psi or 100 kPa.

_____ 27. A document that provides pertinent information and a profile of a particular hazardous substance or mixture.

_____ 28. A pressure-driven membrane filtration process that separates particles down to approximately 0.002 to 0.005 µm diameter from influent water using a sieving process.

Answers

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

Section 4

Iron & Manganese

Iron and Manganese

TENNESSEE DEPARTMENT OF ENVIRONMENT AND CONSERVATION

Limits

- No MCL, only sMCL
  - No health hazard, just aesthetic
- Iron
  - sMCL = 0.3 mg/L
- Manganese
  - sMCL = 0.05 mg/L
  - If levels > 0.02 mg/L, initiate flushing program

Iron Bacteria

- Bacteria oxidizes the ferrous ion (Fe^{2+}) and manganous ion (Mn^{2+}) and reduce carbon dioxide to form an organic slime
- Form thick slimes (**ferric hydroxide**) on water mains
  - Rust colored -- iron
  - Black – manganese
  - **Gallionella – iron bacteria**
- Variations in flow loosens slimes and cause dirty water and tastes & odors complaints
- Controlled by chlorination
- Only one cell of iron bacteria is needed to start an infestation in a well or distribution system

Occurrence of Fe and Mn

- React with dissolved oxygen to form insoluble compounds
  - Solids that cannot be dissolved
- Surface waters are generally free from both
  - Exception: Mn up to 1 mg/L or higher may be found in shallow reservoirs and may come and go several times a year
- Most commonly found in groundwater systems
- Iron bacteria found everywhere
  - Anywhere there is a combination of dissolved oxygen and dissolved iron

Sampling for Iron and Manganese

- Best place to look is household plumbing fixtures
  - Staining of plumbing fixtures indicates high levels of Fe & Mn
- Samples are difficult to collect
  - Particles of scale are dislodged when opening tap will enter sample
  - Scale can form on inside of sample bottle and be left behind when sample is poured out (acidification will prevent this)
- Collect samples from a plastic sample line located as close to the source (i.e. well) as possible
  - Open tap slowly
  - Allow water to flow 1 minute for each 10 feet of sample line
- Test sample within 48 hours
  - If holding time will be longer, preserve sample with nitric acid
  - If visible rust or clay in sample, test sample right away
    - Acidifying the sample will dissolve the iron and give high results

Analysis of Iron and Manganese

- Atomic absorption
  - Preferred method but expensive
- Colorimetric
  - Sufficiently accurate in most circumstances
  - Use either a spectrophotometer, a filter photometer, or a set of matched Nessler tubes with standards

Analysis of Total Iron (CSUS)

- Colorimetric test procedure
  - 1. Measure 50 mL of sample into flask
  - 2. Add 2 mL concentrated HCl and 1 mL hydroxylamine solution
  - 3. Heat to boiling
    - Boil until volume is reduced to 20 mL
    - Cool to room temperature.
  - 4. Transfer into 100 mL flask
  - 5. Add 10 mL acetate buffer and 2 mL phenanthroline solution
    - Dilute to 100 mL
  - 6. Measure absorbance at 510 nm with spectrophotometer

Analysis of Manganese (CSUS)

- Colorimetric test procedure
  - 1. Measure 100 mL of sample into flask
    - Flash should be marked at the 90 mL level
  - 2. Add 5 mL of special reagent and 1 drop H_2O_2
  - 3. Concentrate to 90 mL by boiling
    - Add 1 gram ammonium persulfate
    - Cool immediately under water tap
  - 4. Dilute to 100 mL
  - 5. Measure the absorbance at 525 nm with a spectrophotometer

Analysis of Total Iron (Hach)

- Colorimetric test procedure
  - 1. Fill sample cell with 10 mL of sample
  - 2. Add 2 FerroVer Iron Reagent Powder Pillow to the sample cell
    - Swirl to mix
  - 3. Let sit for 3 minute reaction time
    - If iron is present, sample will turn orange
    - If sample contains rust, let sit for 5 minutes
  - 4. Zero instrument with blank
  - 5. Read results given by spectrophotometer at 510 nm
- Summary of method:
  - FerroVer Iron converts all soluble iron and most insoluble iron in the sample to soluble ferrous iron. The ferrous iron reacts with the phenanthroline indicator in the reagent to form an orange color in proportion to the iron concentration.

Analysis of Manganese (Hach)

- Colorimetric test procedure
  - 1. Pour 10 mL of sample into sample cell
  - 2. Add contents of one Ascorbic Acid Powder Pillow to each cell
  - 3. Stopper and invert cell to dissolve the powder
  - 4. Add 12 drops of Alkaline-Cyanide Reagent Solution
    - Swirl to mix
  - 5. Add 12 drops of PAN Indicator Solution, 0.1%
    - Swirl to mix
    - An orange color will appear if manganese is present
  - 6. Let sit for 2 minute reaction time
  - 7. Read results given by spectrophotometer at 560 nm
- 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 Mn2+. An alkaline-cyanide reagent is added to mask any potential interferences. PAN Indicator is then added to combine with the Mn2+ to form an orange colored complex.

Analysis of Iron and Manganese

Iron

- Hach's method has a detection range of 0.02 - 3.0 mg/L
- Three minute reaction period needs to take place before reading

Manganese

- 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)

Phosphate Treatment

- Can be used if Mn < 0.3 mg/L and Fe < 0.1 mg/L
- Three types of polyphosphates
  - Pyrophosphate
  - Tripolyphosphate
  - Metaphosphate
- Polyphosphate delays precipitation of oxidized Mn to minimize scale build up on pipe walls
- Chlorine must be fed too to prevent the growth of iron bacteria
- Treatment most effective when added upstream of chlorine
- Never feed chlorine upstream of polyphosphate because it will oxidize the Fe and Mn and form insoluble precipitates too soon
- Solutions with > 60mg/L may be very viscous (thick)
- Do not use a solution over 48 hours old
  - Polyphosphates react with water to form orthophosphates which are not as effective

Remedial Action – Alternate Source

- Cost of iron and removal plant will be same as or more than drilling a new well
- Investigate alternate source of water free of iron and manganese
  - Sample nearby private wells
  - Talk to well drillers in the area
  - Talk with state engineers and regulators

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Removal by Ion Exchange

- If no dissolved oxygen is present, iron and manganese can be removed while softening
- If water to be treated contains any dissolved oxygen, rust and insoluble manganese dioxide will form, fouling the resin
- Advantage – plant requires little attention
- Disadvantages – danger of fouling resin and high initial cost
- Operate as close to design flows as possible
- Monitor treated water on a daily basis
  - If Fe and Mn start to appear in treated water, it is time to regenerate the resin
    - Make a brine of 0.01 lb of sodium bisulfite per gallon

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Oxidation by Aeration

- Iron and manganese can be oxidized to insoluble form by aeration
  - Mn oxidation by aeration is very slow and therefore rarely done
- Must maintain flow
  - Too high – not enough reaction time
- Reaction basin follows aeration
  - Allows time for oxidation reaction to take place
  - Minimum amount of detention time is 20 minutes (Design Criteria 4.7.1(b))
- After reaction, insoluble iron (ferric hydroxide) is removed by sedimentation or filtration
  - Maximum filtration rate is 3 gpm/ft^2 (Design Criteria 4.7.1 (c))

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Oxidation by Aeration

- Reaction time

↑ pH	↓ Time
↓ organic substances	↑ Time
↓ temperature	↑ Time

- Advantage – no chemicals required
- Disadvantages – small changes in raw water may affect the pH soluble organics level and slow the oxidation rates
  - This can reduce the plant capacity

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Oxidation with Chlorine

- Chlorine will oxidize both iron and manganese into an insoluble form
- The higher the residual, the faster the reaction time
- Treatment process
  - Raise residual up to high levels
  - Filter out insoluble particles
  - Lower chlorine level with dechlorinating agent
- Do not use this method on water with high organics
- Be sure not to add too much dechlorinating agent and bring the residual too low

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Oxidation with Permanganate

- Dose must be exact
  - Too little – Mn will not oxidize
  - Too much – pink water goes to distribution system
- Often used in the form of Zeolite or a manganese greensand filter
- Manganese greensand filters can operate in three modes
  - **Continuous regeneration (CR)**
  - **Intermittent regeneration (IR)**
  - **Catalytic regeneration**

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Mn Greensand Operational Modes

- Continuous Regeneration (CR)
  - Used for waters with iron up to 15 mg/L
  - Requires frequent backwashing
  - Chlorine and potassium permanganate are added ahead of the manganese greensand bed
    - Chlorine is added first to oxides most of the iron
    - Permanganate is then added to oxidize the remaining iron and soluble manganese
  - As the water passes through the greensand bed, the insoluble iron oxide particles are filtered out and any remaining permanganate is reduced to manganese oxide
  - The manganese oxide attaches to the greensand, thereby continuously regenerating the greensand

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Mn Greensand Operational Modes

- Intermittent Regeneration (IR)
  - Suitable for water containing only or mostly manganese with small amounts of iron
  - The manganese and some iron in the raw water oxidizes directly only the grains of greensand
    - If iron concentrations are too high, insoluble iron oxides will quickly foul the media
    - To prevent this, oxidize iron before it enters the bed
  - Bed must be regenerated due to oxidation capacity being used up
  - Backflow a dilute potassium permanganate solution through the bed using 1.5 oz $KMnO_4$ per cubic ft of media followed by rinsing

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Mn Greensand Operational Modes

- Catalytic Regeneration
  - Suitable for water with iron and manganese concentrations < 1.0 mg/L and the pH > 7.0
  - Chlorine is added before the filter to a residual of 0.5 to 1.0 mg/L
    - Keeps the greensand continuously regenerated
  - Advantages
    - Filter run lengths are longer than other modes
    - Higher filtration rates
    - Backwash waste suspended solids are low
    - Chemical operating costs minimal
      - Only chlorine

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TENNESSEE DEPARTMENT OF ENVIRONMENT AND CONSERVATION

Manganese Greensand Filters

California State University, Sacramento

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Iron and Manganese

- Caused by water being in contact with soil and rocks and dissolving the iron and manganese
  - More prevalent in groundwater
- Iron
  - Symbolized by Fe
  - sMCL = 0.3 mg/L
- Manganese
  - Symbolized by Mn
  - sMCL = 0.05 mg/L

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Fe and Mn Treatment

- Chemical treatment
- Ion Exchange
- Oxidation to insoluble forms followed by filtration
  - Aeration
  - Chlorine
  - Permanganate

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Conventional vs Manganese Greensand

- Greensand is finer than filter sand
- Filtration rate is slower
  - 2-5 gpm/ft^2
- Backwash rate is lower
  - 12 gpm/ft^2 for greensand vs. 15 gpm/ft^2 for conventional
- Manganese greensand filter can remove up to 95% of both Fe and Mn

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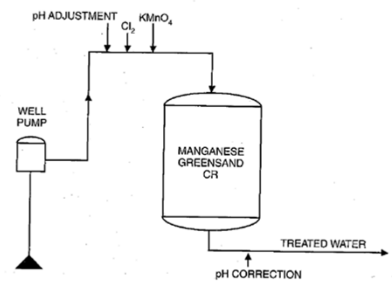

Fig. 12.5 Typical flow diagram of a continuous regeneration (CR) greensand process
(Permission of Hungerford & Terry, Inc.)

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Equipment

- Filter with special filtering media
  - Greensand
  - Anthracite coal
    - Minimum of 6 inches - Design Criteria 4.7.3 (c)
- Continuous potassium permanganate fed prior to filter
- Filter must be able to be backwashed with air
- Filter must be able to be backwashed with permanganate solution for regeneration
- Various sampling points on either side of filter

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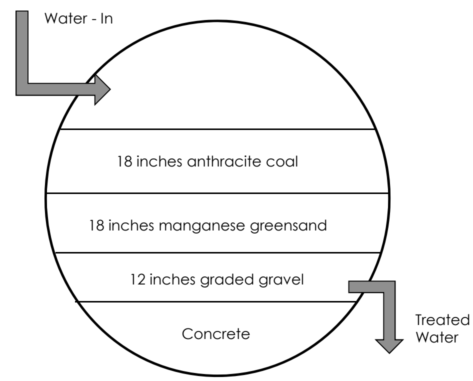

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Restrictions

- Maximum Fe concentration = 10 mg/L
- Maximum Mn concentrations = 5 mg/L
- Minimum pH = 6.2
  - For continuously regenerated (CR) manganese greensand process
- Sufficient detention time
  - Must give enough time for chemicals to react

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Backwashing

- Filter must be backwashed to remove filtered particulates
  - When head loss reaches 10 psi

    or
  - After treating a predetermined number of gallons
- Air wash is used for plants with high levels of manganese
  - Helps separate grains from the sticky manganese hydroxide oxidation products
  - Agitation keeps filter media in a free, loose, fluid condition

Regeneration

2 methods to regenerate greensand

- 1. Shut down and pour 5% potassium permanganate solution into the filters. Let sit for 24 hours. Back wash filters to flush excess KMnO4

Regeneration

- 2. Increase KMnO4 dosage until pink water flows out of greensand media. Then decrease KMnO4 until water is a slight pink color before the filter. If there is still pink water after filtration, keep decreasing KMnO4 dose until no pink water is present in the filtrate.
- Pink color is the best indicator that the greensand is regenerated or recharged
- Be careful not to lower the permanganate level too far
  - too little permanganate will allow iron and manganese to enter the distribution system

Continuous Regeneration

- Feed potassium permanganate prior to Mn greensand filter
- Permanganate will be reduced to manganese oxide
- Manganese oxides precipitate onto the greensand grains
- Continuous regeneration is achieved

Problem	Cause	Solution
Filter effluent clear, iron low, manganese higher than raw water	Manganese being leached from greensand grains	Increase frequency of regeneration
	Bed insufficiently regenerated	Regenerate bed with 0.5 oz/ft^3 of $KMnO_4$ Make sure proper influent chemicals are being continuously fed

Problem	Cause	Solution
Filter effluent turbid with yellow to brownish color. Iron and manganese high.	Too much alkali being fed ahead of filter.	Reduce alkali feed. Keep influent pH 6.2-6.5.
	Polyphosphate being fed ahead of filter.	Discontinue polyphosphate feed. Check bed for mounds, pockets and channeling. Back wash.
	Iron organically bound: reactions with oxidizing agent produce a non-filterable colloid.	Feed alum or other coagulant prior to filter.

Problem	Cause	Solution
Excessive pressure drop across bed immediately after backwashing.	Accumulation of greensand fines at surface of bed.	Scrape after backwashing, or if necessary replace bed.
	Backwash rate too low.	Increase backwash rate to 10-12 gpm/ft^2.
	Filter bed cemented.	Break up cemented areas with air-water wash combination.
	Well throwing fine sand, silt, and colloidal clay.	Check well supply after pump start up. Allow well to pump overboard at start of pumping cycle.

Continuous Regeneration/Intermittent Regeneration systems 37 TDEC - Fleming Training Center

Problem	Cause	Solution
On multiple unit installation, water quality good on some units, bad on others.	Unequal distribution of pre-feed chemicals.	Inject chemical at a point where thorough mixing of chemicals with raw water occurs before diversion to the various filters

Continuous Regeneration systems 38 TDEC - Fleming Training Center

Problem	Cause	Solution
Iron breakthrough before recommended maximum change of pressure of 10 psi is reached.	Some iron waters filter in depth and do not build up head loss.	Backwash should be initiated by total number of gallons treated rather than by head loss. Use ΔP as a back up to prevent exceeding ΔP of 10 psi.
Faint pink color in filter effluent.	Permanganate feed rate is too high.	Operate filter 1-2 hours with $KMnO_4$ feed off. Then reset feeder at slightly lower setting.

Intermittent Regeneration systems 39 TDEC - Fleming Training Center

Problem	Cause	Solution
Low capacity.	Manganese oxide coating stripped from greensand grains due to insufficient regeneration. May be especially troublesome with high sulfide waters.	Increase frequency of regeneration. Pre-feed Cl_2 with sulfide waters. Replace bed if required.
	Manganese greensand heavily iron-fouled.	Use CR method with dual-media anthracite/manganese greensand bed to prevent iron fouling.
	Excessive grain growth due to high manganese oxide buildup.	Increase frequency of regeneration. Bed replacement may eventually be required.

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Daily Testing

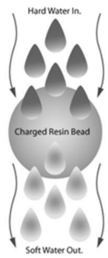
- Iron and manganese
  - Indicates that plant is operating at a level that meet state water quality requirements
- pH
  - Important due to relation between pH and corrosivity of the water
  - Needs to stay between 6.2 and 6.8 for effective Fe and Mn removal by the CR process
- Chlorine residual

Section 5

Softening

SOFTENING

California State University: Sacramento
Water Treatment Plant Operation Vol. II



WHAT MAKES WATER HARD

- *Caused by divalent metallic cations*
- *Cations react with*
  - *Soap to form precipitates*
  - *Anions in water to form scale*
- *Caused by certain hardness causing ions:*
  - *Calcium* } Main hardness causing ions
  - *Magnesium* }
  - *Strontium*
  - *Iron*
  - *Manganese*
- *Hardness is an expression of the concentration of calcium and magnesium ions*

WHAT MAKES WATER HARD

- *Caused mainly by the salts of calcium and magnesium*
  - *Bicarbonate*
  - *Carbonate*
  - *Sulfate*
  - *Chloride*
  - *Nitrate*
- *These anionic salts combine with the cations (Ca & Mg) to cause water hardness*
- *Excessive hardness causes increased use of soap, scale formation in boilers, and can cause objectionable tastes*

HARDNESS LEVELS

Description	Hardness in terms of mg/L as calcium carbonate
Extremely soft to soft	0 - 45
Soft to moderately soft	46 - 90
Moderately hard to hard	91 - 130
Hard to very hard	131 - 170
Very hard to excessively hard	171 - 250
Too hard for domestic use	Over 250

WHAT MAKES WATER HARD

- *Calcium*
  - *caused by calcium ions (Ca^{2+})*
- *Magnesium*
  - *caused by magnesium ions (Mg^{2+})*
- *Total hardness*
  - *sum of calcium and magnesium*
  - *Total hardness = Ca hardness + Mg hardness*

WHAT MAKES WATER HARD

- *<u>Carbonate</u> – caused by alkalinity present in water up to the total hardness*
  - *Usually less than total hardness*
  - *Aka Temporary hardness*
    - *Can be removed by the use of lime only*
    - *Can be settled out by heat*
- *<u>Noncarbonate</u> – that portion of total hardness in excess of the alkalinity*
  - *Aka permanent hardness*
    - *Requires both lime and soda ash to remove*
    - *Cannot be removed or precipitated by heat*

WHAT MAKES WATER HARD

- *Alkalinity – the capacity of water to neutralize acids*
  - *Caused by water's content of carbonate, bicarbonate, and hydroxide*
  - *Occasionally borate, silicate, and phosphate*
  - *Expressed in mg/L of equivalent $CaCO_3$*
- *Calcium carbonate equivalent – expression of the concentration of specified constituents in water in terms of their equivalent value to calcium carbonate*

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WHY SOFTEN WATER

- *Benefits*
  - *Removal of iron and manganese*
  - *Control of corrosion when proper stabilization of water is achieved*
  - *Disinfection due to high pH values when using lime*
  - *Sometimes a reduction in tastes and odors*
  - *Reduction of some total solids content by the lime treatment process*
  - *Removal of radioactivity*

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WHY SOFTEN WATER

- *Limitations*
  - *Free chlorine residual is predominantly hypochlorite at pH > 7.5 and is a less powerful disinfectant*
  - *Costs and benefits must be carefully weighed*
  - *Ultimate disposal of process wastes*
  - *THMs in treated water may increase*
  - *Production of "aggressive" water that can corrode distribution piping.*

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CHEMISTRY OF SOFTENING

- *Hardness is measured using titration*
- *Amount of carbonate and noncarbonate hardness depends on water alkalinity*
  - *If alkalinity > total hardness, all hardness is carbonate hardness*

    Carbonate hardness = Total hardness
  - *If total hardness > alkalinity, the alkalinity is carbonate hardness*
    - *Difference b/w total hardness and alkalinity is noncarbonate hardness*

    Carbonate hardness = alkalinity

    Noncarbonate hardness = Total hardness - alkalinity

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HOW WATER IS SOFTENED

- *Methods*
  - *Chemical precipitation*
    - *Cannot remove all hardness*
    - *If treating water with 150 mg/L or more, hardness will be reduced to 80-90 mg/L*
    - *Lowest achievable level = 30-40 mg/L $CaCO_3$*
  - *Ion exchange*
    - *Can remove all hardness*

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HOW WATER IS SOFTENED

- *Hardness causing ions are converted from soluble to insoluble forms*
- *Ca and Mg become less soluble pH increases*
  - *Can be removed as insoluble precipitates at high pH levels*
- *Addition of lime*
  - *Increases they pH by increasing they hydroxide (OH^-) concentration*
    - *Forms calcium carbonate which precipitates out*
  - *Increases phenolphthalein alkalinity*
    - *Forms magnesium hydroxide which precipitates out*

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HOW WATER IS SOFTENED - LIME

- *Two types of lime:*
  - *Hydrated lime*
    - *Calcium hydroxide - Ca(OH)2*
    - *Slaked lime*
    - *Can be used directly*
  - *Quicklime*
    - *Calcium Oxide – CaO*
    - *Unslaked lime*
    - *Must first be slaked to form Ca(OH)2*
      - *Slake – to mix with water so that a true chemical combination takes place*

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HOW WATER IS SOFTENED - STABILITY

- *Softening chemically changes the water and makes it no longer stable due to pH and alkalinity changes*
- *If magnesium carbonate hardness must be removed, the water will be supersaturated with calcium carbonate and magnesium hydroxide*
  - *Deposition of precipitates will occur in filters and distribution system*
  - *Produces a pH of about 10.9*
  - *Lower the pH to better precipitate calcium carbonate and magnesium hydroxide*
    - *Recarbonation*

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HOW WATER IS SOFTENED - STABILITY

- *Recarbonation will lower the water's pH and alkalinity*
  - *A process in which CO_2 is bubbled into the water being treated to lower the pH*
  - *If done before filtration, buildup of excess lime and calcium carbonate & magnesium hydroxide precipitates in the filter will be minimized*
  - *Care must be taken, because recarbonation can cause the calcium carbonate to become insoluble again and cause carbonate hardness*

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HOW WATER IS SOFTENED – CAUSTIC SODA SOFTENING

- *Can use sodium hydroxide (NaOH aka caustic soda) in place of soda ash*
- *Can remove both carbonate and noncarbonate hardness*
- *Removes carbon dioxide & carbonate hardness and forms sodium carbonate (soda ash) hardness*
  - *These will react to remove the noncarbonate hardness*
- *Rubber gloves, respirator, safety goggles, and a rubber apron must be worn when handling caustic soda*
  - *Strong base that will attack fabrics, leather and burn skin*

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HOW WATER IS SOFTENED - LIME SOFTENING

- *Water having only carbonate hardness can be acceptably softened with lime*
  - *Lime reacts with bicarbonate to form calcium carbonate and magnesium hydroxide*
    - *Converts soluble to insoluble form*
  - *Calcium carbonate will precipitate and settle out at pH > 10*
  - *Magnesium carbonate will react with additional lime at pH > 11 to form magnesium hydroxide*
    - *This will then precipitate out*

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HOW WATER IS SOFTENED - SPLIT LIME TREATMENT

- *A portion of water is treated with an excess amount of lime*
  - *pH > 11 to remove magnesium*
- *Source water is then added in the next basin to neutralize the excess lime treated portion*
  - *Lowers the pH*
- *Magnesium is almost completely removed from dosed portion*
- *Can eliminate need for recarbonation*
- *Softened and unsoftened water mixture tends to recarbonate in the final blend or mix of treated water*

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HOW WATER IS SOFTENED – LIME-SODA ASH SOFTENING

- *Soda ash – sodium carbonate*
- *Required when water contains noncarbonate hardness (permanent hardness)*
- *Increases the carbonate concentration*
- *Non carbonate hardness requires the addition of soda ash*
- *Could be required even if all hardness is calcium hardness*

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HANDLING, APPLICATION, AND STORAGE OF LIME

- *Delivered in bags or in bulk quantity*
- *Never store quicklime near combustible materials*
  - *Will generate heat if gets wet*
- *Storage*
  - *Quicklime: no more than 6, preferably 3 months*
  - *Hydrated lime: no more than 3 months*
- *Applied by dry feeding techniques*
  - *Volumetric*
  - *Gravimetric – more accurate*
- *Protective clothing*
  - *Long sleeve shirt, pants, head protection, gloves*
  - *If contacts skin or eyes, flush immediately and consult a physician*

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STABILITY

- *Natural waters are more or less stable – in chemical balance*
- *Unstable water will be either scale forming or corrosive*
- *Stability can be determined by*
  - *Langelier Index*
  - *Marble test*
  - *Suspending nails on strings in filter*

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STABILITY – MARBLE TEST

- *To run the marble test*
  1. *Collect a sample of tap water that has been softened and stopper the sample bottle*
  2. *To an identical sample, add 1 gram of powdered calcium carbonate. Mix and let stand for 1 hour.*
  3. *Filter both samples*
  4. *Run pH and alkalinity on both samples*
  5. *The goal is to have the sample of softened tap water as nearly matched to the softened sample treated with calcium carbonate*
     - *If pH & alkalinity are higher in softened sample, you are over treating and water is scale forming*
     - *If pH & alkalinity is higher is sample with calcium carbonate, you are under treating*
     - *If similar, the stability is near*

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SLUDGE RECIRCULATION AND DISPOSAL

- *Sludge is formed when calcium and magnesium hardness is converted to insoluble precipitates*
- *Most common method of disposal is landfill*
  - *Dewater sludge with drying bed or by mechanical means*
  - *Haul sludge to landfill sites designed to handle such waste*
- *Other methods*
  - *Sanitary sewer*
  - *Land application*

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ION EXCHANGE SOFTENING

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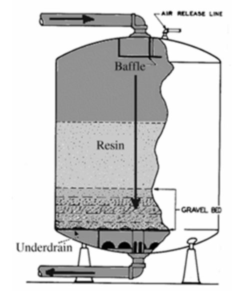
ION EXCHANGE UNITS

- *3 basic types*
  - *Upflow unit*
    - *water enters from bottom and flows up through the ion exchange bed*
  - *Gravity unit*
    - *constructed and operated like a gravity rapid sand filter*
  - *Pressure downflow unit*
    - *most common and similar to typical pressure filter*
- *"Zeolite" considered to mean the same thing as ion exchange*

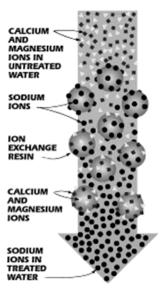
ION EXCHANGE



- *4 stages of operation*
  - *Service*
  - *Backwash*
  - *Brine*
  - *Rinse*

ION EXCHANGE: SERVICE

- *Hard water forced into top of unit and flows down through exchange resin*
- *Calcium and magnesium ions exchange with sodium ions on the resin*
- *Sodium ions are released into the water*

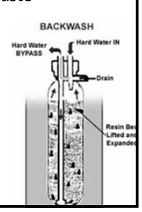


ION EXCHANGE: SERVICE

- *Service life of resin depends on several factors:*
  - *Size of unit*
    - *Units vary is size from a few ft^3 to several hundred ft^3*
  - *Source water hardness*
    - *The harder the water, the more Ca and Mg there is to be removed decreasing the run time of the resin*
  - *Removal capacity of the resin*
    - *Expressed in grains of hardness removal/ft^3*
    - *Capacity ranges 20,000 to 30,000 grains of hardness removal/ft^3*

ION EXCHANGE: BACKWASH

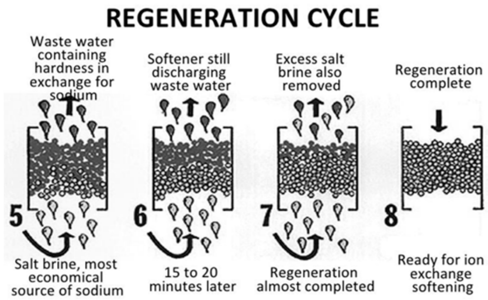
- *Unit is taken out of service and flow is reversed*
- *Expands and cleans the resin particles and removes any iron, manganese or particulates that have accumulated during service*
- *Should be applied at a slow steady rate to avoid causing a surge and washing resin out with the waste*
- *Bed expansion should be 75-100%*
- *A small amount of resin may be lost, but if a steady loss occurs there may be significant problem*



ION EXCHANGE: BRINE

- *Also called regeneration*
- *When resin is exhausted, it can be recharged by pumping a concentrated brine solution through it*
- *Sodium ions in brine exchanged with Ca and Mg ions on resin*
- *Regeneration rate*
  - *1-2 gpm/ft^3 for first 55 minutes*
  - *3-4 gpm/ft^3 for last five minutes of the fast drain*
- *Ideal brine concentration is 10-14% NaCl solution*
- *Salt dosage for preparing brine very important*
  - *5-15 lbs salt/ft^3 of resin*

ION EXCHANGE: BRINE



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ION EXCHANGE: RINSE

- *Apply clear rinse from top of unit to remove brine solution*
- *Flow pattern same as service, but effluent goes to waste*
- *Typically takes 20-40 minutes*
- *If not sufficiently rinsed, water will have a salty taste*

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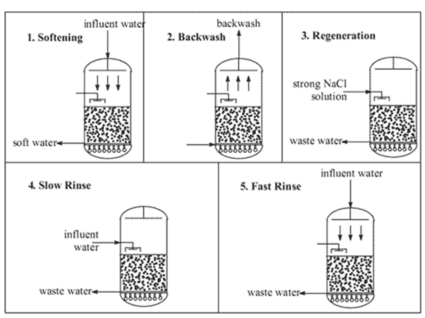
ION EXCHANGE: OPERATIONS



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CONTROL TESTS

- *Softener Influent*
  - *Test for iron and manganese*
    - *Insoluble particles will plug the filter media*
    - *Soluble ionic forms will exchange onto the media and not be completely removed during regeneration*
  - *Monitor source water for hardness*
    - *If hardness increases, resin service time will decrease before regeneration is required*
- *Softener Effluent*
  - *Test hardness at end of regeneration stage*
    - *Indicates if regeneration was done properly*

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IRON AND MANGANESE

- *Seriously reduce the life of the exchange capacity of resin due to iron fouling or the loss of exchange capacity*
- *Softener will remove soluble iron (ferrous) from water*
  - *Resin bed will develop orange/rust appearance*
  - *If resin becomes iron coated, softener efficiency will decrease*
- *Softener will filter (strain) insoluble iron (ferric) from water*
  - *Upper layer can become plugged causing short-circuiting*
  - *Incomplete contact will lead to hardness leakage and loss of softening efficiency*

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BRINE DISPOSAL

- *Waste consists of mostly calcium, magnesium, and sodium chlorides*
  - *Corrosive to metals and can be toxic to environment*
- *Options*
  - *Discharge to sewer*
    - *Wastewater plant must be able to handle this kind of waste*
  - *Discharge to receiving waters*
    - *Must be permitted by TDEC*
  - *Sanitary landfills*
    - *Costs money to dispose*

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MAINTENANCE

- *Constant attention should be given to brine pumps and piping*
- *Pump often made of brass to protect against corrosion*
  - *Impeller should be bronze and the pump shaft stainless steel*
  - *Pump should have strainer or screen on suction side*
    - *Check strainer assembly quite often as rocks, coal, sand and other particles in the salt can clog or destroy a pump impeller*

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MAINTENANCE

- *Use of packing instead of mechanical seals is recommended for brine pumps*
  - *Some sand will typically end up in pump*
  - *Packing is easier to install, cheaper, and will usually out last a mechanical seal in this situation*
- *Brine pump motor should be heavy duty and made of cast iron*
- *Inspect brine solution make up water line*
  - *Provides potable water to salt supply*
  - *PVC is corrosion resistant*
- *Wet salt brine storage tanks must be protected from contamination*

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TROUBLESHOOTING

- *Service Stage*
  - *> 1 gpg hardness signals a problem*
- *Backwash Stage*
  - *Check for adequate flow rates and for sufficient time*
  - *Watch for iron fouling*
    - *If high concentrations of iron have been applied to resin, it will be an orange, rusty color and head loss will increase*
    - *Increase backwash time and provide a surface wash*
    - *Sodium hydrosulfite can be used to remove heavy iron coatings*

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TROUBLESHOOTING

- *Brine Injection Stage*
  - *If hardness leakage early in stage, check amount and saturation of brine solution*
  - *If excessive hardness leakage immediately after regeneration, shut down unit & check media level*
    - *Bed could be disrupted form excessive backwash or rinse rates OR*
    - *Iron fouling may have caused channeling and short-circuiting*
- *Rinse Stage*
  - *Make sure rinse does not start to early (inadequate regeneration)*
  - *Rinse rate too low will not remove all waste material*

40

BLENDING

- *Ion exchange softeners produce water with **zero** hardness*
- *Water with no hardness is very corrosive*
- *Ion exchange softener effluent is mixed with filtered water, that bypassed the softener, having a known hardness concentration (split treatment)*
- *This allows the finished water to have the desired amount of hardness to be sent to the distribution system*

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RECORD KEEPING

- *Flow through the softener each day*
- *Blend rates and gallons that have by-passed the unit*
- *Total gallons of brine used*
- *Pounds of salt used*
- *Tests performed on softeners*
  - *Source water*
  - *Softener effluent*
  - *Blended water*

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Softening Vocabulary

A. Alkalinity
B. Anion
C. Calcium carbonate equivalent
D. Cation
E. Divalent
F. Hard water
G. Hardness
H. Hydrated lime
I. Insoluble
J. Ion
K. Ion exchange
L. Ion exchange resins
M. Methyl orange alkalinity
N. Phenolphthalein alkalinity
O. Precipitate
P. Quicklime
Q. Recarbonation
R. Saturation
S. Slake
T. Supersaturated
U. Titrate

_____ 1. The condition of a liquid when it has taken into solution the maximum possible quantity of a given substance at a given temperature and pressure.

_____ 2. Limestone that has been burned and treated with water under controlled conditions until the calcium oxide portion has been converted to calcium hydroxide ($Ca(OH)_2$).

_____ 3. An expression of the concentration of specified constituents in water in terms of their equivalent value to calcium carbonate.

_____ 4. A material that is mostly calcium oxide (CaO) or calcium oxide in natural association with a lesser amount of magnesium oxide.

_____ 5. An electrically charged atom or molecule formed by the loss or gain of one or more electrons.

_____ 6. A process in which a chemical solution of known strength is added drop by drop until a certain color change, precipitate, or pH change in the sample is observed (end point).

_____ 7. The alkalinity in a water sample measured by the amount of standard sulfuric acid required to lower the pH of the water to a level of 4.5, as indicated by the change in color from orange to pink.

_____ 8. A water treatment process involving reversible interchange of ions between the water being treated and a solid resin.

_____ 9. Water having a high concentration of calcium and magnesium ions.

_____ 10. A negatively charged ion in an electrolyte solution.

_____ 11. The alkalinity in a water sample measured by the amount of standard acid required to lower the pH to a level of 8.3, as indicated by a change in color from pink to clear.

_____ 12. Something that cannot be dissolved.

_____ 13. A process in which carbon dioxide is bubbled into the water being treated to lower the pH.

_____ 14. Having a valence of two, such as the ferrous ion, Fe^{2+}.

_____ 15. The capacity of water to neutralize acids.

_____ 16. A characteristic of water caused mainly by the salts of calcium and magnesium, such as bicarbonate, carbonate, sulfate, chloride, and nitrate.

_____ 17. An insoluble, finely divided substance that is a product of a chemical reaction within a liquid.

_____ 18. A positively charged ion in and electrolyte solution.

_____ 19. An unstable condition of a solution in which the solution contains a substance at a concentration greater than the saturation concentration for the substance.

_____ 20. Insoluble polymers that are capable of exchanging acceptable cations or anions to the water being treated for less desirable ions.

_____ 21. To mix with water so that a true chemical combination (hydration) takes place.

Answers

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

Section 6

Fluoride

Water Fluoridation Principles and Practices For Water Facility Operators

Water Fluoridation

Health Benefits
Regulatory Perspective
Fluoride Additives
Equipment/Facilities
Laboratory Analysis
Personnel Safety
Operations

Who, What, Where, Why, How

- **Fluoridation is adjustment of water fluoride**
- **Used for optimum oral health benefits**
- **One of ten great public health achievements of the twentieth century (CDC)**
- **Water fluoridation has a 60-year history of success**

Who?

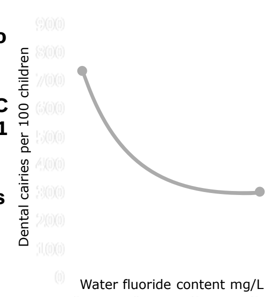
- **Dr. Frederick S. McKay initiated a study in 1908 of "Colorado Brown Stain" in Colorado Springs**
- **Important conclusions…**
  - Affected teeth more resistant to dental decay
  - Life-long residents had stained teeth, more recent residents did not
  - High fluoride content of water identified in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

Who? (continued)

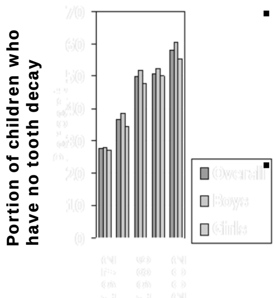
- **In 1930s, Dr. H. Trendley Dean conducted the "21 Cities Study"**
- **Important conclusions:**
  - Optimum levels of fluoride for enhancing oral health (natural breakpoint at 1 mg/L)
  - 1.0 mg/L provided best combination of reduction in tooth decay (caries) and low risk of fluorosis
  - Established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

What?

- **Adjustment of fluoride in water to an optimum range of 0.7-1.2 mg/L**
- **Recommended CDC control range is 0.1 below to 0.5 mg/L above optimum**
- **Decreased benefits below optimum**
- **No additional benefit and more severe fluorosis above 2 mg/L**



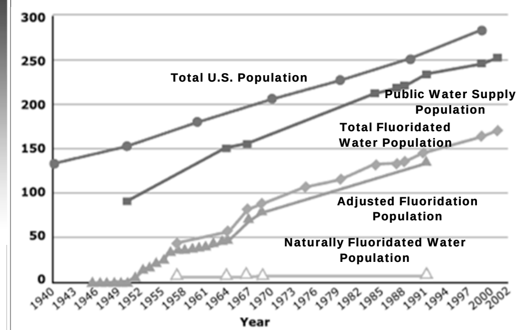
What?



- Fluoridation has contributed to a remarkable decline in the prevalence and severity of tooth decay
- Potable water industry professionals have been leaders

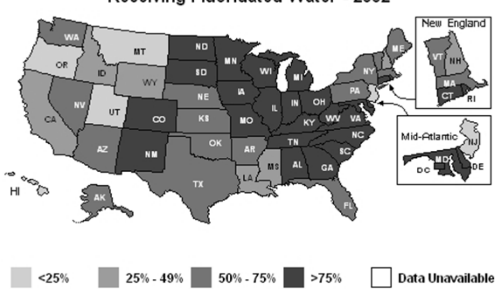
Fluoridation Growth, by Population

United States, 1940—2002



Source: CDC Water Fluoridation Reporting System. December 31, 2002.

Percent of Population on Public Water Systems Receiving Fluoridated Water - 2002



Source: Water Fluoridation Reporting System 2002

Halo Effect

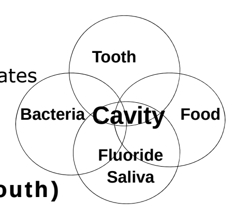
- Processed products shipped to non-fluoridated communities
- Fluoride in toothpaste and food chain
- Difference in caries now only 20%-40%

Why?

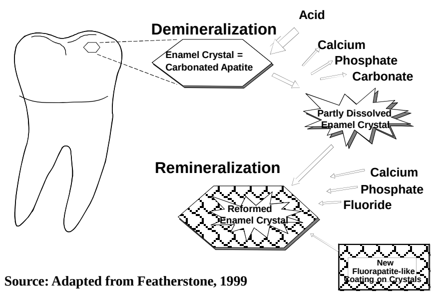
- Fluoridated communities have 20%-40% fewer caries (dental decay)
- Cost-effective results: every dollar spent on water fluoridation avoids $38 in dental care, while increase in drinking water costs to consumers is less than 1%
- Benefits all consumers across socio-economic status
- Benefits all age groups, from children to senior citizens

Risk Factors for Caries

- Diet
  - sugars and carbohydrates
- Oral hygiene
- Xerostomia (Dry Mouth)
  - fluoride
  - salivary flow and composition
- Bacteria Levels (especially mutans streptococci)



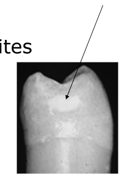
How Fluoride Works



Source: Adapted from Featherstone, 1999

Progression of Caries

- **First sign of a cavity is an increased microporosity of enamel**
  - demineralization of apatite crystallites
    - A "chalky" appearance of the enamel
  - demineralization is reversible
    - ***crystallites can regrow***



Remineralization -- Demineralization

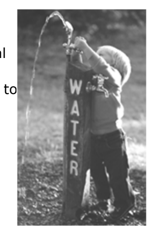
Sound → Decay: Histologic Evidence; Earliest Enamel Caries; Overt Enamel Caries; Overt Dentinal Caries; Indicated for Restoration

Fluoride Public Health Issues

- **Fluoridation has resulted in a remarkable decline in the prevalence and severity of tooth decay**
- **Despite this reduction, dental caries is still the most common preventable chronic disease in the U.S.**
  - 1 of 4 elementary school children
  - 2 of 3 adolescents
  - 9 of 10 adults

Fluoride Public Health Issues

- **Tooth decay uneven across the general population**
- **Populations with increased risk:**
  - Low SES
  - Low level of parental education
  - Little, if any, access to "dental care"



- **Water fluoridation benefits all people young, old, rich, and poor**

Fluoride Is Naturally Occurring

- **Surface water typically low, less than 0.2 mg/L**
- **Groundwaters can have fluoride from less than 0.1 mg/L to over 5 mg/L**
- **Ocean water is typically 0.8 to 1.4 mg/L**

Enamel Fluorosis

- **Occurs when children with developing teeth consume excessive fluoride (pea-sized toothpaste sufficient)**
- **Ingestion of high-fluoride toothpaste by children a major cause of fluorosis**
- **Potential for enamel fluorosis increases as water content exceeds 2 mg/L**
- **Excessively high fluoride levels, generally greater than 10 mg/L, may result in skeletal fluorosis**

Mild Fluorosis

Moderate Fluorosis with Stains

Alternatives to Fluoridated Water

- **Fluoridated water most common vehicle (various estimates of 220-300 million people worldwide)**
- **Fluoridated salt second most common vehicle (various estimates of 40-300 million people worldwide)**
- **Dietary fluoride supplements -- drops, tablets, or vitamins (60 million people-WHO 2003)**
- **Fluoridated milk used in a few places**

Challenges

- **Opponents of community water fluoridation have made claims that optimally fluoridated water can cause an array of health problems including:**
  - Cancer
  - Increased bone fractures
  - Effects on the renal, gastrointestinal, and immune systems
  - Lower IQ in children
  - Down's syndrome
  - Allergies
  - AIDS
  - Alzheimer's disease
  - Reproductive problems

Credible Scientific Evidence

- **Studies & Research**
  - For 60+ years, extensive investigations demonstrate safety and effectiveness
    - Solid design
    - Can be replicated

Alarming allegations can drive public policy

Credible Scientific Evidence

- **Occasional studies have suggested an association between fluoridation and one adverse effect or another; however, these individual studies typically have failed to account for confounding factors or have had other flaws, and the findings have not been replicated by other independent researchers**

Credible Scientific Evidence

- Expert Committees and Task Forces
  - Independent reviews
    - University of York, UK (2000)
    - U.S. Surgeon General's Report (2000)
    - CDC Fluoride Recommendations (2001)
    - U. S. Guide to Community Preventive Services (2001)
  - National Research Council Review completed in 1993, Update currently in review

Safe and Effective

- Expert scientific panels, medical and professional organizations, and public health officials have concluded that water fluoridation is safe and effective
- Water fluoridation has been endorsed by the past five Surgeons Generals of the United States including the current one, Dr. Richard Carmona

Public Policy on Fluoridation

- Recognized by the American Dental Association, U.S. Public Health Service, American Medical Association, World Health Organization, American Water Works Association, and virtually every scientific and professional organization in the health field

Fluoridation Facts

- CDC web site at www.CDC.gov/OralHealth
- American Dental Association "Fluoridation Facts" available from www.ADA.org
- Your State Water Fluoridation Program and State Dental Director

Impact on Water Bill

- Average water and wastewater bill for a typical family is $41.95/month (source 2004 AWWA Raftelis survey)
- Average annual cost to fluoridate water supply for typical household of 2.4 people $4.25 (source Griffin; J.Public Health Dentistry, 1992 adjusted for inflation)
- Results in equivalent cost to fluoridate typically less than 1 percent of annual utility bill

Health Benefits

Questions?

Water Fluoridation

Health Benefits
Regulatory Perspective
Fluoride Additives
Equipment/Facilities
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Safe Drinking Water Act (SDWA)

- **Passed by Congress December 16, 1974**
- **Reauthorized in 1986 and 1996**
- **Assures that drinking water supplied to the public is safe**
- **Administered and enforced by individual states when they adopt criteria equal or exceeding the federal standards**
- **Tennessee does not require fluoridation of drinking water**

National Primary Drinking Water Regulations

- **Contaminant**
  - Any physical, chemical, biological, or radiological substance or matter in water
  - Some contaminants are nutrients that promote good health at low concentrations including fluoride, copper, iron, and others

EPA and Water Fluoridation

- **EPA and the PHS were early partners in promoting water fluoridation**
  - **1962 and 1972 Engineering Manual was predecessor to AWWA MOP #4**
  - **Regional Fluoridation Engineers**
- **1974 SDWA defined water fluoridation as a state program, not an EPA program**
- **TN does not require fluoridation of drinking water**

Water Additives Not Regulated by EPA

- **EPA focuses on safe water and contaminant levels that result in unfavorable health outcomes**
- **Other entities provide standards covering water additives (AWWA, NSF International)**
- **Water fluoridation is a state program, not a federal program**
- **TN does not require fluoridation of drinking water**

National Primary Drinking Water Regulations

- **MCL**
  - Maximum Contaminant Level
  - The maximum permissible level of a contaminant in water which is delivered to any user of a public water system.
  - Assure no short-term or long-term health risk
  - Economically and technologically feasible
  - States can set stricter standards

National Primary Drinking Water Regulations

- **MCLG**
  - Maximum Contaminant Level Goal
  - Maximum level of a contaminant in drinking water at which no known or anticipated adverse effect on the health of persons would occur, and includes a margin of safety.
  - Non-enforceable health-based goal

National Primary Drinking Water Regulations

- **Maximum Fluoride Levels**
  - MCLG - 4.0 mg/L
  - MCL - 4.0 mg/L

National Secondary Drinking Water Regulations

- **Aesthetic Qualities of Water**
- **Not Federally Enforceable**
- **Intended as Guidelines for the States, if they allow fluoridation**

National Secondary Drinking Water Regulations

- **sMCL**
  - Secondary Maximum Contaminant Level
  - EPA website indicates that this was promulgated for naturally high fluoride waters
  - 2.0 mg/L

National Primary Drinking Water Regulations

- **Sampling**
  - Groundwater sources - 3 year
  - Surface water sources - Annual

National Primary Drinking Water Regulations

- **Public Notification – MCL**
  - Tier 2 notification requirements
  - Within 30 days of violation
  - Applies to all CWS's
  - Specific language
  - Description of CWS efforts to achieve compliance

National Primary Drinking Water Regulations

- **Public Notification – SMCL**
  - Any single exceedance of 2.0 mg/L SMCL triggers notification process
  - Tier 3 notification requirements
  - Within 12 months of exceedance
  - Applies to all CWS's
  - Specific language

State Water Fluoridation Program

- **Managed at the state level, if fluoride is fed**
- **12 states have mandatory fluoridation requirements, other state programs promote implementation**
  - Not required in Tennessee
- **CDC provides technical assistance and support**

Regulatory Perspective

- **Water fluoridation programs managed at the state level to promote good health**
- **TN does not require fluoridation**
- **Optimal level**
- **Control range**
- **EPA has established regulatory levels that are considerably above the levels for optimal oral health benefits**
  - MCL 4.0 mg/L
  - MCLG 4.0 mg/L
  - SMCL 2.0 mg/L

Regulatory Perspective

Questions?

Water Fluoridation

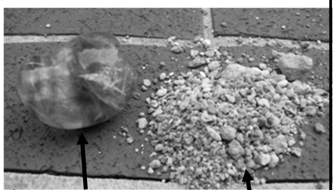
Health Benefits
Regulatory Perspective
Fluoride Additives
Equipment/Facilities
Laboratory Analysis
Personnel Safety
Operations

Fluoride Additives

- **Three Common Additives in U.S.**
  - Sodium fluoride (NaF)
  - Sodium fluorosilicate (Na_2SiF_6 or NaFS)
    - (sodium hexafluorosilicate, sodium silicofluoride, sodium sil)
  - Fluorosilicic acid (H_2SiF_6 or FSA)
    - (FSA, hydrofluoroslicic acid, HFS, hexafluorosilicic acid)

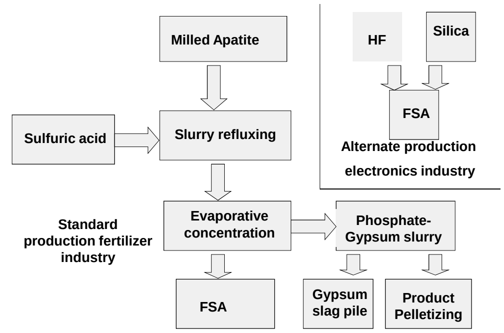
What additive is used at your facility?

Apatite



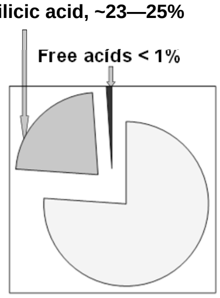
- **Mixture of calcium compounds**
  - Calcium phosphate
  - Calcium carbonates
  - Calcium fluorides (Contains 3 to 7% Fluoride)
- **Primary source for fluoridation additives**
- **Raw material for phosphate fertilizer**
- **US largest world production; Florida principal location**

Fluorosilicic Acid (FSA)



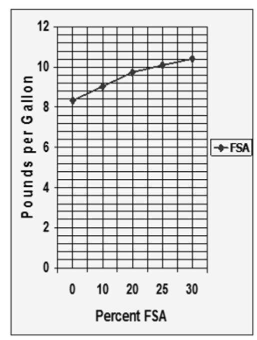
Fluorosilicic Acid (H_2SiF_6) FSA

- **Straw-colored, transparent**
- **Fuming corrosive acid – FSA is in equilibrium with volatile HF**
- **Derived from phosphate fertilizer manufacturing**



Fluorosilicic Acid (FSA)

- **22 to 26% FSA (as weight basis in water solution)**
- **Solution pH 1.2**
- **Density (25%) 10.1 pounds per gallon**
- **Avoid dilution range of 10:1 to 20:1 (precipitation of silica is a potential problem)**



Sodium Fluorosilicate (NaFS)

- **Old name: "Sodium Silicofluoride"**
- **White odorless crystalline powder**
- **Produced by neutralizing fluorosilicic acid with sodium carbonate or sodium chloride**
- **Solubility varies with temperature**
- **Solution pH 3.0 to 4.0**
- **14.0 pounds per million gallons to provide 1.1 mg/L F-**

Sodium Fluoride (NaF)

- **First to be used**
- **White odorless salt**
  - powder or crystalline
- **Produced by neutralizing fluorosilicic acid with caustic soda (NaOH)**
- **Relatively constant solubility of 4%**
- **Ideal for fluoride saturators**
- **Solution pH 7.6**
- **1.8 pounds per MG to provide 1.1 mg/L F-**

Fluoride Additives Standards

- **American Water Works Association specifies manufacturing and quality**
  - AWWA B701-06 – Sodium Fluoride
  - AWWA B702-06 – Sodium Fluorosilicate
  - AWWA B703-06 – Fluorosilicic Acid
- **NSF International – ANSI/NSF 60-2002 specifies distribution and purity**
  - Key concept is additive must contribute less than 10 % of the MAL for any contaminant

AWWA Verification Tests

FSA	NaFS	NaF
• Fluoride content - specific gravity	• Fluoride content -specific ion	• Fluoride content -specific ion
• Fluoride content - titration	• Moisture content	• Moisture content
• Free acid	• Size (sieve)	• Size (sieve)
• Heavy metals	• Insoluble matter	• Insoluble matter
	• Heavy metals	• Heavy metals
		• Saturated solution turbidity

Additive Availability

- **Shortages occur mostly at the local level**
- **Problems with phosphate fertilizer production affect national supply**
- **Dry additives can be imported, FSA also from Mexico**
- **Plan to maintain 2 to 3 month inventory, coordinate with supplier**

FSA Delivery

- **Rail tank cars (20,000 gallons)**
- **Truck tank cars (4,000–6,000 gals)**
- **Tote tanks (300 or 400 gallons)**
- **55-gallon drums**
- **13-gallon carboys**

FSA Delivery Issues

- **Most problems occurs after shipment leaves manufacturing location or depot**
- **Typical problems**
  - Breakdown and release from transfer hoses
  - Delivery in damaged containers
  - Improperly or inadequately equipped delivery personnel
  - Attempted delivery to wrong storage area
  - Transport related trash including black particles attributed to breakdown of vehicle tank liners, plastic bags, other trash

FSA Storage

- **Preferred storage location is inside building**
- **Keep sealed with air vent (HF) to outside**
- **Ensure storage area has adequate ventilation or air changes per hour**
- **Seal all electrical and other conduits**
- **Spill containment for 110 percent volume (double-wall tank or barrier)**
- **FSA is aggressive – use corrosion resistant materials**
- **Bulk storage container should never be used for additive feed supply…include day-tank**

Fluoridation Unrelated to Pipe Corrosion or Lead Levels

- **Some operators may think that since HF gas released from concentrated H_2SiF_6 storage results in corrosion, water fluoridation will corrode pipes**
- **EPA and University of Michigan (Ann Arbor) researchers have proven that at temperatures and concentrations for water fluoridation, FSA achieves complete dissociation to fluoride, hydrogen, and silica and cannot produce HF**
- **Silicates are actually used as a stabilizer for water corrosion**

FSA 55-Gallon Drum

CORRECT Outside vent

IMPROPER

300 to 400 Gallon Tote Tank

Up to 10,000 Gallon HDPE

- **Polyethylene tanks available from 10 to 10,000 gallons**
- **Gangs of multiple tanks can increase storage volume**

Depressed floor provides containment for spills

Fiberglass Storage to 20,000 Gal

Vent to atmosphere

- **Fiberglass tanks have been used for storage, but may be susceptible to glass-fiber attack**
- **Verify that resins and coatings are suitable for hydrogen fluoride**

Concrete barrier provides containment for spills

Vent to Outside Structure

IMPROPER VENT

FSA Is Aggressive

- **FSA will damage concrete surfaces**
- **A dual application of epoxy undercoat with urethane topcoat provides corrosion resistance**
- **Consult with coating manufacturer for acceptable products**

Dry Additive Containers

- **Sizes**
  - 50-pound bags
  - 100-pound bags
  - 125 to 400-pound fiber drums
  - 2,500-pound supersacks
- **Handling**
  - Use knife to slit bag
  - Secured disposal to avoid personnel exposure

Dry Additive Delivery Issues

- **Most problems occurred after shipment leaves manufacturing location or depot**
- **Typical problems**
  - Delivery in damaged packaging
  - Improperly or inadequately equipped delivery personnel
  - Attempted delivery to wrong storage area
  - Mixing with other chemicals
  - Degradation of product during transport

Dry Additive Storage

- **Separate room**
  - do not mix additives
  - secured access
- **Convenient to feed location**
- **Good ventilation**
- **Elevated platform**
  - keep dry additives on pallets
- **Limit stacks to 6 bags**
- **Protected from elements**
  - additives cake when compressed and exposed to moisture

2,500 lbs Supersack Delivery

Dry Spills

- **Sweep and place in secure container**
- **Typically, supplier will agree to pick up for disposal**
- **Check Codes and Regulations**
  - State hazardous waste agency
  - Local Fire Marshall

Liquid Spills

- **Ensure that storage tank is in spill containment barrier or on containment pallets**
- **Use spill control pillows or dams that adsorb acid to contain liquid from spreading**
- **Neutralize and then consult with authorities on disposal requirements**
- **Avoid “flushing” to public sewer or on-site septage (septic tank) system**

Liquid Spills

Neutralization – Lime

$$H_2SiF_6 + Ca(OH)_2 \rightarrow CaSiF_6 + 2H_2O$$

$$CaSiF_6 + 2Ca(OH)_2 \rightarrow 3CaF_2 + SiO_2 + 2H_2O$$

Calcium fluoride and silica (sand) are considered non-hazardous and accepted at most landfills

0.39 pound of lime is required to neutralize one pound of acid for an acid strength of 25%

Liquid Spills

- **Caustic soda or soda ash can be used for FSA spills**
- **Use of these agents will result in either sodium fluorosilicate or sodium fluoride**
  - Both are hazardous materials
  - Special caution is required to clean up the residue, and disposal may involve special licensing

Fluoride Additives

- **Three additives**
  - Fluorosilicic acid
  - Sodium fluorosilicate
  - Sodium fluoride
- **AWWA and NSF International Standards**
- **Delivery and storage considerations**
- **Clean up of spills/neutralization**

Fluoride Additives

Questions?

Water Fluoridation

Health Benefits
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Fluoride System Selection

- There is no one specific type of system or equipment that is best
- Historically
  - Large city - FSA
  - Medium system – FSA, dry feeder
  - Small system – FSA, dry feeder or saturator

How Many Fluoridation Systems?

- Surface water system may have one treatment plant with one fluoride feed point
- Groundwater system may have multiple wells (or well fields) in locations scattered throughout their distribution system
  - Each location may require a separate feed system

Fluoride Additive Selection

- Fluoride Products Availability
- Existing Facilities
  - Compatibility with water system
  - Availability of space
  - Number of treatment sites (fluoride injection points)
- Characteristics of the Water
  - Natural fluoride level
  - Type of flow (variable or steady state)
  - Pressure (discharge)

Fluoride Additive Selection (continued)

- Estimated overall cost
  - Capital (initial)
  - Operation and Maintenance (O&M)
  - Chemicals
- State rules, regulations, and preferences

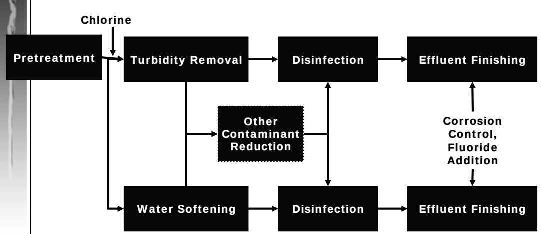
Context of Fluoridation to Water Treatment

- Must be compatible with other processes
- Must not contribute to water quality violations
- Different from other water treatment processes in being routinely unrelated to safe drinking water standards
- Similar to fire fighting in that it promotes a community benefit
- EPA's perspective is that fluoride is like copper: beneficial nutrient levels are close to levels that result in undesirable cosmetic results

Objectives of Water Treatment

- Disinfection to protect against pathogenic organisms
- Reduction of contaminants for health effects
- Oxidation of undesirable reduced compounds
- Aesthetics – taste, odor, and color
- Not treatment, but a community benefit is fire fighting, which is the original reason for many community water systems

Simplified Water Treatment



Fluoridation Design Basics

- Basic design principles for fluoridation same as for other water treatment processes
- Equipment and process design same as for other standard water treatment processes

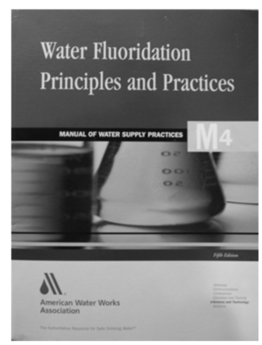
It's Really Very Simple

…You need a tank to hold the FSA or solution formed from the dry additive, and a pump…

…but the devil is in the details….

Standard Reference Guidance

- American Water Works Association Manual of Practice (MOP) No. 4 – Water Fluoridation Principles and Practices (fifth edition 2004)



Experience Builds Knowledge

"In theory, there is no difference between theory and practice…in practice, there is."

-Yogi Berra

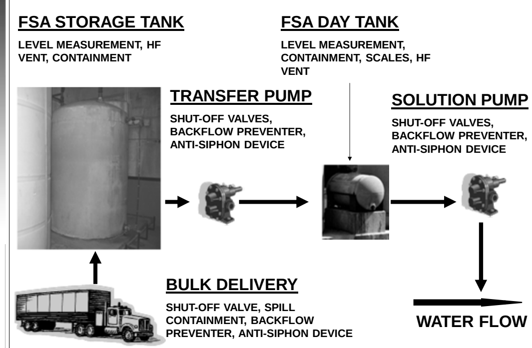
Fluoride Additive Feed Equipment Requirements

- Precise Delivery
- Small Quantities/Capacities
- Reliable
- Corrosion Resistance
- Safety in Handling Hazardous Products

Fluoride Feed Equipment

- FSA Fed With Small Metering Pump
- Saturated Solutions of NaF
- Unsaturated solutions of NaF or NaFS

FSA Schematic Process Diagram



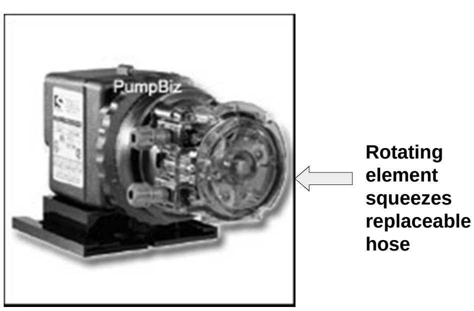
Metering Pump Classification

- **Centrifugal**
  - hydraulic vortex induces pressure delivery
- **Positive displacement**
  - Hydraulic vortex induces pressure delivery

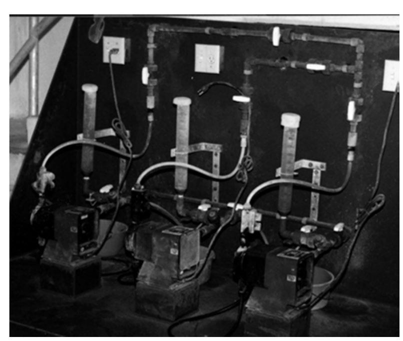
Positive Displacement Pumps

- **Peristaltic**
  - Also known as hose pump or tube pump
- **Diaphragm**
- **Piston**
- **Other (not used in fluoridation)**
  - Progressive cavity
  - Screw
  - Rotary lobe or gear

Peristaltic Pumps



Solution Feed Pumps



Diaphragm Pump

Replaceable diaphragm

Fluorosilicic Acid Feed

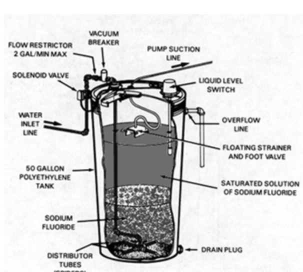
Dry Additive Feeders

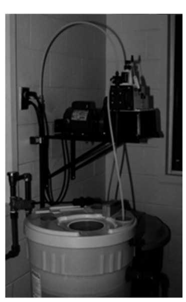
- **Fluoride Saturators**
  - Upflow: most common
  - Downflow: rarely used in United States
  - Venturi: rarely used except in large installations
- **Dry Feeders**
  - Volumetric
  - Gravimetric

Fluoride Saturators

- **Operating Procedure**
  - Generally uses sodium fluoride
  - Consistent fluoride additive bed maintained in tank
  - Water flows through bed
  - Water becomes saturated
  - Saturated solution injected

Typical Upflow Saturator





Water Softener With Saturator

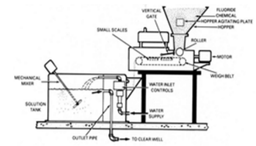
- **In areas with high hardness, a water softener is often needed to minimize the potential for calcium fluoride scale formation**

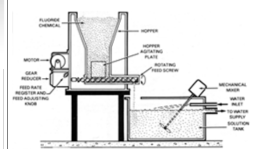
Dry Additive Feeders

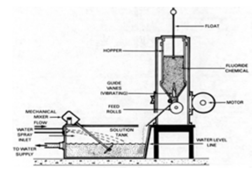
- **Dry Volumetric Feeders**
  - Delivers a constant volume of fluoride additive
  - Generally sodium fluorosilicate, but also used with sodium fluoride

Dry Additive Volumetric Feeders

- rotating disk
- oscillating pan
- vibratory pan
- roll
- rotating screw







Dry Feeder Solution Mixing

- **Minimum 5 minutes to fully dissolve NaFS**
- **Hard water, colder temperatures (less than 60°F), and crystalline form of additive can increase the required time to fully dissolve NaFS**

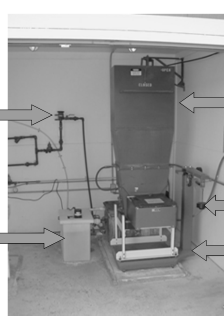
Dry Feeder Solution Mixing Continued

- **Failure to produce a clear, homogeneous solution indicates:**
- **Dissolving chamber too small**
- **Detention time inadequate**
- **Dilution water insufficient**
- **Agitation insufficient**
- **Short-circuiting**

Volumetric Feeder Installation

Water supply with backflow/ vacuum breaker

Solution mixing tank with agitator



Top loading bin hopper

Feeder

Scales

Volumetric Feeder Installation

Solution pump

Solution mixing tank with agitator

Top loading bin hopper

Additive storage and feed platform

Feeder

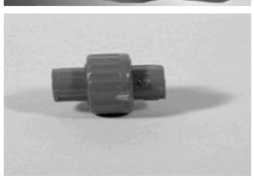
Types of Auxiliary Equipment

- Water Meters
- Pacing Meters
- Vacuum Breakers
- Anti-Siphon Valves
- Day Tanks
- Mixers
- Scales
- Continuous analyzers

Types of Auxiliary Equipment

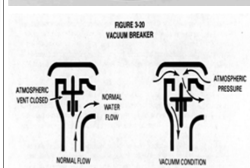
- Unions
- Valves
- Strainers
- Timers
- Alarms
- Flow Switches
- Pressure Switches
- Hauling Equipment

Piping Considerations



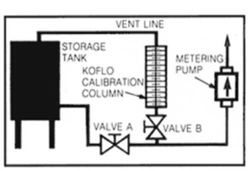
- Use fluoride compatible materials such as PVC, HDPE
- Include numerous shut-off valves and unions at key locations to facilitate pipe repairs
- Identify the pipe

Backflow and Air-Relief Valves



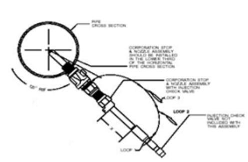
- Include backflow prevention and air-relief valves in key locations so that tanks do not siphon or drain in the event of a line break

Calibration Cylinders



- Calibration cylinders allow verification of pump discharge rates

Injector

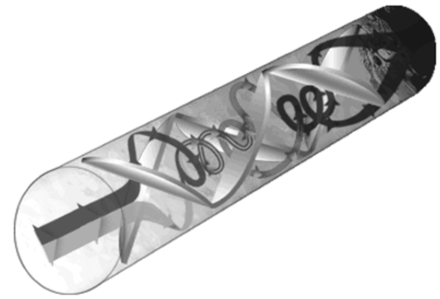


- When solution is added to a pipe, an injector should be used to ensure good mixing with the water flow
- The injector should be placed in the lower third of the pipe and extend into the pipe approximately one-third of the pipe's diameter

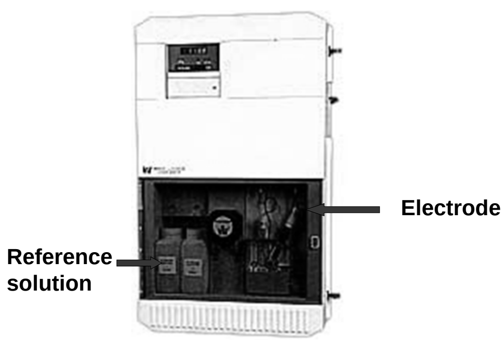
Injector

- Some contractors will install the injector into the crown (top) of the pipe due to easy access, but this will result in poor mixing.
- The fluorosilicic acid solution is denser (heavier) than water, so if the injector is pointed down towards the lower portion of the pipe, then the solution will sink to the bottom of the pipe and the solution plume will be poorly mixed.

Static In-line Mixer

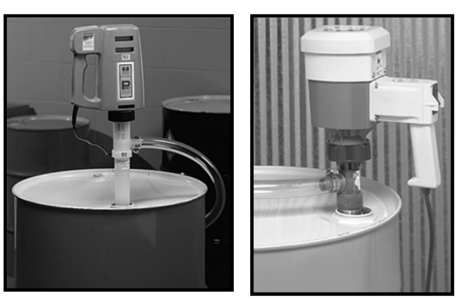


Continuous Analyzers

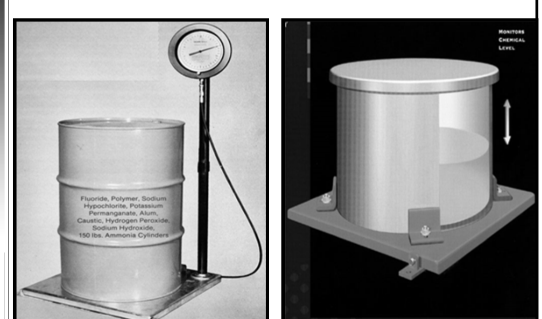


Drum Pump - Hand

Drum Pump - Electric

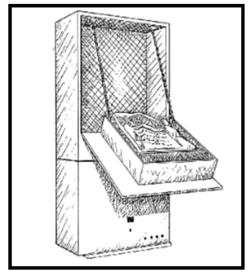


Drum or Tank Scale



Containment Pallets


Bag Loading Hopper




Storage of Fluoride Products

- **Storage of additive**
  - CDC recommends 3 months (annual average basis)
- **Consult with vendors on product availability/reliability to determine appropriate storage requirements**

Size/Capacity of Equipment

- **Day tank sized for 1 to 3-day holding capacity of solution depending on regulations**
- **Saturator can be appropriately sized if also used as daytank**
- **Pumps provide maximum delivery equal to water capacity…do not provide excess fluoride solution delivery capability**

Design Modifications

- **Many states require review and approval of proposed modifications or additions prior to implementation. Know your state requirements.**

Equipment/Facilities

Questions?

Water Fluoridation

Health Benefits
Regulatory Perspective
Fluoride Additives
Equipment/Facilities
Laboratory Analysis
Personnel Safety
Operations

Fluoride Testing Methods

- **Three Principal Methods**
  - Colorimetric
  - Specific Ion Electrode
  - Inductively Coupled Plasma Spectroscopy (ICP-MS)

Increasing Accuracy
Increasing skill and ability

Fluoride Testing Methods

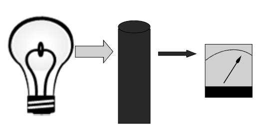
- **Colorimetric**
  - Compares reduction of indicator solution color influenced by ions
- **Specific Ion Electrode**
  - Measures ionic activity as a relative indicator
- **(ICP-MS)**
  - measures the number of ions in a fixed volume on basis of mass to charge ratio

Method Selection

- **Speed**
- **Economy**
- **Test Purpose**
- **Interferences**

Colorimetric Elements

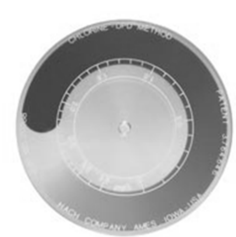
- **Source of Radiant Energy (lamp)**
- **Absorption Body**
- **Energy Detector**



Visual Determinations

"Do YOU See What I See?"

- **Color Perception**
- **Anomalous Trichromatism**
  - Difficulty in matching colors
- **Confuse Reds & Greens**



Chlorine DPD Color Wheel

Absorbance Measurement

- **Two types of Instruments**
  - Filter Photometer (Colorimeter)
  - Spectrophotometer
    - More accurate than a colorimeter

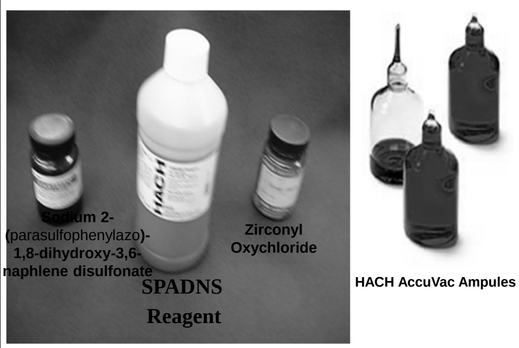
SPADNS Method

The colorimetric method relies on a reagent with color. For fluoride, this is

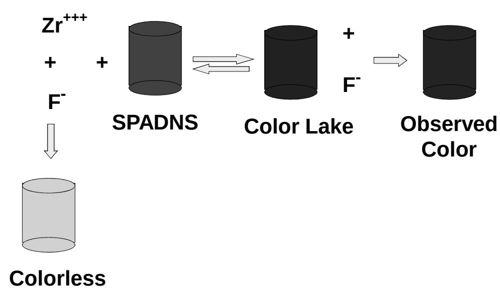
SPADNS

- **Sodium 2-(parasulfophenylazo)-1,8-dihydroxy-3,6-naphlene disulfonate**

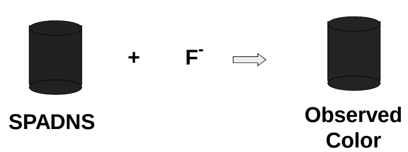
SPADNS Method



Zirconium SPANS Complex



Zirconium SPANS Complex



- **The observed reduction in color is an indication of the amount of fluoride in the solution**
- **A deep red color indicates an absence of fluoride, and a light red color indicates a high fluoride concentration**

Colorimetric Analysis Sources of Error

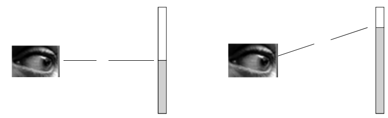
- **Sample collection**
- **Sample handling**
- **Testing cell**
- **Standards**
- **Electronic**
- **Calibration**
- **Interfering substances**

Sample Collection

- **Is solution fully mixed?**
- **Is container used for collection clean?**
  - Was glassware cleaned with phosphate based detergent?
- **Is person introducing contamination?**
- **Is chlorine a contaminate?**
  - Sodium arsenite removes chlorine interference

Sample Handling

- **Skill in using a pipette**
- **Bulb or pipette may be contaminated**
- **Parallax in measurement**



Testing Cell (cuvette)

- **Cell might be dirty or smeared**
- **Residuals could interfere**
- **Consistent optical clarity between cells**
- **Chips or scratches**

Standards

- **Use fresh standards**
- **Appropriate calibration of test**
- **Use true deionized water (zero fluoride)**

Electronics

- **Weak batteries**
- **Leaking batteries**
- **Deterioration of electronics**

Verification

- **Correct instrument verification**
- **Background color or turbidity**
- **Temperature differences**

SPADNS Interferences

Concentration of substance (mg/L) req. to cause error of plus or minus 0.1 mg at 1.0 mg/L fluoride		
Interfering Substance	SPADNS	Electrode
Alkalinity	5,000 (-)	7,000 (+)
Aluminum	0.1 (-)	3.0 (-)
Chloride	7,000 (+)	20,000 (-)
Iron	10 (-)	200 (-)
Hexametaphosphate	1.0 (+)	50,000
Phosphate	16 (+)	50,000
Sulfate	200 (+)	50,000 (-)

SPADNS Interferences

Concentration of substance (mg/L) req. to cause error of plus or minus 0.1 mg at 1.0 mg/L fluoride		
Interfering Substance	SPADNS	Electrode
Chlorine	Must be completely removed with arsenite*	5,000
Color & Turbidity	Must be removed or compensated for	___

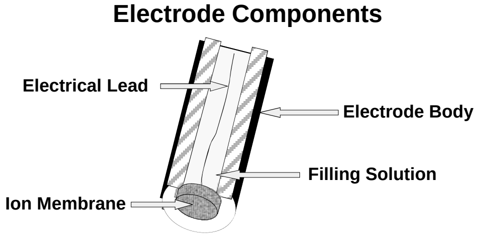
*Most suppliers (Hach is one of them) have arsenite in their SPADNS to remove up to 5.0mg/L free chlorine

HACH Pocket Colorimeter

Hach DR 4000

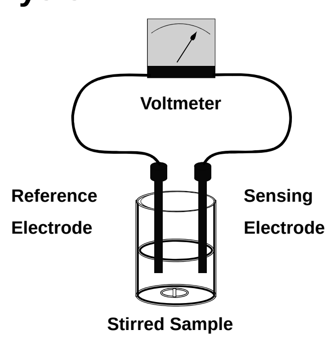
Specific Ion Electrode Analysis

Electrode Components



Measures Fluoride Ion Activity
LaF Crystal "Membrane"

Specific Ion Electrode Analysis



Specific Ion Electrode Analysis

- **Advantages**
  - Greater Range, 0.1 – 10.0 mg/L
  - Fewer Interfering Substances
  - Less Susceptible to Technique Errors
- **Disadvantages**
  - Expensive

Specific Ion Electrode Analysis

- **Total Ionic Strength Adjusting Buffer**
  - Adjusts pH 5 – 5.5 to Optimize Fluoride Ion Availability
  - Adjusts Total Ionic Strength by Swamping Background
  - Complexes Iron & Aluminum

Total Ionic Strength Adjusting Buffer

- **TISAB II**
  - Equal parts TISAB & Sample
  - Complexes up to 5 mg/L Aluminum or Iron

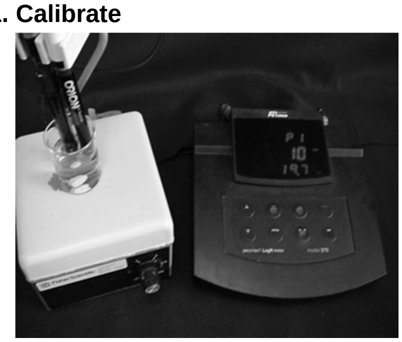
Total Ionic Strength Adjusting Buffer

- **TISAB III**
  - CDTA
  - 5.0 – 5.5 pH
  - Up to 5.0 mg/L Aluminum or Iron
  - Concentrated
- **TISAB IV**
  - Tartrate
  - 8.5 pH
  - Up to 100 mg/L Aluminum or Iron
  - Complexes Lanthanum

Specific Ion Electrode Analysis

Specific Ion Electrode Analysis

1. Calibrate



Specific Ion Electrode Analysis

2. Prevent carryover

Specific Ion Electrode Analysis

3. Read

Specific Ion Analysis Sources of Error

- Sample collection
- Sample handling
- Standards
- Electronic
- Element
- Interfering substances

Sample Collection

- Is solution fully mixed?
- Is container used for collection clean?
- Is person introducing contamination?

Sample Handling or Method Related

- Parallax in measurement
- Improper stirring
- Bubble
- Complexation (TISAB)
- Concentration out of range

Standards

- Use fresh standards
- Appropriate calibration of test
- Use true deionized water (zero fluoride)

Electronics

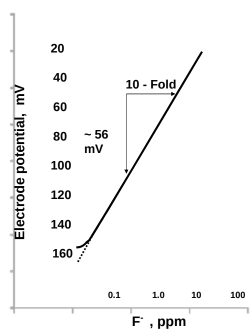
- **Weak batteries**
- **Leaking batteries**
- **Deterioration of electronics**
- **Instrument drift**
  - Batteries
  - Temperature

Fluoride Electrode Element

- **Broken Lead**
- **Leaking**
- **Filling solution**
  - Correct Type
  - Correct Amount
- **Crystallized / plugged membrane**
- **Correct reference electrode**

Suspect the Fluoride Electrode?

- **Check the Slope**
- **Pair Reference Electrode with a pH Electrode & Perform a pH Calibration**



Specific Ion Interfering Substances

Concentrations Causing 0.1 mg / L Error

	mg/L	Effect
Aluminum	3.0	↓
Iron	200	↓
Hexametaphosphate	>50,000	
Phosphate	>50,000	
Sulfate	>50,000	
Chlorine	5,000	

A negative effect means that the indicated value is lower than the actual Fluoride concentration, and vice versa.

Storing the Electrodes

- **Fluoride Single Junction** ⇒ **DRY!!**
- **Fluoride Combination** ⇒ **Filling Solution**
- **Reference** ⇒ **Filling Solution**

Laboratory Analysis

- **Colorimetric Method (SPADNS) can provide satisfactory results, but is subject to many interferences and operator methodology errors**
- **Specific Ion Electrode Method provides more reliable results, but requires greater operator effort**
- **Care and attention to methodology details is essential to achieve satisfactory results**

Laboratory Analysis

Questions?

Water Fluoridation

Health Benefits
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Respirators

- **NIOSH approved air purifying respirator with fluoride rated replaceable canisters**

Respirators

- **Correct procurement, training, and maintenance**
  - Ensure mask is correctly sized for the individual and provides the appropriate protection: integral eye protection preferred
  - Verify that canister is particulate and hydrogen fluoride rated
  - Training and practice on correct use
  - Replacement schedule for canister
  - Periodically inspect seals for wear

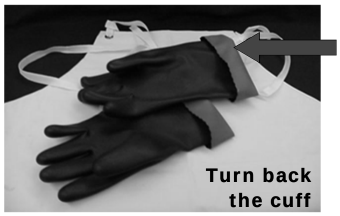
Dry Additive Safety Equipment

- **Eye protection**

FSA Safety Equipment

- **Heavy apron / coveralls**
- **Long-sleeve gauntlet gloves**
- **Durable rubber boots**

Latex gloves do not provide protection



Turn back the cuff

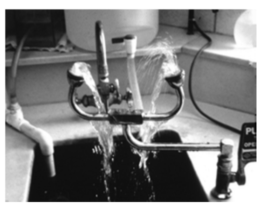
FSA Safety Equipment

- **Full face shield / safety goggles**

FSA Safety Equipment

- **Safety shower / eye wash**

Test regularly!



FSA Safety Equipment

- **Face shield**
- **Safety goggles**
- **Heavy apron**
- **Gloves**
- **Rubber boots**
- **Safety shower**
- **Eye wash**
- **Coveralls**

Fluorosilicic acid

Corrosive acid

Protective gear required

face shield, gloves, apron, boots, and respirator

Water Fluoridation

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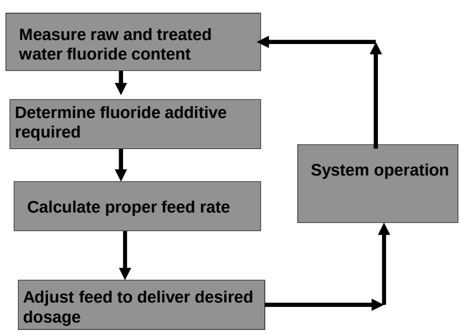
Optimal Fluoride Levels

- Based on maximum daily air temperature (presumed water consumption) from 0.7 to 1.2 mg/L
- Benefits to oral health decline as fluoride levels drops below optimum
- Little incremental benefit gained as fluoride levels increase over optimum
- CDC recommends control range 0.1 mg/L below to 0.5 mg/L above optimum level

Goal Is To Maintain Optimal Level

- For benefits of fluoridation to be realized, fluoride must be maintained at or near optimal level
- Principal reason for low or erratic fluoride levels is poor operation and maintenance

Simplified Process Control Scheme



Process Calculations - Units

- Capacity
  - MGD
  - gpm
  - m^3/day
- Fluoride dosage
  - mg/L = ppm
- Fluoride additive feed rate
  - lb/day, lb/hr, mL/min, gpd, gph

Process Calculations

- Desired dosage
  - Amount of fluoride chemical needed to obtain optimal level
- Optimal level
- Natural level

Dosage (mg/l) = Optimal level (mg/l) - Natural level (mg/l)

Process Calculations

- Chemical purity and available fluoride ion (AFI)

Chemical	Formula	Purity	Available Fluoride Ion (AFI)
Sodium Fluoride	NaF	98%	0.452
Sodium Fluorosilicate	Na_2SiF_6	98.5%	0.607
Fluorosilicic Acid	H_2SiF_6	23%	0.792

Process Calculations

- **Fluoride feed rate**

$$\text{Fluoride feed rate}_{(lb/day)} = \frac{\text{Dosage}_{(mg/l)} \times \text{Capacity}_{(MGD)} \times 8.34}{\text{AFI} \times \text{chemical purity}}$$

Process Calculations

- **Calculated dosage**

$$\text{Fluoride feed rate}_{(lb/day)} = \frac{\text{Dosage}_{(mg/l)} \times \text{Capacity}_{(MGD)} \times 8.34}{\text{AFI} \times \text{chemical purity}}$$

Rearrange to get . . . .

$$\text{Dosage}_{(mg/L)} = \frac{\text{Feed Rate}_{(lbs/day)} \times \text{AFI X Chemical Purity}}{\text{Capacity}_{(MGD)} \times 8.34}$$

Process Calculations

- **Quantity to treat 1 MG at 1 mg/L**
  - Sodium fluoride (98%) - 18.8 lbs
  - Sodium fluorosilicate (98%) - 14.0 lbs
  - Fluorosilicic acid (23%) - 45.7 lbs. ~ 4.6 gal

Calculation Problem 1

- **Plant 1 has an average daily flow of 1.4 MGD and the source water has a natural fluoride level of 0.15 mg/L. The optimal level for oral health is 0.9 mg/L. If the FSA has a concentration of 25%, what is the dosage required and how many gallons will be necessary?**

Calculation Problem 1 (step 1)

Average daily flow is 1.4 MGD
Optimal fluoride level is 0.9 mg/l
Natural fluoride level is 0.15 mg/l

Optimal minus natural is the dosage
0.9 – 0.15 = <u>0.75 mg/L</u>

Calculation Problem 1 (step 2)

Average daily flow of 1.4 MGD
Optimal minus natural is 0.9 – 0.15 = 0.75 mg/L

$$\text{Fluoride feed rate}_{(lb/day)} = \frac{\text{Dosage}_{(mg/l)} \times \text{Flow}_{(MGD)} \times 8.34}{\text{AFI} \times \text{chemical purity}}$$

$$44.23\ (lb/day) = \frac{0.75_{(mg/l)} \times 1.4_{(MGD)} \times 8.34}{0.792 \times 0.25}$$

Feed Rate (44.23); **AFI** (0.792); **Purity** (0.25)

Calculation Problem 1 (step 3)

Average daily flow of 1.4 MGD
Optimal minus natural is
0.9 – 0.15 = 0.75 mg/L

$$44.23\ (\text{lb/day}) = \frac{0.75\ (\text{mg/l}) \times 1.4\ (\text{MGD}) \times 8.34}{0.792 \times 0.25}$$

44.23 lbs/day divided by 24 hours is 1.8 lbs per hour

FSA at 25 percent purity weighs 10.1 pounds per gallon to give 0.18 pounds per hour

The total feed rate is:

- 4.38 gallons per day (44.23 lbs / 10.1 pounds per gallon)
- 0.183 gallons per hour (4.38 gal per day / 24 hours)
- 692.7 mL per hour (.183 gph X 3780 mL/gal)

Calculation Problem 2

- Plant 2 has an average daily flow of 5.8 MGD and the source water has a natural fluoride level of 0.2 mg/L. The optimal level for oral health is 0.8 mg/L. The fluoride product is sodium fluorosilicate with 98% purity. What is the dosage required and how many pounds will be necessary?

Calculation Problem 2 (step 1)

Average daily flow is 5.8 MGD

Optimal fluoride level is 0.8 mg/L

Natural fluoride level is 0.2 mg/L

Optimal minus natural is
0.8 – 0.2 = <u>0.6 mg/L</u>

Calculation Problem 2 (step 2)

Average daily flow of 5.8 MGD
Optimal minus natural is
0.8 – 0.2 = 0.6 mg/L

$$\text{Fluoride feed rate}\ (\text{lb/day}) = \frac{\text{Dosage}\ (\text{mg/l}) \times \text{Flow}\ (\text{MGD}) \times 8.34}{\text{AFI} \times \text{chemical purity}}$$

$$48.79\ (\text{lb/day}) = \frac{0.6\ (\text{mg/l}) \times 5.8\ (\text{MGD}) \times 8.34}{0.607 \times 0.98}$$

Feed Rate   AFI   Purity

Calculation Problem 2 (step 3)

Average daily flow of 5.8 MGD
Optimal minus natural is
0.8 – 0.2 = 0.6 mg/L

$$48.79\ (\text{lb/day}) = \frac{\text{Dosage}\ (\text{mg/l}) \times \text{Flow}\ (\text{MGD}) \times 8.34}{0.607 \times 0.98}$$

The feed rate is 49 pounds per day, or:

- 2.0 lb/hr (48.79 / 24 hours)
- 0.92 kg / hour (2.0 / 2.2 to get Kg)
- 15 mg/ min (0.92 kg/hr X 1000 mg/kg / 60 min/hr)

Calculation Problem 3

- Plant 3 has an average daily flow of 0.45 MGD and the ground water has a natural fluoride level of 0.4 mg/L. The optimal level for oral health is 1.1 mg/L. The fluoride product is sodium fluoride with 96% purity. What is the dosage required and how many pounds will be necessary?

Calculation Problem 3 (step 1)

Average daily flow is 0.45 MGD
Optimal fluoride level is 1.1 mg/L
Natural fluoride level is 0.4 mg/L
Optimal minus natural is
1.1 – 0.4 = 0.7 mg/L

Calculation Problem 3 (step 2)

Average daily flow of 0.45 MGD
Optimal minus natural is
1.1 – 0.4 = 0.7 mg/L

$$\text{Fluoride feed rate (lb/day)} = \frac{\text{Dosage (mg/l)} \times \text{Flow (MGD)} \times 8.34}{\text{AFI} \times \text{chemical purity}}$$

$$6.05\ \text{(lb/day)} = \frac{0.7\ \text{(mg/l)} \times 0.45\ \text{(MGD)} \times 8.34}{0.452 \times 0.96}$$

Feed Rate — AFI — Purity

Calculation Problem 3 (step 3)

Average daily flow of 0.45 MGD
Optimal minus natural is
1.1 – 0.4 = 0.7 mg/L

$$6.05\ \text{(lb/day)} = \frac{0.7\ \text{(mg/l)} \times 0.45\ \text{(MGD)} \times 8.34}{0.452 \times 0.96}$$

The feed rate is 6.05 pounds per day, or:

- 0.252 lb/hr (6.05 / 24 hours)
- 114.3 gram/hr (.0252 lb/hr X 453.6 gram/lb)

Operation

- Understand how it works
  - Read the manual
  - Understand the operating cycle
    - When the equipment operates automatically
    - When the equipment shuts down automatically
  - Know what it sounds like

Sampling

- Minimum EPA sampling may only require annual testing
- AWWA and CDC both recommend daily sampling of product water
- Hourly testing of product water is often practiced by larger facilities that are well operated
- Occasional spot-sampling at random locations in the distribution system can identify other problems with system such as storage tanks
- Verify sampling location is representative of flow

Records

- Verify state records and reporting requirements
- Operational records
- Laboratory records
- Maintenance records
- Customer comments

Operational Records

- **Source/product water fluoride level (daily)**
- **When and where sampling occurred**
- **Amount of fluoride additive used (daily)**
- **Pump or feeder calibration curves and pump or feeder operational settings (quarterly)**
- **Make-up water for saturators and feeders**
- **Assay on chemical purity (with each delivery)**
- **Check with state on other record or documentation requirements**

Operational Records

- **Reporting of operating results important for public health**
- **Results are compiled and help public health officials, medical doctors, dentists, and other health care providers make good decisions for communities and patients**
- **Submit results monthly**

Laboratory Records

- **Dates, times, technician, location, methodology, etc. for sampling events**
- **Results of split-sampling with state proficiency laboratory**
- **Verification of analytical procedure against standards**
- **Maintenance of laboratory equipment**

Maintenance Records

- **Dates of maintenance activities**
- **Documentation when pump hoses or heads are replaced**
- **Electrical records related to possible fluoride system operation**
- **Vendor for parts, supplies, and equipment manuals**
- **Preventative maintenance not repairs:**
  - continuous, dependable operation

Suggested Maintenance

- **Daily**
  - Watch for trouble
    - Inspect system, listen to sounds
    - Look for leaks or differences
  - Liquid systems
    - Check solution levels, check level switch
    - Check hoses for air locks
    - Check pump for prime
    - Refill day tank
  - Dry feeders
    - Check for compaction
    - Refill additive hopper

Suggested Maintenance

- **Every 3 months-FSA feed system**
  - Check all piping for leaks, and gas venting for integrity
  - Check pipes/hoses for encrustations
  - Inspect tank level measurement (floats, gauges, etc)
  - Calibrate pump delivery rate

Suggested Maintenance

- **Every 3 months-dry feeder**
  - Thoroughly clean, remove cinders/ encrustations
  - Check belts; adjust if necessary
  - Lubricate bearings
  - Calibrate feeder dispensing rate
  - Rotate your additive inventory

Suggested Maintenance

- **Every 3 months-saturator**
  - Thoroughly clean, remove cinders/ encrustations in saturator, pipes and hoses
  - Verify uniform flow through additive bed: no short circuiting or piping
  - Verify water softener in working order
  - Clean water strainer
  - Check all piping for leaks
  - Inspect tank level measurement (floats, gauges, etc)
  - Calibrate pump delivery rate
  - Rotate your additive inventory

Suggested Maintenance

- **Every 6 months**
  - Motor driven pumps
    - Check lubrication, adjustments
  - Foot valves, lines, hoses, injector
    - Check for crystalline deposits
    - Disassemble and clean
  - Vacuum breaker, Anti siphon valve
    - Test operation
    - Disassemble, replace worn parts
  - Saturator
    - Drain, disassemble and clean

Suggested Maintenance

- **Annually**
  - Metering pump
    - Disassemble and replace worn parts
    - Replace hoses, diaphragms, seats, etc
    - Clean valves
      - Foot valve
      - Suction, discharge valves
      - Anti siphon valves; vacuum breaker
      - Injection check valves
  - Dry feeder
    - Check for worn gears, replace worn parts
    - Lubricate, change gear oil

Troubleshooting

- **Change in the equipment**
- **Deviations in sound or smell**
- **Change in amount of chemical fed**
- **Change in fluoride concentration**

Trouble Shooting – continued

- **Pump won't pump**
  - Check hoses & fittings
  - Test check valves, foot valve
  - Check back pressure
  - Verify float/level controller operation
- **Pump won't pump like it used to**
  - Clogged foot valve or strainer
  - Ruptured diaphragm
  - Worn seals
  - Change of pump stroke or speed
  - Pumps or pipes clogged with impurities

Trouble Shooting – continued

- **Softener**
  - Verify water hardness before/after softener
  - Check backwashing/regeneration
- **Excessive output**
  - Siphoning
    - Pumping downhill without an anti-siphon valve
  - Little or no pressure at injection point
  - Change of stroke length or speed

Trouble Shooting – Dry Feeders

- **Feed helix not turning but power ON**
  - Check for obstructions
- **Chemical will not feed**
  - Increase frequency of hopper agitator
  - Check moisture content (fish eyes)
  - Is material bridging or packing in bin
- **Erratic feed**
  - Binding of drive shaft or helix
  - Low speeds

Low Fluoride Readings

- **In a saturator**
  - Inadequate chemical depth
  - Incomplete mixing-verify no short circuiting or piping in bed
  - Inconsistent chemical addition
  - Accumulation of cinders, encrustations
  - Verify no slimes or grease layers in gravel or additive bed
  - Verify softener working properly
  - Test the solution strength to verify that the solution is saturated

High Fluoride Readings

- **Phosphates**
  - When using SPADNS method
  - Verify with ISE meter
- **Sample chlorine residual**
- **Check natural level**
  - Fluctuations due to
    - Run off
    - Low river flows
    - Seasonal variations

Variable Fluoride Readings

- **Check feeder or pump for variable output-recalibrate settings**
- **Air binding in metering pumps**
- **Low chemical levels in saturator or insufficient material in bin hopper**
- **Intermittent operations**
- **Are calculations being conducted correctly? Do they compare to records of actual additive being consumed?**

Variable Fluoride Readings

- **Verify additive purity, water content or silica content**
- **Verify chemical not bridging or packing in bin**
- **Verify additive does not have excessive moisture or fish eyes**
- **Incomplete mixing, verify that mixing tank has adequate volume for hydration / saturation**

Variable Fluoride Readings

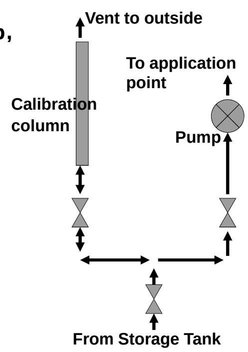
- Is tank experiencing stratification of concentrations? (different batches, complete dissolution, storage tanks?)
- Maintenance can result in unintended changes to controls and wiring
- Are controls and process working as intended?
- Is wiring correct?
- Does solution pump activates with one service pump but not the other?

Low Fluoride Readings

- Interferences with lab tests
- Glassware
  - Poor glassware
  - Improperly cleaned glassware
  - Phosphate detergent used
- Rinse with distilled water
- Sample temperatures
- Improper laboratory methodology
- Instrument errors, damage

Calibration for Pumps

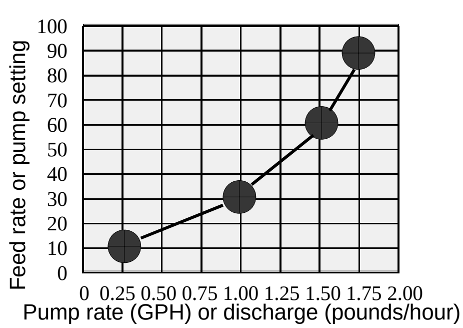
- Close valve to pump, open valve to calibration column and fill
- Close valve from storage tank, open valve to pump
- Measure time to pump measured volume for various pump settings



Calibration for Dry Feeders

- Conduct pan test
  - Fill hopper to normal depth
  - Set machine to low feed rate, allow discharge rate to achieve a stable and consistent rate, then collect discharge over a measured time in first pan
  - Repeat for several higher feed rates collecting discharge over measured time in sequential pans
  - Measure weight of pans with material and subtract pan weight to obtain material feed rate for each discrete machine setting

Calibration Curve



Calibration of Feed Delivery

- Calibration curve must be prepared for each pump or feeder
- Verify curve accuracy monthly, more frequently if additive character changes or maintenance is performed on equipment
- Curve should be based on 4 to 5 settings over the full range
- Always include the date of the calibration test

Overfeed

- **CDC provides overfeed recommendations, verify state specific requirements**
- **Water treatment facilities should have overfeed instructions with operator instruction on procedures**

Overfeed

- **For overfeeds less than MCL, continue operation while problem is identified**
- **For overfeeds exceeding MCL**
  - Temporarily stop operations while problem is identified
  - Notification of state personnel
  - Flush lines
  - Notify the public

Water Fluoridation Operations

Questions?

Section 7

Water System Security

WATER SYSTEM SECURITY

A Field Guide

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EMERGENCY PLAN

- Goal:
  - Assign roles and responsibilities to specific individuals and groups within the organization
  - Provide guidelines for conducting appropriate response actions
  - Establish systems that can mitigate the effect of an emergency or critical incident, prevent it from escalating, and enhance the recovery process

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PLANNING

- Three main levels of planning
  - Strategic
    - Comprehensive
    - Long term
    - Generalized
  - Operational
    - Focused
    - Short term
  - Tactical
    - Specific objective
    - Narrow goals

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HOW TO PLAN

- Follow steps
  - Assess the current conditions
  - Determine goals and objectives
  - Allocate appropriate resources
  - Implement the plan
  - Assess the plan and modify, if needed

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EMERGENCY RESPONSE PLAN

- Improves understanding and cooperation within a utility and with external emergency responders
- Produces higher level of coordination
- Allows critical resources to be applied better
- Produces a physical document detailing emergency response capabilities and responsibilities
- Should be an ever changing document

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VULNERABILITY ASSESSMENT

- A process in which the effects of an unforeseen event are evaluated.
- Should include all aspects of the entire system
  - Physical
  - Operational
  - Critical mission

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VULNERABILITY ASSESSMENT

- Four step process
  - Identify and describe major components of the total water supply system
  - Identify threats and estimate potential effects of those threats on the each component of the system
  - Establish performance goals and acceptable levels of service for the system
  - If determined that system will fail to operate at desired levels, identify
    - Key or critical system components
    - Appropriate corrective measures

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IDENTIFY MAJOR SYSTEM COMPONENTS

- Administration and operations
- Source water
- Transmission system
- Finished water storage
- Distribution system
- Supporting infrastructure
  - Electric power, transportation, communications

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IDENTIFY MAJOR SYSTEM COMPONENTS

- Be as detailed as possible
  - Maps and blue prints
  - Geographic information system (GIS)
  - Hydraulic models
  - General description for distribution system
    - Pressure zones
    - Location of pressure relief valves
    - Pipe sizes
    - Pipe material and ages
    - Typical distance between hydrants
    - Major valve locations

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IDENTIFY THREATS, ESTIMATE POTENTIAL EFFECTS

- Accident
- System malfunction
- Vandalism
- Human error
- System aging
- Natural disaster
- Extortion
- Sabotage
- Waste leakage/seepage
- Terrorism
- Civil unrest

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IDENTIFY THREATS, ESTIMATE POTENTIAL EFFECTS

- This step should include
  - Variety of utility staff
    - Engineering, operations, and maintenance personnel
  - Local law enforcement staff
    - Different and fresh perspective
    - May see something that utility staff overlooked

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IDENTIFY THREATS, ESTIMATE POTENTIAL EFFECTS

- Critical components of system
- Most likely components to be threatened
- Level of threat

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IDENTIFY THREATS, ESTIMATE POTENTIAL EFFECTS

- Individual
  - Vandal
    - Has a goal in mind, but not necessarily a target
    - Crime is one of opportunity
  - Lone wolf
    - An individual working independently
    - Target is clearly defined
  - Insider
    - Present or former employees and contractors

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IDENTIFY THREATS, ESTIMATE POTENTIAL EFFECTS

- Groups
  - Domestic extremist groups
  - Terrorist organizations

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ESTABLISH PERFORMANCE GOALS & ACCEPTABLE SERVICE LEVELS

- What is the mission of a water utility?
- Is it to provide safe, clean drinking water at all times?
- What about water for fire protection or sanitary purposes?
- If a disaster strikes, can the utility proved an adequate supply of water to fight fires?
- Who are the priority customers that may need uninterrupted service?

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IDENTIFY CRITICAL SYSTEM COMPONENTS AND SYSTEM VULNERABILITY

- Critical Components
  - Components whose failure will most affect the delivery of safe and adequate drinking water
  - Most vulnerable to failure or partial failure due to an intentional act or natural disaster
  - Failure will reduce system's ability to meet minimum requirements

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IDENTIFY CRITICAL SYSTEM COMPONENTS AND SYSTEM VULNERABILITY

- Critical Components
  - Personnel
    - Most critical component
  - Operational considerations
    - Planning, operations, maintenance, security procedures and activities
  - Physical facilities
    - Source water reservoir, pipelines, pumps, treatment facilities, buildings, tanks and vehicles
  - Biological and chemical processes
    - Generate or threaten the production and delivery of safe water
  - Cyber, supervisory control and data acquisition (SCADA), and communications
    - Sensors, computers, internet, intranet, telecommunications, telemetry, and computer based communications

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PERSONNEL

- Subject to wide range threats
  - Physical
  - Biological
  - Chemical
  - Psychological threats

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OPERATIONAL CONSIDERATIONS

- The "how" you do things must be considered when evaluating critical components, threats, and mitigating measures
  - Operational aspects
  - Routine and scheduled inspections
  - Who performs what functions
  - Passive or active security measures

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PHYSICAL FACILITIES

- "Things" we see and work with on a daily basis
  - Source water
  - Pumps
  - Tanks
  - Distribution lines
  - Etc.

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CHEMICAL, BIOLOGICAL, and RADIOLOGICAL CONCERNS

- Dangerous contaminants could be added to the water supply at any point
  - From source to distribution system
  - Released in a facility
- Destruction of chemicals that are used by utility to treat drinking water
- Contamination of treatment chemical

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CYBER, SCADA, and COMMUNICATION ISSUES

- SCADA or other data systems are vulnerable
  - Many equipped with "back doors" to allow access by system administrators
  - Connected to email which can carry viruses
- AMR (automatic meter readers)
  - How would the utility bring in revenue

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PROTECTING SENSITIVE INFORMATION

- In the wrong hands, a vulnerability assessment could be very dangerous
- Freedom of Information Act (FOIA)
  - Law that gives you the right to access information from the federal government.
  - If federal agency obtained assessment, it could become public record
- Vulnerability assessments may not be protected under state or local "open record" or "sunshine" laws or codes.
  - Could be available for the public to view

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PROTECTING SENSITIVE INFORMATION

- Have utility/city attorney do some background work
  - Study state and local FOIA-type laws and codes to determine what the utility would have to reveal after conducting a vulnerability assessment
  - Before drawing up a request for proposal of vulnerability assessment, determine if the assessment could be written to fit under any exemptions provided in state or local laws

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PROTECTING SENSITIVE INFORMATION

- If sensitive information is requested, utilities should require:
  - Identification of organization or persons requesting information
  - Exactly what information they wish to review
  - What purpose they seek that information
- Utility attorney should review request before releasing any information

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INTERDEPENDENCIES

- A utility relies on other utilities and services
  - Electric power
  - Natural gas
  - Diesel or propane fuel
  - Sanitary sewer system
  - Telecommunications
  - Transportation system
  - Emergency responders

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MITIGATION MEASURES

- Define safeguards or mitigation measures that can protect assets
- Things to consider during mitigation
  - Fiscal resources
  - Staff resources
  - Political considerations
  - Social and cultural considerations
  - Legal and regulatory considerations

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MITIGATION MEASURES PERSONNEL

- Establish a "culture of security"
  - Incorporate security in every aspect of the utility and its mission
  - Include security in the daily routine
  - Identify it as key organizational value
  - Appoint a security manager responsible for addressing security needs at the utility

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MITIGATION MEASURES PERSONNEL

- Develop written security policies and procedures
- Incorporate these policies and procedures into the general emergency preparedness plan
- Make sure all crucial roles and responsibilities are assigned to appropriate personnel
  - Employees, contract service providers, or emergency service providers

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MITIGATION MEASURES PERSONNEL

- Policies and procedures to consider
  - Make it a rule that all doors are locked and alarms set at your office, well houses, treatment plants, and vaults
  - Tell your employees to question strangers in your facilities, and do not allow access to anyone who does not have a valid reason for being there
  - Indicate restricted areas by posting "Employees Only" signs
  - Do not leave keys in equipment or vehicles at any time

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MITIGATION MEASURES PERSONNEL

- Train the people who must implement these procedures
- Conduct background checks on employees
  - Initially and periodically
- Control entry to the plant
  - Keys, ID badges, etc.

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MITIGATION MEASURES OPERATIONAL

- Source Water Treatment
  - Must be able to get raw, untreated water during emergencies.
  - Establish connections with nearby utilities
- Distribution System
  - Tamper proof hydrants and valve boxes
  - Fence around vulnerable areas with lock
  - Early warning systems to notify operator of changes in chemical characteristics, flows, pressures, and temperature
  - Establish emergency notification protocol with the sanitation system
    - This needs to go both ways

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MITIGATION MEASURES OPERATIONAL

- Operations
  - Educate employees
    - Instruct them to report unusual situations
    - Cross train them to provide back up capabilities during emergencies
  - Develop agreements with neighboring utilities
  - Control public access to critical information about the utility
  - Vary the scheduling of operational procedures
  - Establish a protocol for determining at what point you take action, notify law enforcement, notify the public and/or shut down the system

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MITIGATION MEASURES VISITORS

- Look at policies addressing contractors, visitors, and scheduled tour groups
- Eliminate or limit public access to critical areas of the plant
- Ensure all visitors have proper identification
- Schedule, screen and verify all deliveries to the plant and delivery personnel

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MITIGATION MEASURES PHYSICAL

- Primary objective is to prevent theft and sabotage
- Accomplished by deterring or defeating the adversary
  - Deter – system must be perceived as too difficult to defeat
  - Defeat – requires detection, delay, and response

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MITIGATION MEASURES PHYSICAL

- Detection
  - Discover via a protective force
  - Analyzing must included with this step
  - Exterior and interior detection sensor technologies
    - Microwave
    - Infrared (passive and active)
    - Vibration
    - Video motion detectors
    - Close circuit television systems
    - Proximity

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MITIGATION MEASURES PHYSICAL

- Delay
  - Provide obstacles to increase adversary's task time
  - May be passive or active
  - Obstacles are usually physical barriers
    - Fencing, gates, locks
    - Distance
    - Guard stations
    - Roadway configurations
    - Visual barriers

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MITIGATION MEASURES PHYSICAL

- Response
  - Prevent adversary from accomplishing the intended act
  - Includes
    - Communicating with the response force
    - Deploying the response force
    - Neutralizing the adversary
  - Primary response force is local law enforcement

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MITIGATION MEASURES CYBER, SCADA, & COMMUNICATIONS

- Install virus-protection software for email and internet access
- Categorize data and protect it accordingly
- Limit control of remote terminals to on-site or main terminals only
- Keep your operating system current
- Install a data log that can track all activity on a SCADA system
- Install intrusion detection software

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EMERGENCY RECOVERY

- Recovery plan must address the steps to be taken and provide an estimate of the time it will take for those steps to occur
- Management must consider the medium and long term steps that will allow the utility to completely recover from the disaster
  - Reduce the probability of additional injuries or damage
  - Perform emergency repairs based on priority demand
  - Return system to normal levels

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CRISIS COMMUNICATIONS

- Be the first to deliver the bad news
- When dealing with the media
  - Appoint one person to be the spokesperson
  - Prepare fact sheets and background information; have press release templates that can be quickly filled in with details
  - Set up pressroom that separates media from emergency command center
  - Be on time
  - Spell out your name and title when introducing yourself
  - Always repeat the question you are about to answer

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CRISIS COMMUNICATIONS

- When dealing with the media
  - Address fears by offering facts, not assumptions
  - Do not answer "what if" questions
  - Do not discuss costs of an incident
  - If all the facts are not known, admit that.
  - There is no such thing as "off the record"
  - Avoid assigning blame
  - Keep communications simple and direct to avoid confusion
  - Schedule a time for next update and meet this schedule even if there is no new information
  - Recognize and respect media deadlines

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Section 8

Emergency Operations Plan

EMERGENCY OPERATIONS PLAN

1

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PROTECTING THE PUBLIC HEALTH

- Safe and reliable drinking water should be delivered to the public
- Should meet federal and state requirements
- Should be delivered in adequate quantities and at adequate pressures

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EMERGENCY OPERATIONS PLAN

- Also called EOP
- Identifies natural disasters and other emergencies that may strike a water system
- Assists water system in responding to emergencies quickly and effectively

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EMERGENCY OPERATIONS PLAN

- A carefully planned EOP will:
  - Reduce property damage
  - Minimize downtime
  - Prevent illness
  - Save lives
  - Reduce system liability
- Emergency response planning is essential

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EMERGENCY OPERATIONS PLAN

- EOP's include specific responses to:
  - Routine emergencies
  - Natural disasters
  - Accidents
  - Intentional man-made acts
  - Or any other incident that causes casualties, damage or disruption to the water system

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ROUTINE EMERGENCIES

- Line breaks
- Power outage
- Mechanical failure
- Water contamination

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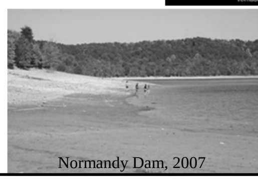
NATURAL DISASTERS

- Tornado
- Flood
- Earthquake
- Ice storm
- Drought


Tornado in Central Oklahoma, USA


Normandy Dam, 2007

7

ACCIDENTS

- Fire
- Chemical spill
- Explosion

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INTENTIONAL MAN-MADE ACTS

- Vandalism
- Terrorism
- Threats

Training Center 9

VULNERABILITY ASSESSMENT

- For those systems who have done the Vulnerability Assessment (VA), the EOP should include response actions to potential threats and malicious acts identified in your VA

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EMERGENCY OPERATIONS PLAN

- The Tennessee Division of Water Supply defines a document that prepares for an emergency response as an "Emergency Operations Plan".
- The US EPA refers to this document as an "Emergency Response Plan (ERP)"

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EOP

- State Rules require all community water systems to have an EOP
  - 1200-5-1-.17(7)
  - "… all community water systems shall prepare an emergency operations plan in order to safeguard the water supply and to alert the public of unsafe drinking water in the event of natural or man-made disasters."

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HISTORY

- After September 11, 2001 the federal government amended the Safe Drinking Water Act (SDWA) to add regulations on emergency preparedness for utilities, including community water systems

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HISTORY CONTINUED

- The BioTerrorism Act of 2002 added amendments to the SDWA that required the revision of water system emergency response plans to incorporate the results of the water system's vulnerability assessment

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HISTORY CONTINUED

- The Terrorism Act required that emergency response plans include plans, procedures and the identification of equipment that can be used in the event of a terrorist or other intentional attack on the water system

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EOP

- The EOP is a living document and should be reviewed and updated every two years
  - When there is a change to the water system configuration
  - Or when required by state or federal regulations

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EOP ELEMENTS

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EIGHT ELEMENTS OF EOP

- System Specific Information
- Roles and Responsibilities
- Communication Procedures
- Personnel Safety
- Alternate Water Source
- Equipment and Spare Parts
- Property Protection
- Water Sampling & Monitoring

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SYSTEM SPECIFIC INFORMATION

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SYSTEM SPECIFIC INFORMATION

- Water system info
- Maps & critical info
- Water source
- Water treatment process
- Distribution system
- Pumping facilities
- Storage facilities
- SCADA system
- Chemical inventory
- Materials/parts inventory
- Critical customers
- Largest customers
- Security features
- Communication equipment
- Office computer equipment

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WATER SYSTEM INFORMATION

- Lists general information about the water system
  - System name & PWSID#
  - Address and directions to plant, office and emergency operations center (EOC)
  - Number of employees and certified distribution operators
  - Utilities used by water plant: electric, phone, gas and cell phone companies
  - Number of connections and population served

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MAPS AND CRITICAL INFO

- EOP should reference
  - Location of distribution maps
  - Detailed plan drawings
  - Site plans
  - Valve and hydrant maps/books
  - Process flow diagrams
  - Operations reports
  - Operating manuals
  - Permits
  - Etc.

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MAPS AND CRITICAL INFO CONTINUED

- Maps and other critical plans may be kept at a secure location and given out only on a "need-to-know" basis at the discretion of the water system manager
- Maps need to be kept-up to date
- Keep duplicate copies secured off-site

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WATER SOURCE

- There are different templates for
  - Surface water
  - Well water
  - Purchased water
  - Spring water

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WATER SOURCE CONTINUED

- Give location for intake or master meter
- Intake pipe size
- Raw water pump info
  - Manufacturer, HP, capacity, year installed
- Well depth, diameter, static water levels
- Chemicals added at intake and quantity stored at intake building

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WATER TREATMENT PROCESS

- Dimensions and detention times for
  - Flash mix
  - Flocculation basins
  - Sedimentation basins
  - Filters
- Chemicals added and point of application, especially chlorine and fluoride

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DISTRIBUTION SYSTEM

- Population served
- Number of residential and commercial meters
- Miles of pipe
- Number of booster pumps and backflow preventers
- Peak, average and minimum daily demands

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PUMPING FACILITIES

- Name/location
- Whether it is a building or underground vault
- Elevation
- Capacity
- Suction and discharge pressure

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STORAGE FACILITIES

- Total number of elevated and ground level tanks
- Storage facility name/location
- Description
  - Welded steel, concrete, elevated, etc.
- Overflow or ground level elevation
- Capacity
- Level control
- Access and security

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SCADA SYSTEM

- Manufacturer of SCADA, Computer hardware running SCADA, Network software, Firewall/Security software, Antivirus software
- Outside access to SCADA
  - Phone line, DSL, cable, other, none
- Is system password protected?

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CHEMICAL INVENTORY

- Chemical brand and common name
- What process is it used for?
- Point of use
- Solid, liquid, gas?
- Strength
- Daily consumption
- Suppliers and their contact info

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MATERIALS & PARTS INVENTORY

- Description
- Serial # or VIN #
- Quantity
- Location

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CRITICAL CUSTOMERS

- Critical customers should be listed and prioritized based on community health issues
  - Hospitals, nursing homes, schools, daycares, etc.
- Name
- Description
- Address
- Phone #
- gal/day needed

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LARGEST CUSTOMERS

- List in prioritized order based on critical products or services to the community
- Name
- Description
- Address
- Phone #
- gal/day needed

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SECURITY FEATURES

- Location of buildings
- Gates, fences
- Doors/windows
- Locks/card key
- Alarm systems
- Security lighting
- Cameras/monitors

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COMMUNICATION EQUIPMENT

- Cell phones
- Pagers
- 2-way radios
- Satellite phones
- Laptops with phone service
- Need description, serial #, quantity and location for all these

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OFFICE COMPUTERS & EQUIPMENT

- Name and contact info for internal and outsource IT person
- Office computer hardware
  - Manufacturer
  - Serial #
  - Description/Processor
  - Location

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ROLES & RESPONSIBILITIES

CHAIN OF COMMAND
EMERGENCY RESPONDER COORDINATOR
INCIDENT COMMAND SYSTEM

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CHAIN OF COMMAND

- In an emergency, system personnel should know
  - Where to report
  - Whom to report to
  - What their responsibilities are during the emergency response

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CHAIN OF COMMAND CONTINUED

- Chain of command establishes lines of authority that preserve order and prevent confusion
- Check this document quarterly to confirm accuracy of personnel and phone numbers

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EMERGENCY RESPONSE COORDINATOR

- The first response in any emergency is to notify the lead person
  - This is the person at the top of the chain of command
  - Referred to as the Emergency Response Coordinator (ERC)
- An alternate ERC should be designated in case primary ERC is unavailable

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EMERGENCY RESPONSE COORDINATOR CONTINUED

- The ERC will asses the emergency and initiate the appropriate response actions
- The ERC will manage the entire emergency response unless an Incident Command Structure (ICS) facilitates a transfer of command

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EMERGENCY RESPONSE COORDINATOR CONTINUED

- Other names given for lead person are
  - Emergency operations coordinator (EOC)
  - Emergency operations leader (EOL)
  - Incident commander (IC)
  - Water utility emergency response manager (WUERM)

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INCIDENT COMMAND SYSTEM

- In a major disaster, emergency or terrorist act, the ERC may need to initiate and/or defer to an Incident Command System (ICS)
- ICS is the model tool for coordinating the response efforts of several agencies as they work an emergency response

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INCIDENT COMMAND SYSTEM CONT

- If another agency takes over command in an ICS situation, the ERC and water system personnel remain in charge of all water system repairs and operations

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COMMUNICATION PROCEDURES

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COMMUNICATION PROCEDURES

- Internal contact list and responsibilities
- External contact list
- Emergency communications plan
- Effective communications
- Personnel safety
- Alternate water source
- Equipment and spare parts
- Property protection
- Water sampling and monitoring

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INTERNAL CONTACTS

- Contact information should be maintained for all people that may need to respond in an emergency
- List should be reviewed quarterly to keep up-to-date
- List should have home and cell number to contact people day or night
- Store back-up file/list at secure off-site location

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EXTERNAL CONTACTS

- Obtain cell phone or 24-hour emergency numbers for all external contacts
- List should be reviewed quarterly to keep up-to-date

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EXTERNAL CONTACTS CONTINUED

- Local police
- Fire and first responders
- Local Government
  - Mayor, Chamber of commerce
- Local media
  - TV, radio, newspaper
- Utilities
  - Electric, natural gas, phone
- Cell phone companies
- Diesel fuel suppliers
- Outside vendors
  - Water plant pipes/parts, chemicals, SCADA
- Contractors
- Pump specialist
- Electricians & Plumbers
- Regulatory agencies
- Critical customers
- Water testing labs

Can you think of other external contacts?

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EXTERNAL CONTACTS CONTINUED

- The TN Department of Homeland Security should be notified of any acts against the water system that may be caused by terrorist
- FBI becomes the lead agency in this case

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EMERGENCY COMMUNICATIONS PLAN

- Communication procedures should be documented
- Alternate communications plans should be included in your EOP in the even that land lines, cell phones or walkie-talkies don't work
- Communicate with cellular companies on the availability of priority channels during an emergency
- Satellite phones should be considered an alternative

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EMERGENCY COMMUNICATIONS PLAN CONTINUED

Emergency Communications Plan

Template A-25 Example

1	Walkie-talkie phones will the be first line of communication in an emergency. If walkie-talkie phones are inoperable, land phones, personal cell phones, and/or 2-way radios should be used to communicate with water system staff and external responders. Office managers will attempt to call phone company/cell phone company to request priority in restoring cell phone signals. (Two trucks and the office currently have three pair of 2-way radios. Two additional pair of 2-way radios are located in the manager's office at the Water System office.) Do not use 2-way radio for communications that should not be released to the public.
2	If phone and radio communication are inoperable, water system personnel should drive to the Emergency Operations Center (EOC) for emergency communication /assignments. Responders should communicate in person by walking or driving until phone service is restored.
3	Contact TEMA immediately for communication /emergency management assistance

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EFFECTIVE COMMUNICATIONS

- Plan how you will communicate with customers and media before emergencies happen
- Designate a media spokesperson
- If 10% of the population speaks Spanish or another language, additional translated versions of public notifications should be made available

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PERSONNEL SAFETY

- The water system should have procedures for securing the safety of utility personnel and the immediate community
- Schedule training sessions on
  - Basic safety procedures
  - Alarm response
  - First aid
  - Personal protection equipment (PPE) usage
  - Evacuation procedures

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ALTERNATE WATER SOURCE

- Identify the sources and procedures for obtaining a short-term and a long-term alternate water supply in the event of an emergency

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PUBLIC NOTICES

- Boil Water Notice
  - No alternate source is required
- Do Not Drink Notice
  - Alternate water source must be provided for drinking and food preparation
- Do Not Use Notice
  - Alternate water source must be provided for drinking, cooking, bathing and even fire fighting (in certain contamination scenarios)

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TANKER TRUCKS

- If tanker trucks are used to transport or store water as an alternate water source, make sure you allow time to disinfect the trucks properly
- See Appendix F for tanker truck disinfection procedures

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EQUIPMENT AND SPARE PARTS

- Identify these that can reduce the impact of an emergency
  - Vehicles
  - Chemicals
  - Tools
  - Spare parts
  - Special equipment
- All heavy equipment, portable generators, spare pumps, etc should be listed here

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EMERGENCY EQUIPMENT

- SCBA
- Toxic gas meters
  - Check and calibrate chlorine alarms and test
- Chlorine repair kits: A, B and/or C kits
  - Plan for chlorine repair parts and supplies
- All PPE for emergency

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PROPERTY PROTECTION

- Establish a procedure for locking down the facility and establishing a secure perimeter to the plant grounds and buildings
- Enter a potential crime scene with caution, if you believe suspects are still present, call 911

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PROPERTY PROTECTION CONTINUED

- The ERC will communicate with local police and emergency response teams to determine if the building should be locked down and site perimeter secured
- Look over the grounds and note any persons or vehicles in the vicinity
- Look, listen and smell for dangerous signs

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PROPERTY PROTECTION CONTINUED

- If you find victims, check out their physical condition, provide comfort and medical attention (if trained)
- Do not clean up, remove items or otherwise disturb the crime scene
- Document any statements/comments made by victims, suspects or witnesses on the scene

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PROPERTY PROTECTION CONTINUED

- After the site is secured and victims are stabilized, begin assessing potential contamination and/or damage to the water system
- Follow the water system's EOP

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WATER SAMPLING & MONITORING

- DWS and approved water lab should be consulted to determine appropriate testing and sampling
- Identify the certified operator or team (and alternates) who is/are responsible for taking samples

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WATER SAMPLING & MONITORING

- Sampling procedures should be outlined for:
  - Decision-making process to determine the tests to run
  - Location and/or source of test kits and/or sample containers
  - When to use preservatives or dechlorinating agents
  - Sample quantity to collect
  - Proper collection procedures

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WATER SAMPLING & MONITORING

- Provide a water sampling plan of your water distribution system
  - Sampling plan is to provide sample protocol and chain of custody
- Laboratory agreements are needed and contacts of outside labs are needed to secure monitoring requirements

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OTHER KEY ELEMENTS TO EMERGENCY PLANNING PROCESS

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WATER CONSERVATION & DROUGHT MANAGEMENT

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DROUGHT MANAGEMENT

- Public water systems and local communities should plan for conditions of low water supply by having an approved drought management plan in place
- *Local Drought Management Planning Guide for Public Water Suppliers*

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DROUGHT MANAGEMENT CONTINUED

- Plan may include, but not limited to the following restrictions
  - Use of water to wash any motor vehicle, motorbike, boat, trailer, or airplane or other vehicle
  - Use of water to wash sidewalks, driveways, decks, home siding, gutters, parking lots or other hard-surface
  - Use of water to irrigate lawns, trees, shrubs, plants and flowers

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DROUGHT MANAGEMENT CONTINUED

- Plan may include, but not limited to the following restrictions (cont.)
  - Use of water to fill indoor or outdoor swimming pools or hot-tubs
  - Use of water in fountain or pond except where necessary to support aquatic life
  - Use of water from a fire hydrant for other than fire fighting purposes

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WATER CONSERVATION

- Voluntary water conservation measures should be emphasized
  - Take short showers
  - Fix leaky faucets and running toilets
  - Don't allow water to run while brushing teeth or shaving
  - Collect rainwater for watering plants, gardens and flowers

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THREAT EVALUATION

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THREAT EVALUATION

- All threats should be taken seriously
- Threats may be reported or delivered in many different forms
  - Consumer complaint of water taste or odor
  - Witness account of tampering with water tank
  - Phone call from alleged perpetrator
  - Emergency room reporting patients with symptoms after drinking water

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THREAT IDENTIFICATION CHECKLIST

- Should be kept next to every phone at the office and water treatment plant
- If a threat is received, the checklist should be completed
  - See A-32 Threat Identification Checklist

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THREAT IDENTIFICATION CHECKLIST

- If you receive a suspicious letter or package, set it aside and do not open it
- Calmly instruct everyone to leave the room immediately
- Close the door
- Wash your hands with soap and water
- Notify your supervisor and/or call 911 if a suspicious substance is visible

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FOLLOW-UP EOP ACTIVITIES

- EOP approval and review date
  - Keep log on approvals
  - Update every two years
- EOP distribution
  - Keep copies numbered for control purposes
  - Keep log on who has what copy and where
- Training
  - Minimum training once a year

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TRAINING

- Orientation or classroom sessions
  - Basic instruction on EOP procedures
- Tabletop workshop
  - Fabricated event with actions/verbal responses and close with evaluation
- Functional exercise
  - Team of simulators develops a realistic major event and staff responds to the event
- Full-scale drills
  - More costly

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TRAINING CONTINUED

- Successful implementation of the EOP plan is going to depend on:
  - Training of employees and contacts
  - Yearly mock trial
  - Rotate personnel on the response teams
  - Annual revisions and updates

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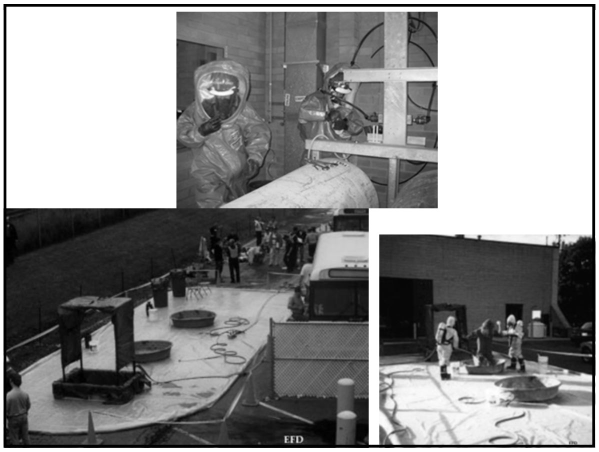

CHLORINE LEAK AT PLANT

- Water plant should have a current evacuation plan for chlorine gas evacuation
- Current plan should evacuate the plant grounds and a minimum ½ mile radius of affected area

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CHLORINE LEAK AT PLANT CONTINUED

1. Chlorine alarms go off and start a response
2. Phone call made of chlorine gas leak in plant
3. Operator makes investigation on site to chlorine room and alarms
4. Leak found and starts response

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CHLORINE LEAK AT PLANT CONTINUED

5. Incident commander notified and incident command started
6. Chlorine alarms acknowledged and evacuation started
7. Chlorine response and repair team activates to contain the leak; locate and isolate chlorine gas leak if possible

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CHLORINE LEAK AT PLANT CONTINUED

8. Water Plant evacuated and secured
9. Staging Area for incident command and safe zone established
10. Notify: 911, Hazmat, Police and Fire Department
11. Coordinate neighborhood evacuated with Police and Fire Department

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CHLORINE LEAK AT PLANT CONTINUED

12. Response Teams are working to isolate the chlorine leak
13. Chlorine repair team finds the leak and repairs the chlorine pressure diaphragm to the chlorine manifold
14. Area is checked for air monitor by gas detector for chlorine gas levels

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CHLORINE LEAK AT PLANT CONTINUED

15. Two hours into the event, the area is secure
    - Incident commander determines that the water plant is safe to return to normal water plant operations
16. Incident command is shut down
17. Normal plant operations and chlorine process are monitored for further compliance
18. Evacuation is canceled

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REFERENCES

- Emergency Operations Planning Guide, TN DWS along with templates can be found at: http://www.state.tn.us/environment/dws/security/svadocuments.shtml

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Section 9

Laboratory Methods

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:

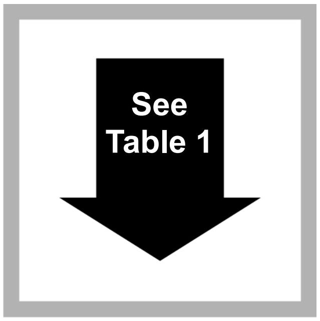
Read the entire procedure before starting the test.
A pH meter is required for NPDES reporting and is recommended for best results.
Substitute six drops of Phenolphthalein Indicator Solution for the Phenolphthalein Indicator Powder Pillow if necessary
Substitute six drops of Bromcresol Green-Methyl Red 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:

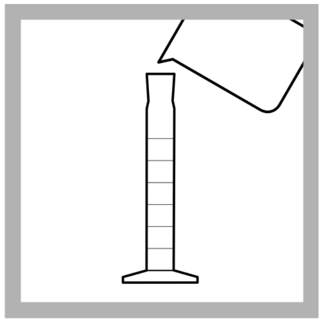
Description	Quantity
Bromcresol Green-Methyl Red indicator powder pillow	1
Phenolphthalein indicator powder pillow	1
Sulfuric acid standard solution, 0.020 N	varies[1]
Buret clamp, double	1
Buret, Class A, 25-mL	1
Graduated cylinder	varies[1]
Erlenmeyer flask, 250-mL	1
Funnel, Micro	1
Support Stand	1

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

Buret titration (Method 8221)

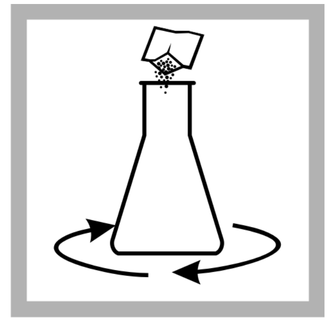


1. Select a sample volume from the *Sample volume selection for expected concentration* table that corresponds to the expected alkalinity concentration in mg/L as calcium carbonate ($CaCO_3$).

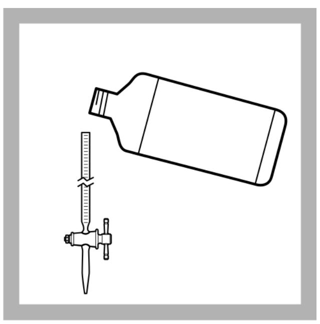


2. Use a graduated cylinder or pipet to measure the sample volume.

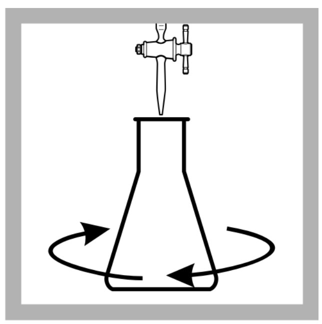
3. Transfer the sample into a 250-mL Erlenmeyer flask. Dilute to about 50-mL with deionized water if necessary.



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

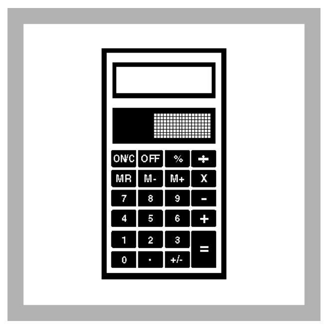


5. Fill a 25-mL buret to the zero mark with 0.020 N Sulfuric Acid standard solution.



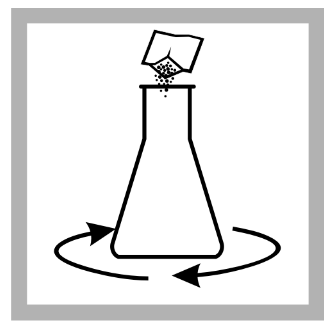
6. While swirling the flask, titrate the sample until the solution color changes from pink to colorless (pH 8.3).

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 $CaCO_3$.

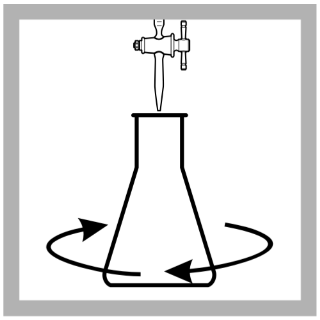


8. Add the contents of one Bromcresol Green-Methyl Red Indicator Powder Pillow to the titrated sample. Swirl to mix.

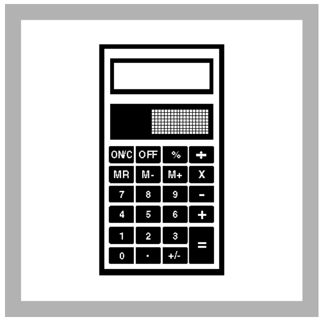
Do not add indicator if a pH meter is used.

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:

$$250 - 170 = 80$$

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

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

Hardness, Calcium

DOC316.53.01157

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:

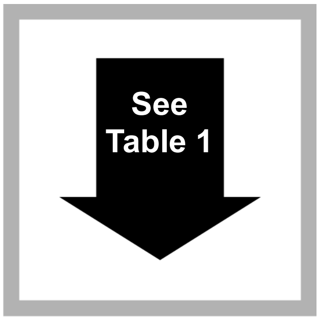
A 0.1-g scoop of CalVer® 2 Calcium Indicator Powder can be used in place of the CalVer 2 Calcium Indicator Powder Pillow.
Magnesium is not included in the results but must be present for a sharp end point. If magnesium is not present, add one to two drops of Magnesium Standard Solution, 10-g/L as $CaCO_3$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

Collect the following items:

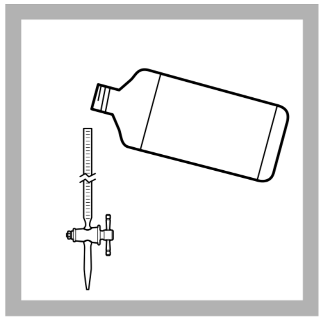
Description	Quantity
CalVer 2 Calcium Indicator Powder Pillow	1
Potassium Hydroxide Standard Solution, 8 N	1 mL
TitraVer Hardness Titrant (see *Range-specific information*)	1 bottle
Buret, Class A, 25-mL, with support stand	1
Erlenmeyer flask, 250 mL	1
Graduated cylinder	1

See *Consumables and replacement items* for reorder information.

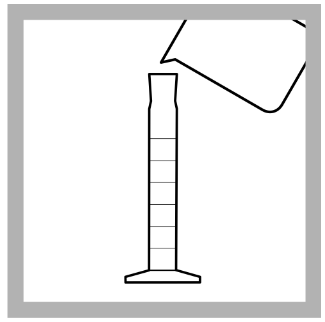
Buret titration



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

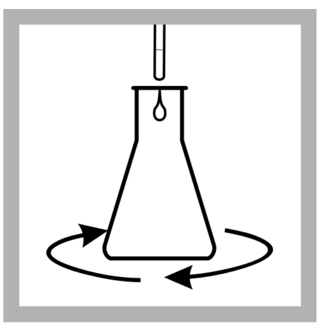


2. Fill a 25-mL buret to the zero mark with the TitraVer Hardness Titrant.

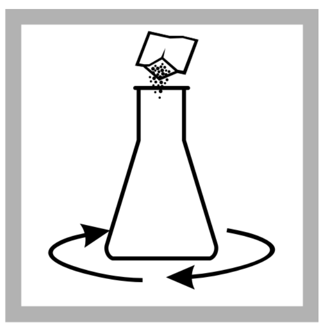


3. Use a graduated cylinder or pipet to measure the sample volume from the *Range-specific information* table.

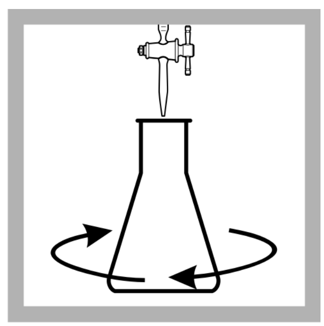
4. Transfer the sample into a 250-mL Erlenmeyer flask. If the sample volume is less than 50 mL, dilute to approximately 50 mL with deionized water. If magnesium is known to be absent, add one or two drops of Magnesium Standard Solution, 10-g/L as $CaCO_3$.



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

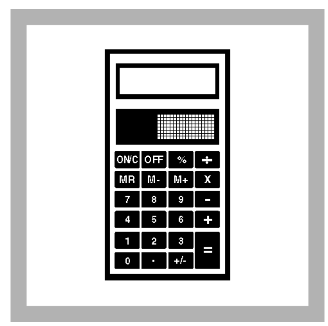


6. Add the contents of one CalVer 2 Calcium Indicator Powder Pillow. Swirl to mix.



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

Chlorine, Free

DOC316.53.01155

USEPA[1] Amperometric Buret Titration Method[2]

Method 8334

0.5 mg/L and above

Buret Titration

Scope and Application: For water and wastewater.

[1] USEPA accepted; 40 CFR Part 141, Section 141.74.

[2] Adapted from *Standard Methods for the Examination of Water and Wastewater* (4500 Cl^-D).

Test preparation

Before starting the test:

Chlorine can be lost from the sample during sample collection. Review the precautions in *Sample collection, preservation and storage* before the test is started.
Use only a 50-mm stir bar. The wrong size can cause the loss of chlorine, unstable readings and loss of method sensitivity, especially when measuring low level chlorine concentrations.
For added convenience when stirring, use the TitraStir® apparatus.
When a new probe is placed in service or when the probe has not been used recently, prepare it according to the Probe Stabilization instructions in the Amperometric Titrator Instruction Manual.

Collect the following items:

Description	Quantity
Phenylarsine Oxide Solution, 0.00564 N	1 bottle
Phosphate Buffer Solution, pH 7	1 mL
Amperometric Buret Titrator System	1
Beaker, 250-mL	1
Graduated cylinder, 250-mL	1

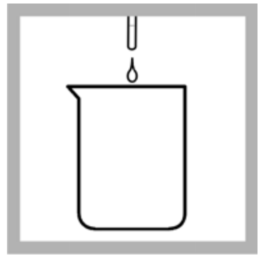
See *Consumables and replacement items* for reorder information.

Buret titration

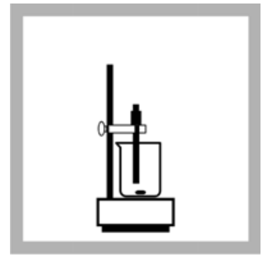
1. Fill the 5-mL automatic buret to the zero mark with 0.00564 N Phenylarsine Oxide (PAO) Solution.

2. Put a 50-mm stir bar into a 250-mL beaker.

Use a graduated cylinder to measure 200 mL of sample. Add the sample to the beaker.



3. If the pH is less than 6 or greater than 7.5, add 1.0 mL of pH 7 Phosphate Buffer Solution to make the prepared sample.

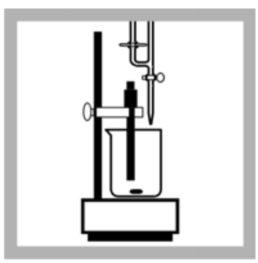


4. Place the beaker of prepared sample on the TitraStir titration stand and turn on the stirring motor. Put the tip of the probe fully into the prepared sample. The platinum wires must be submerged.

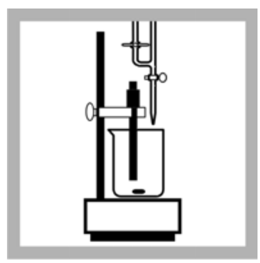
If a stir plate other than the TitraStir® is used, set the speed for moderate mixing. Do not adjust the speed after this point.

5. Turn the BIAS control knob to adjust the value on the display to approximately 1.00.

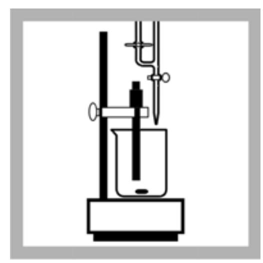
The BIAS adjustment controls the slope of the titration curve. The actual value is not important. Only the relative value as the titration continues is important. A precise adjustment is not necessary.



6. Dispense the titrant into the beaker in small increments while monitoring the values on the Amperometric Titrator. The values will decrease.

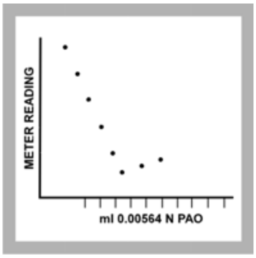


7. Continue dispensing slowly. Near the end point of the titration, write down the value on the display and the corresponding total volume of titrant that was added. Read the volume to the nearest 0.01 mL. Add a small amount of titrant and wait several seconds for a stable value. Write down the value.

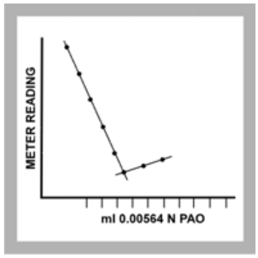


8. Continue the titration by recording at least three points on the downward sloping curve and at least three points after the end point has been reached. The value on the display will not change significantly after the end point.

Buret titration (continued)



9. Make a graph of the titration. Plot the values from the amperometric titrator on the vertical axis and the corresponding volume of titrant on the horizontal axis.



10. Draw the two best intersecting lines through the points as shown above. Find the volume of titrant to the nearest 0.01 mL at the intersection of the two lines. This is the mL titrant end point. This volume is equivalent to the free chlorine concentration in mg/L.

mL titrant =
mg/L free chlorine as Cl_2

Interferences

Refer to the Amperometric Titrator Instruction Manual for a discussion of sources of errors and interferences using the amperometric methods.

Sample collection, preservation and storage

Start the chlorine analysis immediately after the samples are collected. Chlorine is a strong oxidizing agent and is not stable in natural waters. Chlorine reacts quickly with various inorganic compounds and slowly oxidizes organic compounds. Many factors such as sample composition, sunlight, pH, temperature and salinity can cause the decomposition of chlorine in water.

Do not use plastic containers because plastic can react with and consume chlorine. Pretreat glass sample containers to remove any chlorine demand by soaking in a dilute bleach solution (1 mL commercial bleach to 1 liter of demineralized water) for at least 1 hour. Rinse thoroughly with demineralized or distilled water. If sample containers are rinsed thoroughly with demineralized or distilled water after use, only occasional pre-treatment is necessary.

Do not use the same sample containers 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 containers for free and total chlorine determinations.

A common error in testing for chlorine is introduced when a representative sample is not obtained. If sampling from a tap, let the water flow for at least 5 minutes before sample collection. Let the sample container overflow with the sample several times, then cap the container so that there is no headspace (air) above the sample. Start the chlorine analysis immediately.

Summary of method

Free chlorine is measured by a titration at pH 7 with PAO solution to the amperometric end point. The amperometric titration method has greater sensitivity and accuracy when compared to colorimetric methods. Refer to the Amperometric Titrator Instruction Manual for more information.

Consumables and replacement items

Required reagents

Description	Quantity/Test	Unit	Catalog number
Phenylarsine Oxide Solution, 0.00564 N	varies	1 L	199953
Phosphate Buffer Solution, pH 7	1 mL	100 mL MDB	2155332

Required apparatus

Description	Unit	Catalog number
Amperometric Buret Titrator System, 115 VAC	each	1930010
Beaker, 250-mL	each	50046H
Graduated Cylinder, 250-mL	each	50846
Stir bar, 50 mm	each	2095355
TitraStir® apparatus, 115 VAC	each	1940000
TitraStir apparatus, 230 VAC	each	1940010
pH Paper, 0–14 pH range	100/pkg)	2601300

Optional reagents and apparatus

Description	Unit	Catalog number
Chlorine Standard Solution, 10-mL Voluette® Ampules, 50–75 mg/L	16/pkg	1426810
Chlorine Standard Solution, 2-mL PourRite® Ampule, 50–75 mg/L	20/pkg	1426820
Chlorine Standard Solution, 2-mL PourRite Ampule, 25–30 mg/L	20/pkg	2630020
Voluette Ampule breaker 10-mL	each	2196800
PourRite Ampule breaker 2-mL	each	2484600
Water, deionized	500 mL	27249

FOR TECHNICAL ASSISTANCE, PRICE INFORMATION AND ORDERING:
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Chlorine, Free

DOC316.53.01023

USEPA DPD Method[1]

Method 8021

(0.02 to 2.00 mg/L)

Powder Pillows or AccuVac® Ampuls

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

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

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

Test preparation

How to use instrument-specific information

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

Table 1 Instrument-specific information

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

Before starting the test:

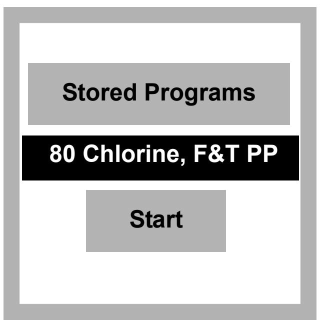
If the test over-ranges, dilute the sample with a known volume of high quality, chlorine demand-free water and repeat the test. Some loss of chlorine may occur due to the dilution. Multiply the result by the dilution factor. Alternatively, samples with high chlorine concentrations may be analyzed directly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

Collect the following items:

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

See *Consumables and replacement items* for reorder information.

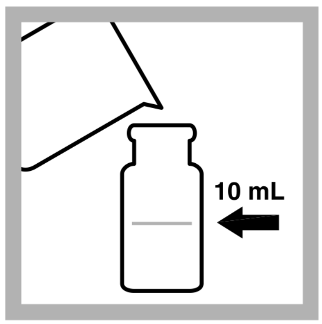
Powder pillow procedure



1. Select the test.

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

Refer to the user manual for orientation.



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

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

ZERO the instrument.

The display will show:

0.00 mg/L Cl_2

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

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

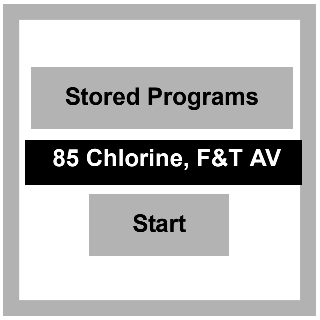
5. Swirl the sample cell for 20 seconds to mix.

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

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

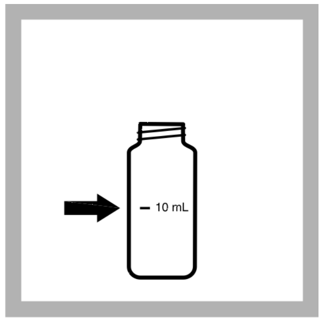
Results are in mg/L Cl_2.

AccuVac Ampuls procedure



1. Select the test.

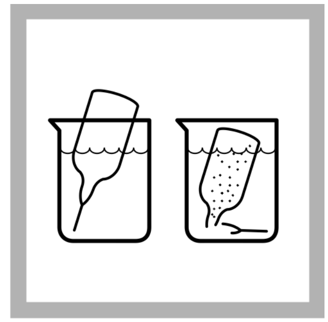
Insert an adapter if required (see *Instrument-specific information*).



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

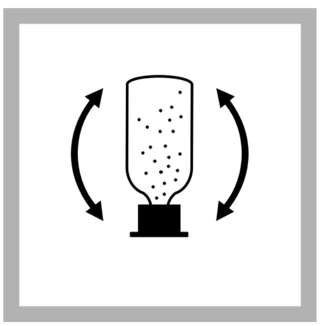
3. Wipe the blank and insert it into the cell holder.

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

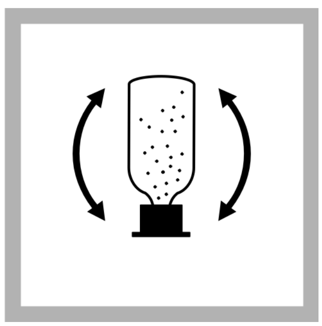


4. Prepared Sample: Collect at least 40 mL of sample in a 50-mL beaker.

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



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



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

READ the results in mg/L Cl_2

Interferences

Table 2 Interfering substances and levels

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

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

Sample collection, preservation and storage

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

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

Accuracy check

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

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

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

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

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

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

Method performance

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

Summary of method

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

Consumables and replacement items

Required reagents

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

Required apparatus

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

Recommended standards

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

Optional reagents and apparatus

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

[1] Includes one vial of 2105560 for 250 tests

Fluoride

DOC316.53.01184

USEPA[1] SPADNS 2[2] **Method 10225**

(0.02 to 2.00 mg/L F^-) **Reagent Solution or AccuVac® Ampuls**

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

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

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

Test preparation

How to use instrument-specific information

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

Table 1 Instrument-specific information

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

Before starting the test:

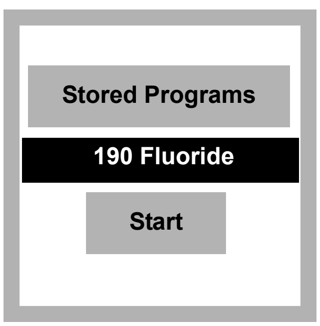
The sample and deionized water should be at the same temperature (± 1 °C). Temperature adjustments may be made before or after reagent addition.
SPADNS 2 Reagent is corrosive. Use care while handling the reagent.
For best results, measure the volume of SPADNS 2 Reagent as accurately as possible.
If the instrument displays Over Measure Range!, dilute a fresh sample with an equal volume of deionized water and repeat the test, using this solution in step 2. Multiply the result by 2.
SPADNS 2 Reagent contains a non-toxic reducing agent to prevent chlorine interference. SPADNS 2 does not contain sodium arsenite.

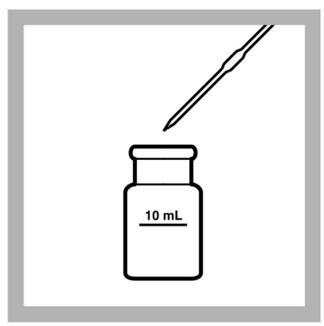
Collect the following items:

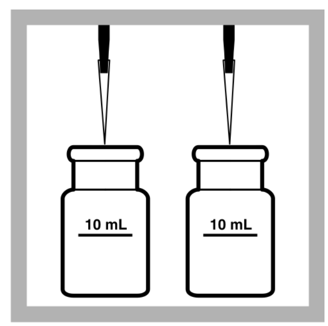
Description	Quantity
Solution test	
SPADNS 2 Reagent Solution	4 mL
Deionized Water	10 mL
Pipet, volumetric, 2-mL	1
Pipet, volumetric, 10-mL	1
Pipet Filler Bulb	1
Sample cells (see *Instrument-specific information*)	2
Thermometer	1
AccuVac test	
SPADNS 2 Fluoride Reagent AccuVac® Ampuls	2
Deionized Water	40 mL
Beaker, 50-mL	1

See *Consumables and replacement items* for reorder information.

SPADNS 2 reagent solution







1. Select the test.

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

2. Prepared Sample: Pipet 10.0 mL of sample into a dry sample cell.

3. Blank Preparation: Pipet 10.0 mL of deionized water into a second dry sample cell.

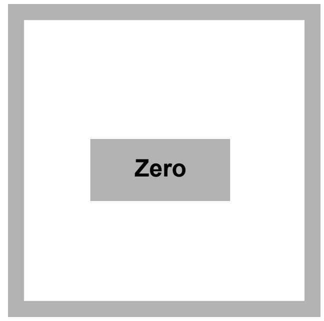
4. Carefully pipet 2.0 mL of SPADNS 2 Reagent into each cell. Swirl to mix.

SPADNS 2 reagent solution (continued)

5. Start the instrument timer.

A one-minute reaction period will begin.

6. When the timer expires, insert the blank.



7. **ZERO** the instrument.

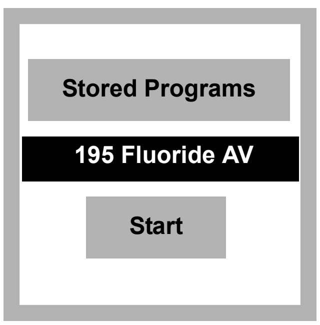
The display will show:

0.00 mg/L F^-

8. Insert the prepared sample cell.

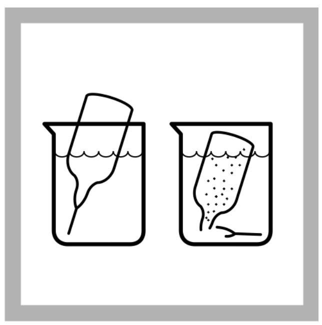
READ the results in mg/L F^-.

SPADNS 2 AccuVac® Ampuls



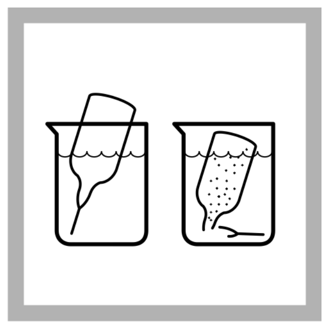
1. Select the test.

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



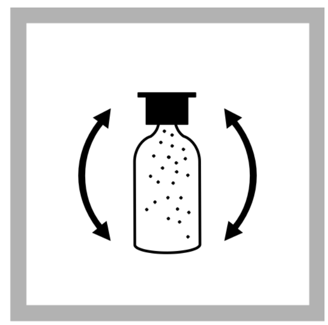
2. **Prepared Sample:** Collect at least 40 mL of sample in a 50-mL beaker.

Fill one SPADNS 2 Fluoride Reagent AccuVac Ampul with sample. Keep the tip immersed while the Ampul fills completely.



3. **Blank Preparation:** Pour at least 40 mL of deionized water into a second beaker.

Fill a second Ampul with deionized water. Keep the tip immersed while the Ampul fills completely.



4. Quickly invert both Ampuls several times to mix.

SPADNS 2 AccuVac® Ampuls (continued)

5. Start the instrument timer.

A one-minute reaction period will begin.

6. When the timer expires, insert the blank into the cell holder.

ZERO the instrument.

The display will show:

0.00 mg/L F^-

7. Insert the prepared sample into the cell holder

READ the results in mg/L F^-.

Interferences

This test is sensitive to small amounts of interference. Glassware must be very clean (acid rinse before each use). Repeat the test with the same glassware to make sure that the results are accurate.

Table 2 Interfering substances

Interfering substance	Interference level
Alkalinity (as $CaCO_3$)	At 5000 mg/L causes a - 0.1 mg/L F^- error
Aluminum	At 0.1 mg/L causes a - 0.1 mg/L F^- error. To check for interferences from aluminum, read the concentration one minute after reagent addition, then again after 15 minutes. An appreciable increase in concentration suggests aluminum interference. Waiting 2 hours before making the final reading will eliminate the effect of up to 3.0 mg/L aluminum.
Chloride	At 7000 mg/L causes a +0.1 mg/L F^- error
Chlorine	SPADNS 2 Reagent contains enough non-toxic reductant to eliminate interference up to 5 mg/L chlorine. For higher chlorine levels: **1.** Dilute sample with deionized water by a factor that will lower chlorine concentration to below 5 mg/L. **2.** Perform the SPADNS 2 reagent solution or AccuVac procedure. **3.** Multiply results by the dilution factor to obtain mg/L Fluoride.
Iron, ferric	At 10 mg/L causes a - 0.1 mg/L F^- error
Phosphate, ortho	At 16 mg/L causes a +0.1 mg/L F^- error
Sodium Hexametaphosphate	At 1.0 mg/L causes a +0.1 mg/L F^- error
Sulfate	At 200 mg/L causes a +0.1 mg/L F^- error

Distillation

Distillation Solution Preparation:

1. Measure 60 mL of deionized water into a 250 mL glass Erlenmeyer flask.
2. With constant stirring, add 120 mL of concentrated Sulfuric Acid. ***Caution: The mixture will become very hot. Allow the solution to cool before handling.***

To eliminate most interferences, dilute the sample from the acid solution as described below:

1. Set up the distillation apparatus for general purpose distillation. Refer to the Distillation Apparatus manual for proper assembly. Use a 125-mL Erlenmeyer flask to collect the distillate.
2. Turn on the water and maintain a steady flow through the condenser.
3. Measure 100 mL of sample into the distillation flask using a 100-mL graduated cylinder. Add a magnetic stir bar and 5 glass beads.
4. Turn the stirrer power switch on. Turn the stir control to 5.
5. Using a 250-mL graduated cylinder, carefully add 150 mL of Distillation Solution into the flask.

Note: *When distilling samples with high amounts of chloride, add 5 mg of Silver Sulfate to the sample for every mg/L of chloride in the sample.*

6. With the thermometer in place, turn the heat control to 10. The yellow pilot lamp indicates the heater is on.
7. When the temperature reaches 180 °C or when 100 mL of distillate has been collected, turn the still off (requires about 1 hour).
8. Dilute the distillate to a volume of 100 mL, if necessary. The distillate may now be analyzed by the SPADNS, SPADNS 2 or the fluoride ion-selective electrode method.

Sample collection, preservation and storage

- Samples may be stored in glass or plastic bottles for at least seven days when cooled to 4 °C (39 °F) or lower.
- Warm samples to room temperature before analysis.

Accuracy check

Standard solution method
Note: *Refer to the instrument user manual for specific software navigation instructions.*

A variety of standard solutions for the entire range of the test is available. Use standard solutions instead of sample to verify the technique.

Minor variations between lots of reagent become measurable above 1.5 mg/L. While results in this region are usable for most purposes, better accuracy may be obtained with steps 1–3.

1. Dilute a fresh sample 1:1 with deionized water.
2. Perform the test again
3. Multiply the result by 2.
4. To adjust the calibration curve with the reading obtained with the standard solution, select **Options>More>Standard Adjust** from the instrument menu.

5. Turn on the Standard Adjust feature and accept the displayed concentration. If an alternate concentration is used, enter the concentration and adjust the curve to that value.

Method performance

Program	Standard	Precision 95% Confidence Limits of Distribution	Sensitivity Concentration change per 0.010 Abs change
190	1.00 mg/L F^-	0.97–1.03 mg/L F^-	0.024 mg/L F^- at 1 mg/L
195	1.00 mg/L F^-	0.92–1.08 mg/L F^-	0.03 mg/L F^- at 1 mg/L

Safety

Follow good safety habits and laboratory techniques throughout the procedure. Consult the *Material Safety Data Sheet* for information specific to the reagents used.

Pollution prevention and waste management

SPADNS 2 Reagent does not contain sodium arsenite. Instead, it contains a non-toxic species to prevent chlorine interference. Dispose of all waste safely in accordance with local and federal guidelines.

Summary of method

The SPADNS 2 Method for fluoride determination involves the reaction of fluoride with a red zirconium-dye solution. The fluoride combines with part of the zirconium to form a colorless complex that bleaches the red color in an amount proportional to the fluoride concentration. This method is equivalent to the EPA method for NPDES and NPDWR reporting purposes when the samples have been distilled. Seawater and wastewater samples require distillation. Test results are measured at 580 nm.

Consumables and replacement items

Required reagents

Description	Quantity/Test	Unit	Catalog number
SPADNS 2 Reagent Solution	4 mL	500 mL	2947549
OR			
SPADNS 2 Fluoride Reagent AccuVac® Ampuls	2	25/pkg	2527025
Water, deionized	10 mL	4 L	27256

Required apparatus (solution)

Description	Quantity	Unit	Catalog number
Pipet Filler, safety bulb	1	each	1465100
Pipet, volumetric, Class A, 2.00-mL	1	each	1451536
Pipet, volumetric, Class A, 10.00-mL.	1	each	1451538
Sample cell, 10 mL square, matched pair	2	2/pkg	2495402
Thermometer	1	each	2635700

Required apparatus (AccuVac)

Description	Quantity	Unit	Catalog number
Beaker, 50-mL	1	each	50041H
Sample cell, 10 mL round, 25 x 54 mm	1	each	2122800
Sample cell, 10 mL round, 25 x 60 mm	1	6/pkg	2427606

Recommended standards

Description	Unit	Catalog number
Fluoride Standard Solution, 0.2-mg/L F^-	500 mL	40502
Fluoride Standard Solution, 0.5-mg/L F^-	500 mL	40505
Fluoride Standard Solution, 0.8-mg/L F^-	500 mL	40508
Fluoride Standard Solution, 1.0-mg/L F^-	1000 mL	29153
Fluoride Standard Solution, 1.0-mg/L F^-	500 mL	29149
Fluoride Standard Solution, 1.2-mg/L F^-	500 mL	40512
Fluoride Standard Solution, 1.5-mg/L F^-	500 mL	40515
Fluoride Standard Solution, 2.0-mg/L F^-	500 mL	40520
Fluoride Standard Solution, 100-mg/L F^-	500 mL	23249
Standard, Drinking Water, Mixed Parameter, Inorganic for F^-, NO_3, PO_4, SO_4	500 mL	2833049

Distillation reagents and apparatus

Description	Quantity	Unit	Catalog number
Cylinder, graduated, 100-mL	1	each	50842
Cylinder, graduated, 250-mL	1	each	50846
Distillation Heater and Support Apparatus Set,115 VAC, 50/60 Hz	1	each	2274400
AND			
Distillation Heater and Support Apparatus Set,230 VAC, 50/60 Hz	1	each	2274402
OR			
Distillation Apparatus Set, General Purpose	1	each	2265300
Flask, Erlenmeyer, 125-mL	1	each	2089743
Flask, Erlenmeyer, 250 mL, Glass	1	each	50546
Glass Beads	1	100/pkg	259600
Stir Bar, magnetic	1	each	1076416
Sulfuric Acid, ACS	1	500 mL	97949

Optional reagents and apparatus

Description	Unit	Catalog number
Silver Sulfate	113 g	33414
Balance Analytical 80 g x 0.1 mg 100–240 V	each	2936701
Weighing papers	500/pkg	1473800

FOR TECHNICAL ASSISTANCE, PRICE INFORMATION AND ORDERING:
In the U.S.A. – **Call toll-free 800-227-4224**
Outside the U.S.A. – **Contact the HACH office or distributor serving you.**
On the Worldwide Web – **www.hach.com**; E-mail – **techhelp@hach.com**

HACH COMPANY
WORLD HEADQUARTERS
Telephone: (970) 669-3050
FAX: (970) 669-2932

Iron, Total

DOC316.53.01053

USEPA[1] FerroVer® Method[2] **Method 8008**

0.02 to 3.00 mg/L **Powder Pillows or AccuVac® Ampuls**

Scope and Application: For water, wastewater and seawater; digestion is required for determining total iron

1 USEPA approved for reporting wastewater analysis, *Federal Register,* June 27, 1980; 45 (126:43459)

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

Test preparation

How to use instrument-specific information

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

Table 1 Instrument-specific information

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

Before starting the test:

Digestion is required for determining total iron for EPA reporting purposes. Use the mild or vigorous digestion. Refer to the *Water Analysis Guide* for more information.
For more accurate results, determine a reagent blank value for each new lot of reagent. Follow the procedure using deionized water in place of the sample. Subtract the reagent blank value from the final results or perform a reagent blank adjust. See the user manual for more information.
Adjust pH of stored samples before analysis.
For turbid samples, treat the blank with one 0.1-g scoop of RoVer Rust Remover. Swirl to mix.

Collect the following items:

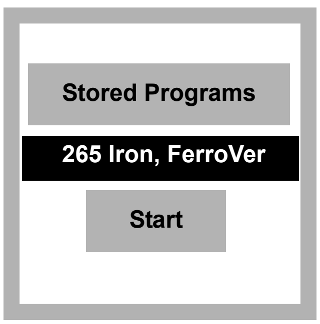
Description	Quantity
Powder Pillow Test:	
FerroVer® Iron Reagent Powder Pillow	1
Sample Cells (see *Instrument-specific information*)	2

Collect the following items: (continued)

Description	Quantity
AccuVac® Ampul test:	
FerroVer® Iron Reagent AccuVac® Ampul	1
Beaker, 50-mL	1
Sample Cells (see *Instrument-specific information*)	1
Stopper of 18 mm tubes	1

See *Consumables and replacement items* for reorder information.

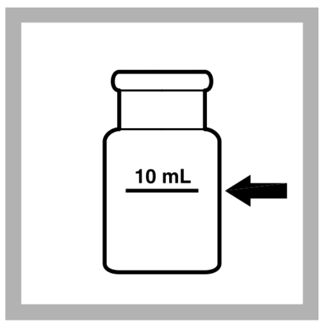
FerroVer method for powder pillows



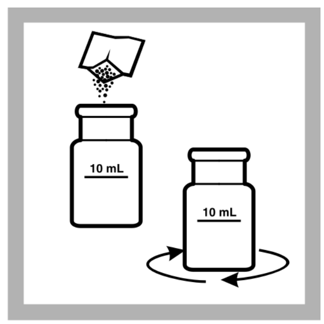
1. Select the test.

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

Refer to the user manual for orientation.



2. Prepared sample: Fill a clean sample cell with 10 mL of sample



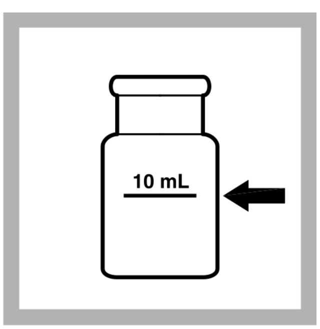
3. Add the contents of one FerroVer Iron Reagent Powder Pillow to the sample cell. Swirl to mix.

Accuracy is not affected by undissolved powder.

4. Start the instrument timer.

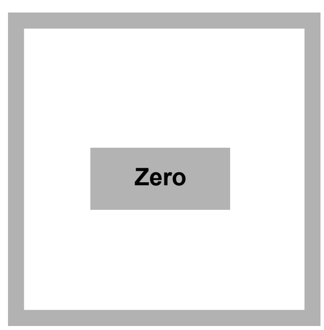
A three-minute reaction period will begin. An orange color will form, if iron is present.

(Allow samples that contain rust to react for at least 5 minutes.)



5. Blank preparation: Fill a second sample cell with 10 mL of sample.

6. When the timer expires, insert the blank into the cell holder.



7. ZERO the instrument.

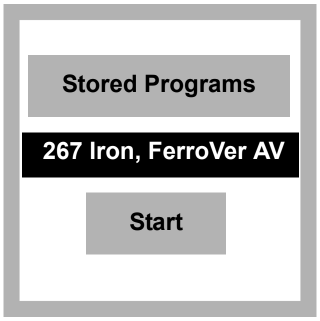
The display will show:

0.00 mg/L Fe

8. Insert the prepared sample into the cell holder.

READ the results in mg/L Fe.

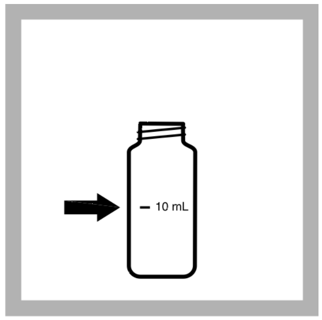
FerroVer method for AccuVac® Ampuls



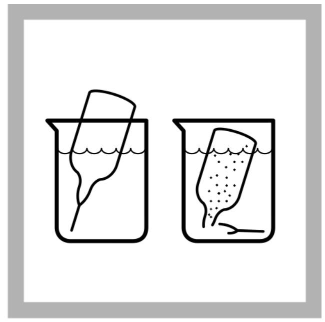
1. Select the test.

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

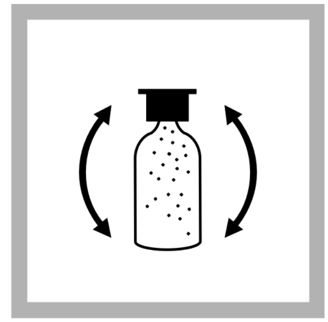
Refer to the user manual for orientation.



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



3. Prepared Sample: Collect at least 40 mL of sample in a 50-mL beaker. Fill a FerroVer Iron AccuVac® Ampul with sample from the beaker. Keep the tip immersed while the Ampul fills completely.



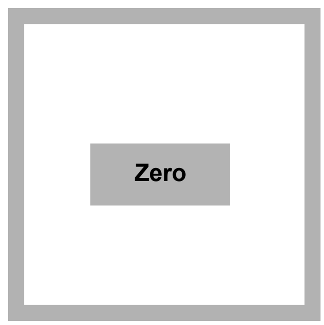
4. Quickly invert the Ampul several times to mix.

Accuracy is not affected by undissolved powder.

5. Start the instrument timer.

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

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



7. ZERO the instrument.

The display will show:

0.00 mg/L Fe

8. Wipe the Ampul and insert it into the cell holder.

READ the results in mg/L Fe.

Interferences

Table 2 Interfering substances

Interfering substance	Interference level
Calcium, Ca^{2+}	No effect at less than 10,000 mg/L as $CaCO_3$.
Chloride, Cl^-	No effect at less than 185,000 mg/L.
Copper, Cu^{2+}	No effect. Masking agent is contained in FerroVer Reagent.
High Iron Levels	Inhibit color development. Dilute sample and re-test to verify results.
Iron Oxide	Requires mild, vigorous or Digesdahl digestion. After digestion, adjust sample to pH 3–5 with sodium hydroxide, then analyze.
Magnesium	No effect at 100,000 mg/L as calcium carbonate.

Table 2 Interfering substances (continued)

Interfering substance	Interference level
Molybdate Molybdenum	No effect at 50 mg/L as Mo.
High Sulfide Levels, S^{2-}	**1.** Treat in fume hood or well-ventilated area. Add 5 mL hydrochloric acid[1], ACS to 100 mL sample in a 250 mL Erlenmeyer flask. Boil 20 minutes. **2.** Cool. Adjust pH to 3–5 with Sodium Hydroxide[1]. Readjust volume to 100 mL with deionized water. **3.** Analyze using *FerroVer method for powder pillows* or *FerroVer method for AccuVac® Ampuls*.
Turbidity	**1.** Add 0.1 g scoop of RoVer® Rust Remover to the blank. Swirl to mix. **2.** Zero the instrument with this blank. **3.** If sample remains turbid, add three 0.2 g scoops of RoVer to a 75 mL sample. Let stand 5 minutes. **4.** Filter through a Glass Membrane Filter and Filter Holder[1]. **5.** Use the filtered sample as the prepared sample and the blank.
Extreme Sample pH	Adjust pH to 3–5.
Highly Buffered Samples	Adjust pH to 3–5.

[1] See *Optional reagents and apparatus*.

Sample collection, preservation and storage

- Collect samples in acid-cleaned glass or plastic containers. No acid addition is necessary if analyzing the sample immediately.
- To preserve samples, adjust the pH to 2 or less with concentrated nitric acid (about 2 mL per liter). Preserved samples may be stored up to six months at room temperature.
- Before analysis, adjust the pH to between 3 and 5 with 5.0 N Sodium Hydroxide Standard Solution.
- Correct the test result for volume additions.
- If only dissolved iron is to be determined, filter the sample before acid addition.

Accuracy check

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

- Iron Voluette® Ampule Standard, 25 mg/L
- Ampule breaker
- TenSette Pipet and Pipet Tips

1. After reading test results, leave the sample cell (unspiked sample) in the instrument.
2. Select Options>More>Standard Additions from the instrument menu.
3. Accept the default values for standard concentration, sample volume and spike volumes. After the values are accepted, the unspiked sample reading will appear in the top row. See the user manual for more information.
4. Open the standard solution ampule.
5. Prepare a 0.1 mL sample spike by adding 0.1 mL of standard to 10 mL of unspiked sample. Start the instrument timer. After the timer expires, read the result.

6. Prepare a 0.2 mL sample spike by adding 0.1 mL of standard to the 0.1 mL sample spike. Start the instrument timer. After the timer expires, read the result.
7. Prepare a 0.3 mL sample spike by adding 0.1 mL of standard to the 0.2 mL sample spike. Start the instrument timer. After the timer expires, read the result.
8. Select **GRAPH** to view the results. Select **IDEAL LINE** (or best-fit) to compare the standard addition results to the theoretical 100% recovery.

Standard additions method for AccuVac Ampuls (sample spike)

1. Fill three mixing cylinders each with 50 mL of sample and spike with 0.2 mL, 0.4 mL and 0.6 mL of standard. Stopper and invert to mix.
2. Transfer 40 mL from each of the three mixing cylinders to three 50 mL beakers.
3. Analyze each standard addition sample as described in the *FerroVer method for AccuVac® Ampuls*.
4. Accept each standard additions reading. Each addition should reflect approximately 100% recovery.

Standard solution method

Note: *Refer to the instrument user manual for specific software navigation instructions.*

Required for accuracy check:

- Iron Standard Solution, 100 mg/L
- 100-mL volumetric flask
- Class A volumetric pipet, 2 mL
- Deionized water
- Pipet filler

1. Prepare a 2.00-mg/L Fe standard solution as follows:
   a. Pipet 2.00 mL of Iron Standard Solution, 100 mg/L, into a 100 mL volumetric flask.
   b. Dilute to the mark with deionized water. Mix well. Prepare this solution daily.
2. Use the 2.00 mg/L Fe standard solution in place of the sample. Follow the *FerroVer method for powder pillows* test procedure.
3. To adjust the calibration curve using the reading obtained with the Standard Solution, select Options>More>Standard Adjust from the instrument menu.
4. Turn on the Standard Adjust feature and accept the displayed concentration. If an alternate concentration is used, enter the concentration and adjust the curve to that value. Mixed-parameter standards are also available to simulate various matrices.

Method performance

Program	Standard	Precision 95% Confidence Limits of Distribution	Sensitivity Concentration change per 0.010 Abs change
265	2.00 mg/L Fe	1.99–2.01 mg/L Fe	0.021 mg/L Fe
267	2.00 mg/L Fe	1.98–2.02 mg/L Fe	0.023 mg/L Fe

Summary of method

FerroVer Iron Reagent converts all soluble iron and most insoluble forms of iron in the sample to soluble ferrous iron. The ferrous iron reacts with the 1-10 phenanthroline indicator in the reagent to form an orange color in proportion to the iron concentration. Test results are measured at 510 nm.

Consumables and replacement items

Required reagents

Description	Quantity/Test	Unit	Catalog number
FerroVer® Iron Reagent Powder Pillows (for 10-mL sample)	1	100/pkg	2105769
OR			
FerroVer® Iron Reagent AccuVac® Ampuls	1	25/pkg	2507025

Required apparatus

Description	Quantity	Unit	Catalog number
Beaker, 50 mL	1	each	50041H
Sample cell, 10 mL round, 25 x 54 mm	1	each	2122800
Sample cell, 10 mL round, 25 x 60 mm	1	6/pkg	2427606
Sample cell, 10 mL square, matched pair	2	2/pkg	2495402
Stopper for 18 mm tube	1	6/pkg	173106

Recommended standards

Description	Unit	Catalog number
Iron Standard Solution, 100 mg/L	100 mL	1417542
Iron Standard Solution, 10 mL Voluette® Ampule, 25 mg/L as Fe	16/pkg	1425310
Metals Drinking Water Standard, LR for Cu, Fe, Mn	500 mL	2833749
Metals Drinking Water Standard, HR for Cu, Fe, Mn	500 mL	2833649
Water, deionized	4 L	27256
Pipet, TenSette, 0.1–1.0 mL	each	1970001
Pipet Tips, for TenSette Pipet 1970001	50/pkg	2185696
Pipet Tips, for TenSette Pipet 1970001	1000/pkg	2185628
Flask, volumetric, Class A, 100 mL	each	1457442
Pipet, volumetric, Class A, 2.00 mL	each	1451536
Pipet Filler, safety bulb	each	1465100

Optional reagents and apparatus

Description	Unit	Catalog number
Beaker, 50 mL	each	50041H
Cylinder, mixing, 50 mL	each	189641
Hydrochloric Acid, concentrated	500 mL	13449
Nitric Acid, concentrated	500 mL	15249

Optional reagents and apparatus (continued)

Description	Unit	Catalog number
Sodium Hydroxide Standard Solution, 5.0 N	100 mL	245032
Glass Membrane Filter, 47 mm	100/pkg	253000
Glass Membrane Filter Holder	each	234000
RoVer Rust Remover	454 g	30001
Spoon, measuring, 0.1 g	each	51100

Manganese

DOC316.53.01057

1-(2-Pyridylazo)-2-Naphthol PAN Method[1] **Method 8149**

LR (0.006 to 0.700 mg/L) **Powder Pillows**

Scope and Application: For water and wastewater; digestion is required for determining total manganese

[1] Adapted from Goto, K., et al., *Talanta*, 24, 652-3 (1977)

Test preparation

How to use instrument-specific information

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

Table 1 Instrument-specific information

Instrument	Sample cell	Cell orientation
DR 5000	2495402	Fill line faces user
DR 3900	2495402	Fill line faces user
DR 3800, DR 2800, DR 2700	2495402	Fill line faces right

Before starting the test:

Rinse all glassware with 1:1 Nitric Acid Solution. Rinse again with deionized water.
The alkaline cyanide solution contains cyanide. Cyanide solutions should be collected for disposal as a reactive (D001) waste. Be sure cyanide solutions are stored in a caustic solution with pH >11 to prevent release of hydrogen cyanide gas. Refer to the current MSDS for safe handling and disposal instructions.
Total manganese determination requires a prior digestion. Refer to the *Water Analysis Guide* for more information.

Collect the following items:

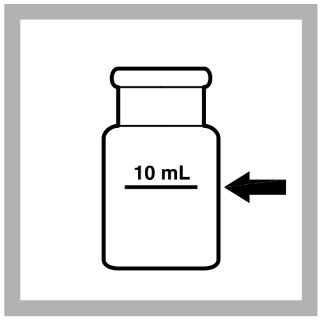
Description	Quantity
Alkaline Cyanide Reagent	12 drops
Ascorbic Acid Powder Pillows	2
PAN Indicator Solution, 0.1%	12 drops
Deionized Water	10 mL
Sample Cells (see *Instrument-specific information*)	2
Stoppers for 18 mm tube	2

See *Consumables and replacement items* for reorder information.

PAN method for powder pillows

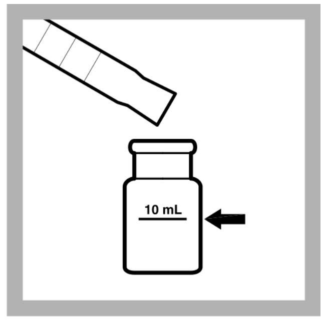
1. Select the test.

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

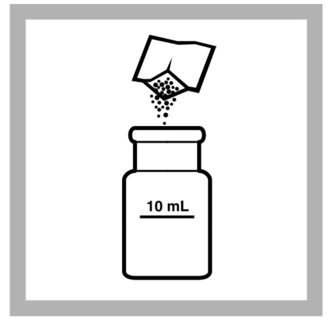


2. Blank Preparation: Pour 10.0 mL of deionized water into a sample cell.

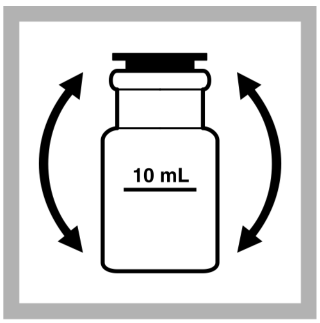
Total manganese determination requires prior digestion.



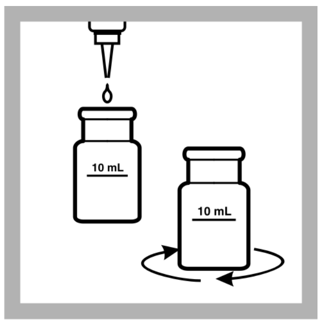
3. Prepared Sample: Pour 10.0 mL of sample into another sample cell.



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

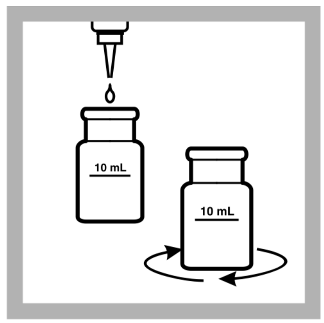


5. Stopper and invert to dissolve the powder.



6. Add 12 drops of Alkaline-Cyanide Reagent Solution to each cell. Swirl gently to mix.

A cloudy solution may form. The turbidity should dissipate after step 7.



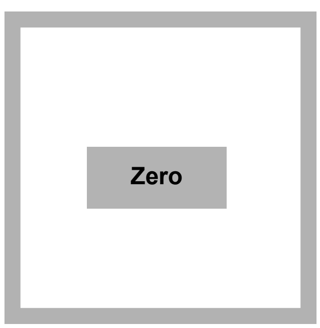
7. Add 12 drops of PAN Indicator Solution, 0.1%, to each sample cell. Swirl gently to mix.

An orange color will develop in the sample if manganese is present.

8. Start the instrument timer.

A two-minute reaction period will begin.

9. When the timer expires, wipe the blank and place it in the cell holder.

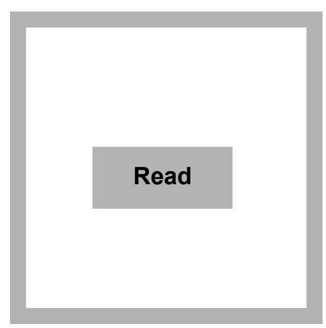


10. ZERO the instrument.

The display will show:

0.000 mg/L Mn

11. Wipe the prepared cell and place it in the holder.



12. READ the results in mg/L Mn.

Interferences

For samples that contain hardness greater than 300 mg/L $CaCO_3$, add 4 drops of Rochelle Salt Solution to the sample **after** adding the Ascorbic Acid Powder Pillow in step 4.

Table 2 Interfering substances

Interfering substance	Interference level
Aluminum	20 mg/L
Cadmium	10 mg/L
Calcium	1000 mg/L as $CaCO_3$
Cobalt	20 mg/L
Copper	50 mg/L
Iron	25 mg/L (If sample contains more than 5 mg/L iron, allow a 10-minute reaction period in step 8.)
Lead	0.5 mg/L
Magnesium	300 mg/L as $CaCO_3$
Nickel	40 mg/L
Zinc	15 mg/L

Sample collection, preservation and storage

- Collect samples in a clean plastic container.
- Adjust the pH to 2 or less with Concentrated Nitric Acid* (about 2 mL per liter).
- Preserved samples can be stored up to six months at room temperature.
- Adjust the pH to between 4–5 with 5.0 N Sodium Hydroxide before analysis.
- Correct the test result for volume additions.

Accuracy check

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

- Manganese PourRite® Ampule Standard, 10-mg/L Mn
- Mixing cylinders (3)
- Ampule breaker, PourRite
- TenSette Pipet

1. After reading test results, leave the sample cell (unspiked sample) in the instrument.
2. Select Options>More>Standard additions from the instrument menu.
3. Accept the default values for standard concentration, sample volume and spike volumes. After the values are accepted, the unspiked sample reading will appear in the top row. See the user manual for more information.
4. Open the standard solution ampule.
5. Use the TenSette Pipet to prepare spiked samples: add 0.1 mL, 0.2 mL and 0.3 mL of standard to three 10 mL portions of fresh sample. Mix thoroughly.

6. Follow the *PAN method for powder pillows* test procedure for each of the spiked samples using the powder pillows, starting with the 0.1 mL sample spike. Measure each of the spiked samples in the instrument.

7. Select **GRAPH** to view the results. Select **IDEAL LINE** (or best-fit) to compare the standard addition results to the theoretical 100% recovery.

Standard solution method

Note: *Refer to the instrument user manual for specific software navigation instructions.*

Required for accuracy check:

- Manganese Voluette Standard Solution, 250 mg/L Mn
- 1 L Class A volumetric flask
- Deionized water
- Class A volumetric pipet, 2 mL
- Pipet filler, safety bulb

1. Prepare a 0.5 mg/L manganese standard solution as follows:
   a. Pipet 2.0 mL of Manganese Standard, 250 mg/L as Mn, into a 1000 mL (1 liter) volumetric flask.
   b. Dilute to the mark with deionized water. Mix well. Prepare this solution daily.
2. Use this solution in place of the sample. Follow the *PAN method for powder pillows* test procedure.
3. To adjust the calibration curve using the reading obtained with the standard solution, select Options>More>Standard Adjust from the instrument menu.
4. Turn on the Standard Adjust feature and accept the displayed concentration. If an alternate concentration is used, enter the concentration and adjust the curve to that value.

Method performance

Program	Standard	Precision 95% Confidence Limits of Distribution	Sensitivity Concentration change per 0.010 Abs change
290	0.500 mg/L Mn	0.491–0.509 mg/L Mn	0.006 mg/L Mn

Summary of method

The PAN method is a highly sensitive and rapid procedure for detecting low levels of manganese. An ascorbic acid reagent is used initially to reduce all oxidized forms of manganese to Mn^{2+}. An alkaline-cyanide reagent is added to mask any potential interferences. PAN Indicator is then added to combine with the Mn^{2+} to form an orange-colored complex. Test results are measured at 560 nm.

Consumables and replacement items

Required reagents

Description	Quantity/Test	Unit	Catalog number
Manganese Reagent Set, 10 mL (50 tests), includes:	—	—	2651700
Alkaline Cyanide Reagent	12 drops	50 mL SCDB	2122326
Ascorbic Acid Powder Pillows	2 pillows	100/pkg	1457799
PAN Indicator Solution, 0.1%	12 drops	50 mL SCDB	2122426
Water, deionized	10 mL	4 L	27256

Required apparatus

Description	Quantity	Unit	Catalog number
Sample cell, 10 mL square, matched pair	2	2/pkg	2495402
Stoppers for 18 mm Tube	2	6/pkg	173106

Recommended standards

Description	Unit	Catalog number
Manganese Standard Solution, 10-mg/L Mn, 2 mL PourRite® ampule	20/pkg	2605820
Manganese Standard Solution, 250-mg/L Mn, 10-mL Voluette® ampule	16/pkg	1425810
Voluette Ampule breaker 10 mL	each	2196800
PourRite® Ampule breaker 2 mL	each	2484600

Optional reagents and apparatus

Description	Unit	Catalog number
Cylinder, mixing, 25 mL	each	2088640
Nitric Acid, concentrated	500 mL	15249
pH paper, 0-14	100/pkg	2601300
Pipet Filler, safety bulb	each	1465100
Pipet, TenSette® 0.1–1.0 mL	each	1970001
Pipet, TenSette, 1.0–10.0 mL	each	1970010
Pipet Tips, for TenSette Pipet 1970001	50/pkg	2185696
Pipet Tips, for TenSette Pipet 1970001	1000/pkg	2185628
Pipet Tips, for TenSette Pipet 1970010	50/pkg	2199796
Pipet Tips, for TenSette Pipet 1970010	250/pkg	2199725
Rochelle Salt Solution	29 mL	172533
Sodium Hydroxide, 5.0 N	100 mL	245032
Stopper for 18 mm tube	25/pkg	173125
Volumetric flask, Class A, 1000 mL	each	1457453
Volumetric pipet, Class A, 2 mL	each	1451536
PourRite® Ampule breaker 2 mL	each	2484600
Manganese Standard Solution, 2-mL PourRite® Ampule, 25 mg/L	20/pkg	2112820

Hardness, Total

DOC316.53.01158

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:

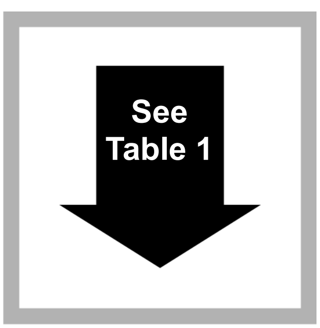
Four drops of Hardness 2 Indicator Solution or a 0.1-g scoop of ManVer 2 Hardness Indicator Powder can be added in place of the ManVer 2 Hardness Indicator Powder Pillow.
Hardness conversions: grains per gallon (gpg) as $CaCO_3$ = mg/L x 0.058; German degrees hardness (Gdh) = mg/L x 0.056

Collect the following items:

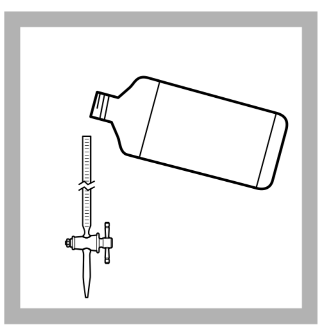
Description	Quantity
ManVer 2 Hardness Indicator Powder Pillow	1
Hardness 1 Buffer Solution	1 mL
TitraVer Hardness Titrant (see *Range-specific information*)	1 bottle
Buret, Class A, 25-mL, with support stand	1
Erlenmeyer flask, 250 mL	1
Graduated cylinder	1

See *Consumables and replacement items* for reorder information.

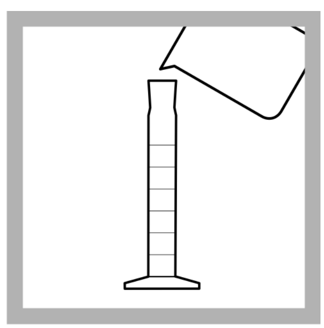
Buret titration



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



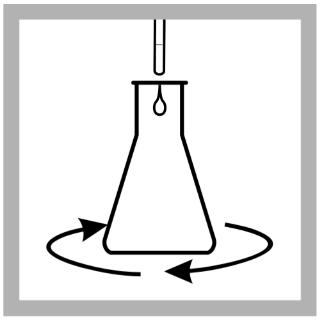
2. Fill a 25-mL buret to the zero mark with the TitraVer Hardness Titrant.



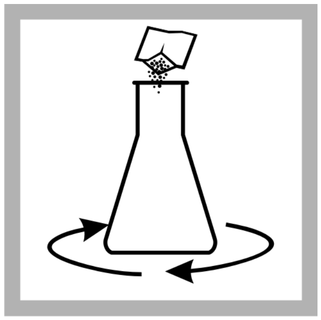
3. Use a graduated cylinder or pipet to measure the sample volume from the *Range-specific information* table.

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.

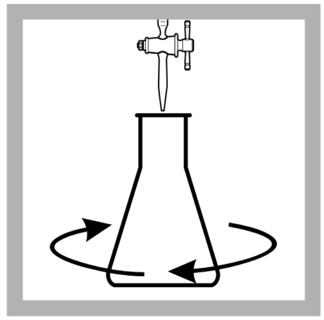
Buret titration (continued)



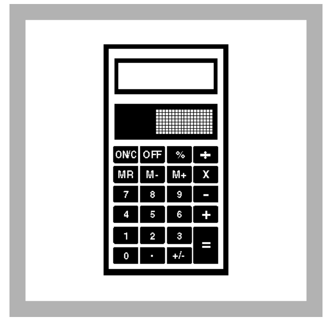
5. Add 1 mL of Hardness 1 Buffer Solution using the 1-mL dropper. Swirl to mix.



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

FOR TECHNICAL ASSISTANCE, PRICE INFORMATION AND ORDERING:
In the U.S.A. – **Call toll-free 800-227-4224**
Outside the U.S.A. – **Contact the HACH office or distributor serving you.**
On the Worldwide Web – **www.hach.com**; E-mail – **techhelp@hach.com**

HACH COMPANY
WORLD HEADQUARTERS
Telephone: (970) 669-3050
FAX: (970) 669-2932

Updated March 2011, Edition 5

Section 10

Filter Evaluation

Filter Evaluations

For Granular Media Filters

Preventive Maintenance

- Think of filter evaluation as preventive maintenance for your filters
  - Unfortunately filters have been evaluated due to a problem or "run to fail" attitude

Review Filter Design

- Before you begin, you need to know:
  - Type of media used
  - Different media depths for each grain size
  - Designed backflow rates
  - Effective size and uniformity coefficients of media
  - Appropriate backwash bed expansion

Review Water Quality

- Don't just look at the water quality being produced by the filter
- Look at the water quality leaving the sedimentation basins too

Water from Sed Basins

- Good rule of thumb
  - If your raw water turbidity is less than 10 NTU most of the time, then you should have about 1 NTU coming in from sedimentation basins
  - If your raw water turbidity is greater than 10 NTU most of the time, then you should have about 2 NTU coming in from sedimentation basins

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Organization

- Remember organization is the key to good data
  - Each filter should have its own file or notebook

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Equipment Needed

- Before starting the filter evaluation you must:
  - Read carefully each procedure
  - Gather all necessary equipment

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Safety

- Remember, a filter bay is a considered a confined space, please take all necessary precautions before entering into filter bay
  - Use a ladder to enter the filter
  - Allow no more than one team member on the ladder at a time
  - Provide a source of forced air to the team members in the filter
  - Troughs can be walked down but not used to jump into the filter
  - No team member should enter the filter alone, practice the buddy system

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Safety cont.

- Never walk directly on filter media
  - Use 2'x2' plywood boards
- Make sure filter is completely drained before entering

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Safety cont.

- While fluidizing the media AND a person HAS to be in the filter bay, it is recommended that they should be attached to an emergency extraction harness and rope
  - NEVER fluidize the media while a person is standing on the surface of the media; they will disappear quickly into the filter media

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Scheduling the Evaluation

- Inspections should be performed on a frequent basis
  - Annual is sufficient
- However, if a problem arises, then an evaluation should be performed more frequently
- Remember, filter will be out of service for at least a day, if not more

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TDEC
TENNESSEE DEPARTMENT OF ENVIRONMENT AND CONSERVATION

Review of Filtration Rules

Chapter 0400-45-01

Public Water System Rules

http://www.tn.gov/sos/rules_all/2012/0400-45-01.20121030.pdf

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0400-45-1-.31(4)(c)

- The turbidity in the combined filter effluent must:
  - Be less than or equal to 0.3 NTU in at least 95% of measurements taken each month
  - And at no time exceed 1 NTU

Notes from Field Office

- Having a filter exceedance is not a violation
- The violation occurs when the water system fails to submit the filter exceedance report of denote a filter exceedance on the Filter Performance Report
  - It would be in the water system's best interest to go ahead and submit a filter exceedance report when in doubt rather than not submit a report at all

Notes from Field Office continued

- It may also be helpful for water systems to have a flow meter and be able to chart the flow of the effluent water going to the clear well against the turbidity

Notes from Field Office continued

- Also, the way the rules is written any measured turbidity level greater than 0.5 NTU in two consecutive readings 15 minutes apart requires a filter profile or obvious reason
  - This means if someone knocks the turbidimeter and the reading is elevated above 0.5 NTU for fifteen minutes or longer, they would technically need to report the filter exceedance
  - The obvious reason being someone bumped the turbidimeter

Notes from Field Office continued

- One example from the Field Office is that one water system had an elevated turbidity reading because a water system personnel sprayed the pipe gallery while cleaning
  - This would be an obvious reason as well

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Notes from Field Office continued

- It may also be helpful for water systems to know that they use the filter data recorded on the back of the MOR to check plant operations, such as turbidity readings
- So it would be in their best interest to ensure the filter data section accurately reflects the daily operations of the filters

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Notes from Field Office continued

- An example is if a system has eight filters and they know that two of the filters are out of service for two weeks
  - Then they would expect that the filter data would reflect this and not show that all eight filters were being used the entire month
  - This goes for the filter run time and could even be the amount of backwash water used

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Levels Exceeded

- Depending on the exceedance level, the system must:
  - Produce a filter profile
  - Conduct a self-assessment and/or
  - Must arrange for the conduct of a comprehensive performance evaluation by the State or a 3rd party approved by the State

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Filter Profile

- Is defined as a graphical representation of individual filter performance, based on continuous turbidity measurements or total particle counts versus time for an entire filter run, from startup to backwash inclusively, that includes an assessment of filter performance while another filter is being backwashed

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Filter Profile continued

- A filter profile is basically a strip chart of the problem filter with the time of the filter backwashes for the filter and other filters denoted on the chart

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Filter Profile continued

- For any individual filter that has a measured turbidity level of greater than 1.0 NTU in two consecutive measurements taken 15 minutes apart
- For any individual filter that has a measured turbidity level of greater than 0.5 NTU in two consecutive measurements taken 15 minutes apart at the end of the first four hours of continuous filter operation after the filter has been backwashed or otherwise taken offline

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Filter Profile continued

- The system must either:
  - Produce a filter profile for the filter within 7 days of the exceedance
    - if the system is not able to identify an obvious reason for the abnormal filter performance
  - and report that the profile has been produced
    - Or report the obvious reason for the exceedance

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FILTER PROFILE REPORT FOR INDIVIDUAL FILTERS

FOR PUBLIC WATER SYSTEMS THAT ARE USING SURFACE WATER SOURCES OR GROUND WATER SOURCES UNDER THE INFLUENCE OF SURFACE WATER THAT ARE REQUIRED TO CONDUCT ADDITIONAL INDIVIDUAL FILTER MONITORING

PUBLIC WATER SYSTEM NAME: TCEQ WSC **PLANT NAME OR NUMBER:** PDWS Water Treatment Plant

PWS ID No.: 1234567 **Month:** February **Year:** 2002

OBVIOUS REASONS

	FILTER NO.: 1	**FILTER NO.:** 1	**FILTER NO.:** 5
	DATE: 02-04-02	**DATE:** 02-04-02	**DATE:** 02-04-02
	TIME: 10:00 AM	**TIME:** 4:15 PM	**TIME:** 11:45 AM
	DURATION: 45.00	**DURATION:** 15.00	**DURATION:** 15.00
	TURBIDITY: 1.32	**TURBIDITY:** 0.57	**TURBIDITY:** 1.05
***OBVIOUS REASONS* (Check all that apply)**			
NONE IDENTIFIED - *A Filter Profile must be submitted*	☐ *(See Profile No. ____)*	☐ *(See Profile No. ____)*	☐ *(See Profile No. ____)*
Filter Problems			
Post-Backwash Turbidity Spike	☐	☑	☐
Prolonged Filter Run Time	☑	☐	☐
Excessive Filter-Loading Rate	☐	☐	☐
Rate-of-Flow Control Valve Failure	☐	☐	☐
Media Defects (insufficient depth, mudballs, etc.)	☐	☐	☐
Inadequate Surface Wash or Backwash Facilities	☐	☐	☐
Backwash Artifact	☐	☐	☑
Turbidimeter Errors			
Incorrect Calibration	☐	☐	☐
Air Bubble	☐	☐	☐
Debris	☐	☐	☐
Chemical Feed Equipment Failure			
Coagulant	☐	☐	☐
Coagulant Aid	☐	☐	☐
Filter Aid	☐	☐	☐
Poor Raw Water Quality	☐	☐	☐
Other Major Unit Process Failures/Maintenance Activities	☐	☐	☐
Specify:			Backwash Filter No. 1

OBVIOUS REASONS

	FILTER NO.: 5	**FILTER NO.:**	**FILTER NO.:**
	DATE: 02-13-02	**DATE:**	**DATE:**
	TIME: 2:15 PM	**TIME:**	**TIME:**
	DURATION: 15.00	**DURATION:**	**DURATION:**
	TURBIDITY: 1.24	**TURBIDITY:**	**TURBIDITY:**
***OBVIOUS REASONS* (Check all that apply)**			
NONE IDENTIFIED - *A Filter Profile must be submitted*	☑ *(See Profile No. 1)*	☐ *(See Profile No. ____)*	☐ *(See Profile No. ____)*
Filter Problems			
Post-Backwash Turbidity Spike	☐	☐	☐
Prolonged Filter Run Time	☐	☐	☐
Excessive Filter-Loading Rate	☐	☐	☐
Rate-of-Flow Control Valve Failure	☐	☐	☐
Media Defects (insufficient depth, mudballs, etc.)	☐	☐	☐
Inadequate Surface Wash or Backwash Facilities	☐	☐	☐
Backwash Artifact	☐	☐	☐
Turbidimeter Errors			
Incorrect Calibration	☐	☐	☐
Air Bubble	☐	☐	☐
Debris	☐	☐	☐
Chemical Feed Equipment Failure			
Coagulant	☐	☐	☐
Coagulant Aid	☐	☐	☐
Filter Aid	☐	☐	☐
Poor Raw Water Quality	☐	☐	☐
Other Major Unit Process Failures/Maintenance Activities	☐	☐	☐
Specify:			

SUBMITTED BY: Hardy Worker **Certificate No. and Grade:** 123-45-6789, BSW **Date:** 24-Feb-02

TCEQ - 10276 (10-02-00) PAGE 1 FPR

Filter Self-Assessment

- For any individual filter that has a measured turbidity level of greater than 1.0 NTU in two consecutive measurements taken 15 minutes apart at any time in each of three consecutive months

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Filter Self-Assessment continued

- Self-assessment must be conducted within 14 days of the exceedance
- Report that the self-assessment was conducted

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Filter Self-Assessment continued

- Must consist of at least the following components:
  - Assessment of filter performance
  - Development of a filter profile
  - Identification and prioritization of factors limiting filter performance
  - Assessment of the applicability of corrections
  - Preparation of a filter self-assessment report

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FILTER ASSESSMENT REPORT FOR INDIVIDUAL FILTERS

FOR PUBLIC WATER SYSTEMS THAT ARE USING SURFACE WATER SOURCES OR GROUND WATER SOURCES UNDER THE INFLUENCE OF SURFACE WATER THAT ARE REQUIRED TO CONDUCT AN INDIVIDUAL FILTER ASSSESSMENT

PUBLIC WATER SYSTEM NAME: ______________________ **PLANT NAME OR NUMBER:** ______________

PWS ID No.: ______________________ **FILTER NUMBER:** ______________

DESIGN SPECIFICATIONS

FILTER TYPE		OPERATING MODE	

	Diameter (ft)	Length (ft)	Width (ft)	Surface Area (ft^2)	Freeboard (ft)	Max Head Loss (ft)
MEDIA BED DIMENSIONS						

MEDIA TYPE						
MEDIA SPECS	Material	Depth (inches)	Min. Size (mm)	Max. Size (mm)	UC	Specific Gravity
Layer 1 Material						
Layer 2 Material						
Layer 3 Material						
Layer 4 Material						
TOTAL DEPTH (inches)						
L/D RATIO						

UNDERDRAIN TYPE				
	No. of Grades	Min. Size (in)	Max. Size (in)	Total Depth (in)
SUPPORT GRAVEL				

TROUGHS		SUPPL. BACKWASH	
Number.			
Separation (inches)		FILTER-TO-WASTE	

	Regulatory Std	Design	Typical	During Backwash	Maximum	App'd Exception
FILTER FLOW RATE (gpm)						
LOADING RATE (gpm/ft^2)						
BW FLOW RATE (gpm)						
BW LOADING RATE (gpm/ft^2)						

	Source	Controller	Meter	Turbidimeter	LOHG
FILTER INFLUENT					
FILTER EFFLUENT					
BACKWASH WATER					

ADDITIONAL REMARKS:

OPERATING PROCEDURES

CALIBRATION	Flow Meter	Backwash Meter	Mech. ROFC	NTU (Primary)	NTU (Secondary)
Method					
Frequency					
Date of Last					

BACKWASH	Turbidity (NTU)	LOH (ft)	Run Time (hr)	Run Volume (gal)	Filtration Rate
Criteria					
Monitoring Interval					

WRITTEN SOPs	
Plant Start-up	
Filter Start-up	
Plant Shutdown	
Filter Shutdown	
Filter Backwash	
Filter Inspection	

ADDITIONAL REMARKS:

I certify that I am familiar with the information contained in this report and that, to the best of my knowledge, the information is true, complete, and accurate.

Operator's Signature: ______________________

Operator's Name (printed): ______________________

Certificate No. and Class: ______________________ **Date:** ______________

Submit Report to TCEQ/WP&RM Division/Public Drinking Water Section(MC-155), ATTN: Monthly Reports, P.O. Box 13087, Austin, TX 78711-3087
The report is due the 10th of the following month

TCEQ - 10277 (10-02-00) **PAGE 1** **Filter Assessment Report**

FILTER ASSESSMENT REPORT FOR INDIVIDUAL FILTERS

FOR PUBLIC WATER SYSTEMS THAT ARE USING SURFACE WATER SOURCES OR GROUND WATER SOURCES UNDER THE INFLUENCE OF SURFACE WATER THAT ARE REQUIRED TO CONDUCT AN INDIVIDUAL FILTER ASSSESSMENT

PUBLIC WATER SYSTEM NAME: ______________________ **PLANT NAME OR NUMBER:** ______________

PWS ID No.: ______________________ **FILTER NUMBER:** ______________

CURRENT CONDITIONS

DATE	TIME	TURBIDITY (NTU)	LOH (ft)	FLOW RATE (gpm)	RUN TIME (hr)	RUN VOLUME (gal)

PHYSICAL CONDITION	
Walls	
Troughs	
Suppl. Backwash	
Flow Meter	
ROFC	
Flow Control Valve	
Turbidimeter	
LOHG	

ADDITIONAL REMARKS:

MEDIA SURFACE CONDITIONS

	Before BW	After BW
MOUNDS		
Number		
Length (inches)		
Width (inches)		
Height (inches)		
DEPRESSIONS		
Number		
Length (inches)		
Width (inches)		
Depth (inches)		
ACCUMULATED FLOC		
Thickness (inches)		
Distribution		

	Before BW	After BW
RETRACTION		
Number		
Length (inches)		
Width (inches)		
Depth (inches)		
CRACKS		
Number		
Length (inches)		
Width (inches)		
Depth (inches)		
MUDBALLS		
No. per ft^2		
Size (inches)		
Distribution		

ADDITIONAL REMARKS:

BACKWASH CONDITIONS

BW FLOW RATE (gpm)	
RISE RATE (inches/minute)	
LOADING RATE (gpm/ft^2)	
DURATION (minutes)	
TOTAL VOLUME (gallons)	
TROUGHS	
Levelness	
Flooding	
SUPPL. BACKWASH	
Duration (minutes)	
Effectiveness	
JETTING	
No. of Sites	
Severity	
BW WATER DISTRIBUTION	
SPENT BWW TURBIDITY	
EXPANSION (inches)	
EXPANSION (percent)	
YIELD (percent)	

ADDITIONAL REMARKS:

Submitted by: ______________________ **Date:** ______________

TCEQ - 10277 (10-02-00) **PAGE 2** **Filter Assessment Report**

FILTER ASSESSMENT REPORT FOR INDIVIDUAL FILTERS

FOR PUBLIC WATER SYSTEMS THAT ARE USING SURFACE WATER SOURCES OR GROUND WATER SOURCES UNDER THE INFLUENCE OF SURFACE WATER THAT ARE REQUIRED TO CONDUCT AN INDIVIDUAL FILTER ASSSESSMENT

PUBLIC WATER SYSTEM NAME: ______________________ **PLANT NAME OR NUMBER:** ______________

PWS ID No.: ______________________ **FILTER NUMBER:** ______________

FILTER PROBE

NUMBER OF SITES	
MEDIA	
Max. Thickness (inches)	
Min. Thickness (inches)	
Typ. Thickness (inches)	
SUPPORT MATERIAL	
Max. Elevation	
Min. Elevation	
Typ. Elevation	

ADDITIONAL REMARKS:

FILTER EXCAVATION

	REFERENCE	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6
SITE CHARACTERISTIC	Normal					
LAYER 1 (Top Layer)						
INTERFACE 1						
LAYER 2						
INTERFACE 2						
LAYER 3						
INTERFACE 3						
LAYER 4						
MUDBALLS						
Max. Size (inches)						
Min. Size (inches)						
Max. Depth (inches)						

	SITE 7	SITE 8	SITE 9	SITE 10	SITE 11	SITE 12
SITE CHARACTERISTIC						
LAYER 1 (Top Layer)						
INTERFACE 1						
LAYER 2						
INTERFACE 2						
LAYER 3						
INTERFACE 3						
LAYER 4						
MUDBALLS						
Max. Size (inches)						
Min. Size (inches)						
Max. Depth (inches)						

MEDIA CONDITION	
Sharpness	
Encrustation	
Uniformity	

ADDITIONAL REMARKS:

ADDITIONAL STUDIES

FILTER PROFILE ATTACHED?	

Note: A Filter Profile must be attached to this report.

PERCENT MUDBALLS	
Media Volume (ml)	
Mudball Volume (ml)	
% Mudballs	

ADDITIONAL REMARKS:

CONCLUSIONS

CONCLUSIONS:

CORRECTIVE ACTION PLAN ATTACHED?

WOULD YOU LIKE SOME TECHNICAL ASSISTANCE FROM THE TCEQ?

Submitted by: ______________________ **Date:** ______________

TCEQ - 10277 (10-02-00) **PAGE 3** **Filter Assessment Report**

FILTER ASSESSMENT REPORT FOR INDIVIDUAL FILTERS

FOR PUBLIC WATER SYSTEMS THAT ARE USING SURFACE WATER SOURCES OR GROUND WATER SOURCES UNDER THE INFLUENCE OF SURFACE WATER THAT ARE REQUIRED TO CONDUCT AN INDIVIDUAL FILTER ASSSESSMENT

PUBLIC WATER SYSTEM NAME: ______________________ **PLANT NAME OR NUMBER:** ______________________

PWS ID No.: ______________________ **FILTER NUMBER:** ______________________

FILTER SCHEMATIC

PREPARE A SIMPLE FILTER SCHEMATIC SHOWING THE LOCATION OF BACKWASH WATER TROUGHS, OBSERVED ANOMOLIES, AND EXCAVATION SITES.

Submitted by: ______________________ **Date:** ______________________

TCEQ - 10277 (10-02-00) **PAGE 4** **Filter Assessment Report**

Comprehensive Performance Evaluation

- For any individual filter that has a measured turbidity level of greater than 2.0 NTU in two consecutive measurements taken 15 minutes apart at any time in each of two consecutive months
- Must be conducted by the State or a third party approved by the State

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Comprehensive Performance Evaluation continued

- System has to arrange for this to be done no later than 30 days following exceedance
- The evaluation completed and submitted to the State no later than 90 days following the exceedance

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Factors affecting filtration

- Physical condition of filter bed
- Physical condition of filter media
  - Depends on how frequently filter is backwashed
  - Media rubs together and eventually wears down
- Filtration rate
- Backwash procedures
  - Need SOP, everyone needs to backwash the same
- Backwash conditions and/or rates

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Filtration Rate

- Filtration rate = (Filtration Velocity) (Area Available for Flow)

$$Q = V \times A$$

Q = Filtration Rate, is constant
V = Filtration Velocity
A = Area Available for Flow between Media Grains

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Filtration Rate

- As Particles are Stored in a Filter Bed, “A” becomes Smaller

$$Q = V \times A$$

Q = Filtration Rate, is constant
V = Filtration Velocity
A = Area Available for Flow between Media Grains

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Filtration Rate

- As “A” becomes Smaller, “V” becomes Larger

$$Q = V \times A$$

Q = Filtration Rate, is constant
V = Filtration Velocity
A = Area Available for Flow between Media Grains

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Filtration Rate

- And, if "V" becomes too Large
  - Particles stored in a filter bed by:
    - Strained particles can be driven deeper into the filter bed
    - Particles stuck to the filter media can be detached from the media surface
    - Then both types of particles will go through the bottom of the filter resulting in turbidity breakthrough

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Filter Run Hour Analysis

- Compares filters to each other throughout the facility
  - Allows the operator to see how many hours the filters are operated through the year, which determines if one is used more than others

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Filter Run Hour Analysis continued

- Procedure
  - Count the number of hours each filter is in service monthly
  - Put together an annual total filter run hours in a graph format

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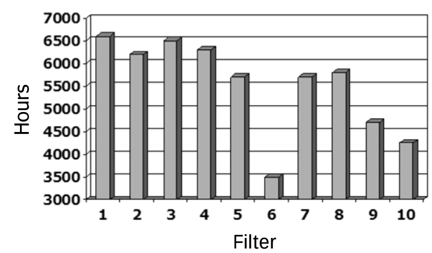
Filter Run Hour Analysis continued



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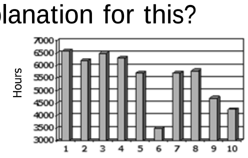
Filter Run Hour Analysis continued

- Filter 6 may have been out of service for maintenance for most of the year
- Filter 9 and 10 were not used as much as the others either, what would be the explanation for this?



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Physical Condition of Bed

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Physical Condition of Filter Bed

- Mounding
- Craters
- Mud/silt on top of filter
- Cracks in filter bed
- Sand separating from walls
- Algae
- Structural defects in filter
  - Blown tiles and/or grout
- Media in troughs
  - Backwash rate too high?
- Levelness of troughs
  - Length and width
  - Between troughs

Visual Observations

- This is your first line of defense in filter monitoring and evaluation
- Look for easy to recognize issues:
  - Media boils
  - Uneven wash distribution
  - Uneven overflow into backwash water troughs
  - Craters
  - Mudballs
- Create a map of any issues found

Media Depth

- Single-media filter
  - Must be 30 inches of sand
- Dual-media filter
  - Must be 30 inches of dual media
    - 10-12 inches of sand
    - 18-20 inches of anthracite
- Take 10-12 core samples and measure
  - Near wall and near center
  - Random

Media Depth continued

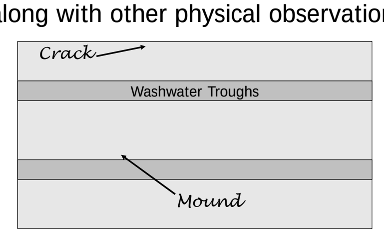
- Determine average media depth
  - First, backwash filter and then drain
  - You will be standing in the filter, have plywood down so you are not standing on the media

Media Depth continued

- Determine average media depth continued
  - Poke 5-ft ruler or steel rod into filter media at random spots until you reach support gravel or underdrains
    - Determined by feel or the sound of a "crunch" once you hit gravel
    - If you are using a steel rod, pinch at surface and carefully pull it out, tape at that point then measure distance
  - Determine average media depth by repeating about 10 times randomly around filter bed

Media Depth continued

- Draw picture of filter and write down depths where the measurement was taken along with other physical observations



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Media Depth continued

Support gravel extremely disrupted

	2 ft	4 ft	6 ft	8 ft	10 ft
2 ft	41	40.75	41	41	41
4 ft	40.75	40.5	41	41	40.75
6 ft	41	41.25	40.75	41	41
8 ft	40.75	41	41	40.75	40.75
10 ft	41	41	40.5	40.5	40.75
12 ft	41	46	46.5	41	41
14 ft	40.75	46	46.25	39	40.75
16 ft	41	39	38.75	37	40.75
18 ft	40.75	41.25	40.75	41	41

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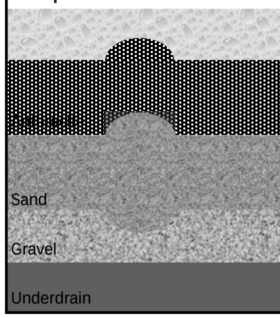
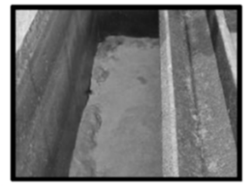
Mounding



- Mounding suggests possible gravel displacement that allows more backwash water through



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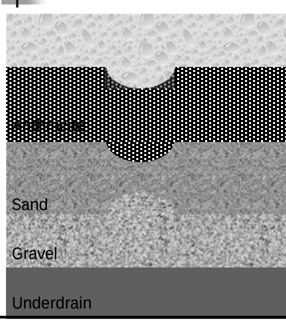
Craters



- Craters suggests underdrain damage or displacement of gravel
  - Allows less backwash water through this area
  - Loss of media can occur

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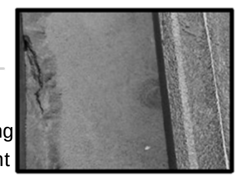
Other Physical Conditions



- Cracks
  - Media binding is occurring
  - Backwash is not sufficient
  - Water passes through cracks and is not filtered
- Separation from walls
  - Suggests media is retaining mud causing a crack along the wall
  - Too much gravel was installed and the backwash is less than desired

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Other Physical Conditions continued

- Algae
  - Algae can clog the filter and needs to be removed
- Structural
  - Make notes of structural defects to the walls, washwater troughs and/or piping:
    - Chipped concrete
    - Exposed rebar
    - Walls or washwater troughs rusting
  - Need to be fixed before it continues to worsen

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Other Physical Conditions continued

- Media in troughs
  - Indicates backwash flow rate is too high
- Levelness of washwater troughs
  - Check the levelness
    - Across the width
    - Down the length
    - Between two troughs next to each other

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Other Physical Conditions continued

- Freeboard measurement
  - This is the measurement between the top of the washwater troughs and the top of the media surface
  - Take measurements when and where level readings were taken

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Backwash Analysis

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Backwash Procedure

- Every plant needs an SOP
  - Everyone needs to backwash the same way every time
  - Variable rate of backwashing
    - Wide open and shut is not good
    - Ramp up: 25%, 50%, 75% then 100% and back down when finished
  - Rewash
  - Time
    - Not too clean nor left too dirty
  - How often
    - Hours run, effluent turbidity, head loss

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Conditions of Backwash

- Intensity
- Time
- Efficiency

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Backwash Intensity

- Measured by:
  - Backwash flow rate
    - ~15-20 gpm/ft^2
    - Design Criteria requires a minimum rate of 18.75 gpm/ft^2 for sand filter
  - Filter bed expansion
    - ~20-30%
    - Design Criteria recommends 50%
      - 4.2.1 K(1)

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Length of Backwash

- Do not wash the filter too much
- Wash until water coming through the bed is about 10 NTU

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Backwash Observations

- Media boils
  - Look for these toward the end of the backwash, you must be able to see the media
- Uneven backwash water distribution
  - Check for areas that are not moving, these areas are not being sufficiently washed and normally have mudballs in that area

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Backwash Observations continued

- Media carryover
  - Can be several issues going on for media carryover
    - Backwash water jetting under trough
    - Too much media expansion near the bottom of the trough
    - Too high a backwash rate

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Backwash Bed Expansion

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Backwash Bed Expansion

- Backwash rate needs to be high enough to completely suspend the filter media in the water
  - To clean the filter bed, the media grains need to be moved and bumped into each other.
  - This creates a scrubbing action that releases the floc from the media

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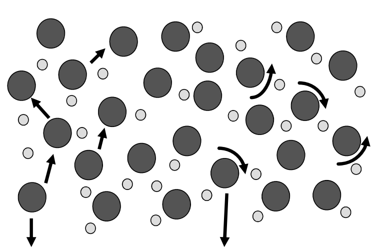
Backwash Bed Expansion continued



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Backwash Bed Expansion continued

- Inadequate bed expansion may lead an operator to believe filter is clean due to backwash water looking "clean"
  - If media is not expanded enough to rub together and knock loose the dirt, backwash water will look clean

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Backwash Bed Expansion continued

- If the filter is not sufficiently expanded during backwash, it will not be sufficiently cleaned
- This can lead to numerous problems:
  - Poor post-backwash recovery
  - Sensitivity to hydraulic surges during flow changes
  - Shortened filter run times
  - Mudball formation

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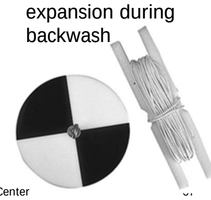
Backwash Bed Expansion continued

- Equipment needed:
  - Secchi Disc or other apparatus to measure bed expansion during backwash



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Backwash Bed Expansion continued

- Steps
  - Determine average media depth
    - Poke 5-ft ruler or steel rod into filter media at random spots until you reach support gravel or underdrains
      - Determined by feel or the sound of a "crunch" once you hit gravel
      - If you are using a steel rod, pinch at surface and carefully pull it out, tape at that point then measure distance
    - Determine average media depth

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Backwash Bed Expansion continued

- Steps
  - Determine bed expansion using a Secchi disk
    - Using a Secchi disk on a rope, lower the disk into the water until you reach the top of the filter
    - Place piece of tape on rope at handrail level
    - Remove the Secchi disk
    - Start backwash

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Backwash Bed Expansion continued

- Steps
  - Determine bed expansion using a Secchi disk
    - Once water clears, lower Secchi disk back down into filter until small amounts of filter cover the disc
      - If it becomes completely submerged, raise and slowly lower again
    - Place piece of tape on rope at handrail level
    - Measure distance between two pieces of tape

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Backwash Bed Expansion continued

- Steps
  - Determine bed expansion using a Secchi disk
    - The distance between the two pieces of tape is your bed expansion in inches

$$\text{Bed expansion, \%} = \frac{(\text{Bed expansion, in})(100)}{\text{Media depth, in}}$$

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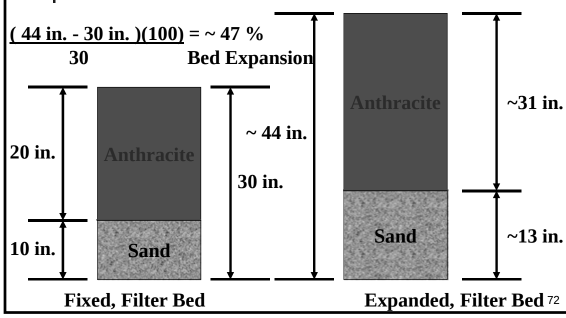
Backwash Expansion Dual-Media Filter



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Low Bed Expansion

- Media may have become encrusted with carbonate or "cemented"
  - Therefore, media has become heavier and will not allow bed to expand normally

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Water Temp vs. Backwash Rates

- Changes in water temperature will affect your backwash rates
- Cold water is more viscous than warm water
- Imagine dropping filter media into cold maple syrup and warm maple syrup
  - Media will stay suspended for a longer period of time in the cold maple syrup
  - Same goes for filter media in cold water versus warm water

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Water Temp vs. Backwash Rates cont.

- If backwash flow rates stay the same, year-round, you will get a higher bed expansion during colder water temps than warmer water temps
  - If rates are not changed during summer and winter months
    - Mudballs may occur during the summer
    - Media loss may occur during the winter
  - Colder water temps need lower backwash rates
  - Warmer water temps need higher backwash rates

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Water Temp vs. Backwash Rates cont.

- Check bed expansion seasonally
  - Chart water temperature and backwash rate that allows a 20% bed expansion throughout the year
  - If you have different filter designs, do one for each design

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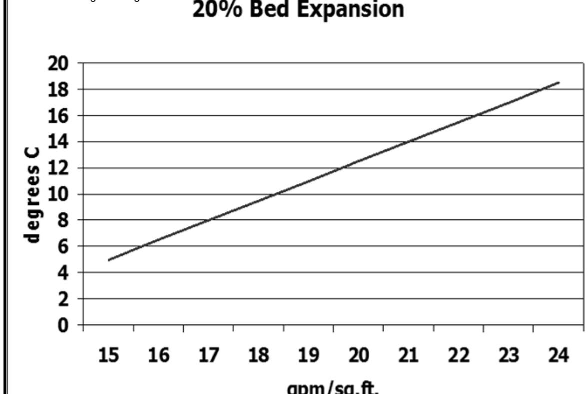

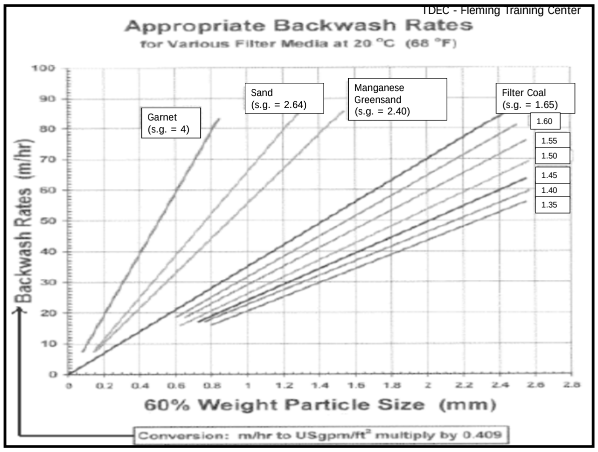
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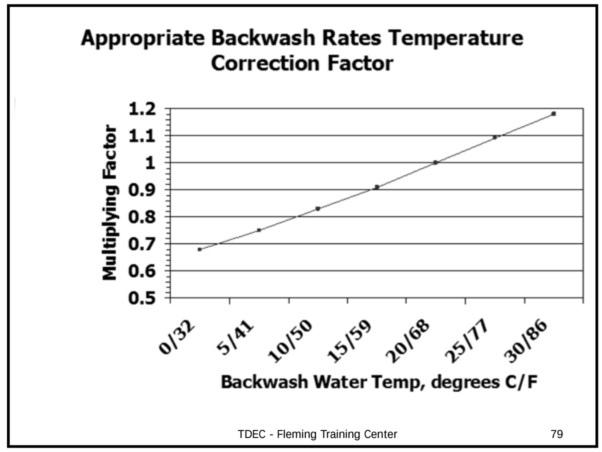
Appropriate Backwash Rates
for Various Filter Media at 20 °C (68 °F)
Garnet (s.g. = 4)
Sand (s.g. = 2.64)
Manganese Greensand (s.g. = 2.40)
Filter Coal (s.g. = 1.65)
1.60
1.55
1.50
1.45
1.40
1.35
Backwash Rates (m/hr)
60% Weight Particle Size (mm)
Conversion: m/hr to USgpm/ft² multiply by 0.409


Appropriate Backwash Rates Temperature Correction Factor
Multiplying Factor
0/32
5/41
10/50
15/59
20/68
25/77
30/86
Backwash Water Temp, degrees C/F
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Filter Bed Expansion Worksheet

Filter Media Depth Measurements			
Measurements	Media Depth, in	Measurements	Media Depth, in
1		11	
2		12	
3		13	
4		14	
5		15	
6		16	
7		17	
8		18	
9		19	
10		20	
Sum of Measurements		Sum of Measurements	
Total Depth = Add the sums of the two columns of measurements			
Average Depth = Divide the total depth by the number of measurements			
Bed Expansion, in			
Bed Expansion, % = (Bed Expansion, in)(100) / Average Media Depth, in			
Water Temperature, °C			
Backwash Control Valve, % Open			
Is this the desirable 20-30%			

Filter Number: ___________ Tester: ______________________________

Date: ___________________ Time: ______________________________

Bed Expansion Math

1. While evaluating a filter, a bed expansion test was performed. During the backwash the filter bed rose 4 ¼ inches. The average media depth was 30 inches. Calculate the bed expansion in percent.

2. While evaluating a filter, a bed expansion test was performed. During the backwash the filter bed rose 6 ½ inches. The average media depth was 31 inches. Calculate the bed expansion in percent.

3. While evaluating a filter, a bed expansion test was performed. During the backwash the filter bed rose 8 inches. The average media depth was 36 inches. Calculate the bed expansion in percent.

4. Filter 5 at a water plant has an average media depth of 29 inches. The bed expanded by 8 inches during backwash. What is the bed expansion in percent?

5. Filter 2 at a water plant has an average media depth of 28 inches. The bed expanded by 4 inches during backwash. What is the bed expansion in percent?

6. Filter 16 at a water plant has an average media depth of 32 inches. The bed expanded by 10 inches during backwash. What is the bed expansion in percent?

7. Calculate the filter bed expansion if the average media depth is 33 inches and the bed expansion is 5.5 inches.

8. Calculate the filter bed expansion if the average media depth is 34 ½ inches and the bed expansion is 7 inches.

9. Calculate the filter bed expansion if the average media depth is 28 inches and the bed expansion is 9 inches.

10. Calculate the filter bed expansion if the average media depth is 31 inches and the bed expansion is 5 inches.

Answers:

1. 14%
2. 21%
3. 22%
4. 28%
5. 14%
6. 31%
7. 17%
8. 20%
9. 32%
10. 16%

Backwash Rise Rate Analysis

Backwash Flow Rate Analysis

- Also known as rise test
- Determines actual backwash rate in gpm/ft^2 and gpm
- Backwash flow meters can become inaccurate and may need calibration
  - Determines meter accuracy

Backwash Flow Rate Analysis

- Equipment needed:
  - Hook gauge – two hooks 6 inches apart
  - Stop watch
  - Tape measure
  - Calculator

Backwash Flow Rate Analysis
continued

- Recommended backwash rates:
  - Single media filters = 18.75 gpm/ft^2
  - Dual media filters = 20 gpm/ft^2

Backwash Flow Rate Analysis
continued

- Steps
  - Measure the length and width of the filter bed and basin
  - Place hook gauge in filter with the top hook well below the washwater troughs
    - Make sure the hook gauge is level front to back and side to side
  - Drain the filter

Backwash Flow Rate Analysis
continued

- Steps
  - Begin backwash
  - Start the timer when the water reaches the top of the bottom hook
  - Stop the timer when the water reaches the top of the top hook
  - Record time
  - Drop water below bottom nail and repeat two more times

Backwash Flow Rate Analysis
continued

- Number Crunch
  - Calculate the volume of the water that rose in the filter

$$\text{volume, gal} = (\text{filter bed length, ft})(\text{filter bed width, ft})(0.5\ \text{ft depth})(7.48\ \text{gal}/\ ft^3)$$

  - Calculate the average time in minutes

$$\text{avg. time, min} = \frac{(Time_1 + Time_2 + Time_3)}{(3)(60\ \text{sec/min})}$$

Backwash Flow Rate Analysis
continued

- Number Crunch
  - Calculate the filter bed area

$$\text{filter bed area, } ft^2 = (\text{bed length, ft})(\text{bed width, ft})$$

  - Calculate backwash rate in gpm

$$\text{backwash rate, gpm} = \frac{\text{volume, gal}}{(\text{avg. time, min})}$$

Backwash Flow Rate Analysis
continued

- Number Crunch
  - Calculate the backwash rate in gpm/ft^2

$$\text{backwash rate, } gpm/ft^2 = \frac{\text{backwash rate, gpm}}{(\text{filter bed area, } ft^2)}$$

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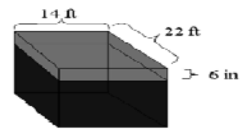
Backwash Flow Rate Analysis
continued

- A filter measures 22 ft by 14 ft. The backwash cycle was started. The water level rose 6 inches in 11 sec, 10 sec and 12 sec during three tests. What is the backwash rate in gpm, gpm/ft^2 and how many gallons were used if it were backwashed for 12 minutes?



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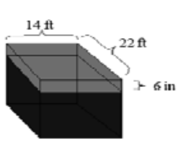
Volume, gal

$$V=(l, ft)(w, ft)(d, ft)(7.48 gal/ft^3)$$

$$V=(22 ft)(14 ft)(0.5 ft)(7.48 gal/ft^3)$$



V= 1151.9 gal

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Average Time, min

11 sec, 10 sec and 12 sec

$$\text{Avg time, min} = \frac{sec_1 + sec_2 + sec_3}{(3)(60\ sec/min)}$$

$$\text{Avg Time, min} = \frac{11 + 10 + 12}{(3)(60\ sec/min)}$$

Avg Time, min = 0.1833 min

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Volume, gal = 1151.9 gal
Time, min = 0.1833 min
Area, ft^2 = 308 ft^2

Sand Bed Area

A filter measures 22 ft by 14 ft.

Sand Area, ft^2 =(length, ft)(width, ft)

Sand Area, ft^2 = (22 ft)(14 ft)

Sand Area, ft^2 = 308 ft^2

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Backwash Rate, gpm/ft^2

$$\text{Filter rate, gpm} = \frac{\text{volume, gal}}{\text{average time, min}}$$

$$\text{Filter rate, gpm} = \frac{1151.9 \text{ gal}}{0.1833 \text{ min}}$$

Filter rate, gpm = 6284 gpm

TDEC - Fleming Training Center 94

Backwash Rate, gpm = 6284 gpm
Volume, gal = 1151.9 gal
Time, min = 0.1833 min
Area, ft^2 = 308 ft^2

Backwash Rate, gpm/ft^2

$$\text{Filter rate gpm/ft}^2 = \frac{\text{filter rate, gpm}}{\text{sand area, ft}^2}$$

$$\text{Filter rate, gpm/ft}^2 = \frac{6284 \text{ gpm}}{308 \text{ ft}^2}$$

Filter rate, gpm/ft^2 = 20.4 gpm/ft^2

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Backwash Gallons Used

Backwash Vol., gal = (Backwash Rate, gpm/ft^2)(Sand Area, ft^2)(time, min)

Backwash Vol., gal = (20.4 gpm/ft^2)(308 ft^2)(12 min)

Backwash Vol., gal = 75,398.4 gallons

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Backwash Flow Rate	Bed Expan., %	Action Needed
Low	<20%	↑ backwash flow rate and repeat bed expan. analysis
Low	20-30%	↑ backwash flow rate and repeat bed expan. analysis
Low	>30%	Check water temp
Correct	<20%	"cementing" of filter?
Correct	20-30%	None
Correct	>30%	Check effective size and uniformity coefficient
High	<20%	"cementing" of filter?
High	20-30%	"cementing" of filter?
High	>30%	↓ backwash flow rate and repeat bed expan. analysis

Backwash Rate Analysis Worksheet

Filter Bay Dimensions			
Length	ft	Width	ft
Filter Bed Dimensions			
Length	ft	Width	ft
Time to Drop 6 inches			
$Time_1$	sec		
$Time_2$	sec		
$Time_3$	sec		

Backwash Volume	
$vol, gal = (bed\ length, ft)(bed\ width, ft)(0.5\ ft\ rise)(7.48\ gal/ft^3)$	
$average\ time, min = \frac{Time_1 + Time_2 + Time_3}{(3)(60\ sec/min)}$	
$filter\ bed\ area, ft^2 = (bed\ length, ft)(bed\ width, ft)$	
$backwash\ rate, gpm = \frac{vol, gal}{(avg.\ time, \text{min})}$	
$backwash\ rate, gpm/ft^2 = \frac{backwash\ rate, gpm}{filter\ bed\ area, ft^2}$	
$backwash\ water\ vol., gal = (backwash\ rate, gpm)(time\ backwashed, min)$	
Is this sufficient backwash rate for your media to achieve at least 20% expansion?	

Filter Number: ___________ Tester: ______________________________

Date: ___________________ Time: _______________________________

Backwash Math

1. A filter measures 28 feet by 20 feet. The backwash cycle is started and the water rises 6” in 12, 13, and 13 seconds. What is the backwash rate in gallons per minute per square foot (gpm/ft^2)?

2. The Randyville Water Plant treats an average of 5.18 MGD. The water is split equally to each of the 8 filters. Each filter basin measures 12 feet wide by 16 feet long and by 24 feet deep. Each filter bed measures 12 feet by 14 feet by 11 feet deep. Filter 6 is taken offline to backwash. Using a hook gauge and a stopwatch, it is noted that the water level in the filter rises 6 inches in 14, 16, and 15 seconds. What is the backwash rate in gallons per minute per square foot (gpm/ft^2) and how many gallons were used if the filter was backwashed for 9 minutes?

3. The Chrisburg Water Plant treats an average of 7.2 MGD. The water is split equally to each of 8 filters. Each filter basin measures 12.5 feet wide by 16.5 feet long by 24 feet deep. Each filter bed measures 12.5 feet by 14 feet by 10 feet deep. Filter 6 is taken offline to backwash. Using a hook gauge and a stopwatch, it is noted that the water level in the filter rises 6 inches in 12 seconds on test 1, 6 inches in 11 seconds on test 2 and 6 inches in 14 seconds on test 3. What is the backwash rate in gallons per minute per square foot (gpm/ft^2)?

4. Determine the backwash rate in gpm/ft^2 for a filter with a surface of 28 feet by 20 feet. The backwash cycle started and the water rose 6 inches in 15, 16, and 16 seconds.

5. Determine the backwash rate in gpm/ft^2 for a filter bay that is 10 by 14 feet and the filter bed is 10 by 12 feet. The test was run three times. The backwash cycle started and the water rose 6 inches in 17, 16, and 16 seconds.

6. Determine the backwash rate in gpm/ft^2 for a filter bay that is 15 by 22 feet and the filter bed is 15 by 20 feet. The test was run three times. The backwash cycle started and the water rose 6 inches in 18, 17, and 20 seconds

7. Determine the backwash rate in gpm/ft^2 for a filter bay that is 16 by 18 feet and the filter bed is 16 by 16 feet. The test was run three times. The backwash cycle started and the water rose 6 inches in 11, 10, and 9 seconds

8. Determine the backwash rate in gpm/ft^2 and the amount of water used if they backwashed for 12 minutes for a filter bay that is 14 by 18 feet and the filter bed is 14 by 16 feet. The test was run three times. The backwash cycle started and the water rose 6 inches in 18, 17, and 20 seconds

9. Determine the backwash rate in gpm/ft^2 and the amount of water used if they backwashed for 14 minutes for a filter bay that is 20 by 32 feet and the filter bed is 20 by 30 feet. The test was run three times. The times required for the water to rose 6 inches were 13, 12 and 15 seconds.

10. Determine the backwash rate in gpm/ft^2 and the amount of water used if they backwashed for 9 minutes for a filter bay that is 24 by 36 feet and the filter bed is 24 by 34 feet. The test was run three times. The times required for the water to rose 6 inches were 14, 15 and 16 seconds.

Answers:

1. 17.72 gpm/ft^2
2. 14.96 gpm/ft^2, 22,619.5 gal
3. 18.19 gpm/ft^2
4. 14.32 gpm/ft^2
5. 13.74 gpm/ft^2
6. 12.24 gpm/ft^2
7. 22.44 gpm/ft^2
8. 12.24 gpm/ft^2, 32,901 gal
9. 16.83 gpm/ft^2, 141,372 gal
10. 14.96 gpm/ft^2, 109,866 gal

Backwash Water Turbidity Analysis

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Backwash Water Turbidity

- Used to determine adequate backwashing duration
- Desired backwash time is determined by the amount of time to drop the backwash water turbidity in the range of 10-15 NTU
  - AWWA recommends 10 NTU as the cutoff for backwashing
- Target time is 6-8 minutes

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Backwash Water Turbidity cont.

- The Interim Enhanced Surface Water Treatment Rule (IESWTR) requires filters to produce water with <0.3 NTU within 30 minutes of the start of the filter run
- Extending backwash until water runs clear may be causing some spikes after backwash
  - The filter may become too clean and needs longer time to "ripen"

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Backwash Water Turbidity cont.

- Equipment needed:
  - Stop watch
  - Sampler for grabbing samples of backwash water
  - Turbidimeter
  - 30 100-mL sample bottles marked in one-minute intervals

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Backwash Water Turbidity cont.

- Procedure:
  - Place all bottles in order
  - One person needed to keep time with stopwatch and another person needed to collect samples
  - Start normal backwash cycle and stopwatch
  - Collect samples of backwash water in trough near discharge end (so it is well mixed) at one-minute intervals with sampler

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Backwash Water Turbidity cont.

- Procedure:
  - Fill 100-mL sample bottles to the line and dump remainder back into filter
  - Repeat this procedure every minute until backwash is complete, extend normal backwash time about 3-5 minutes
  - Take each sample to turbidimeter
  - Mix samples thoroughly and read on turbidimeter
  - Plot readings on graph paper

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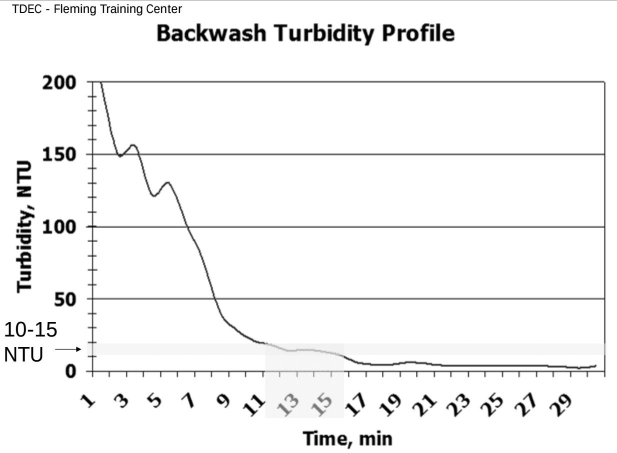

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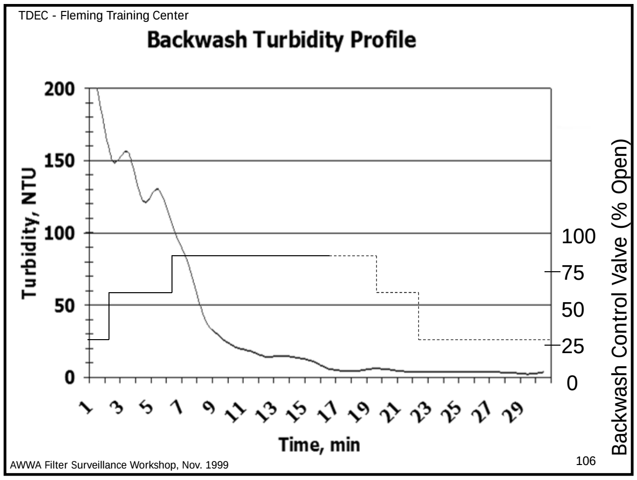

AWWA Filter Surveillance Workshop, Nov. 1999 106

Backwash Water Turbidity cont.

- Troubleshooting:
  - Water clears up after about 2-3 minutes of backwashing?
    - You may be only cleaning the top layer of anthracite
    - To fix this problem, raise backwash flow rate
  - Takes a long time to drop to 10-15 NTU range?
    - Filter may have been dirty for a long time and you are finally cleaning the filter

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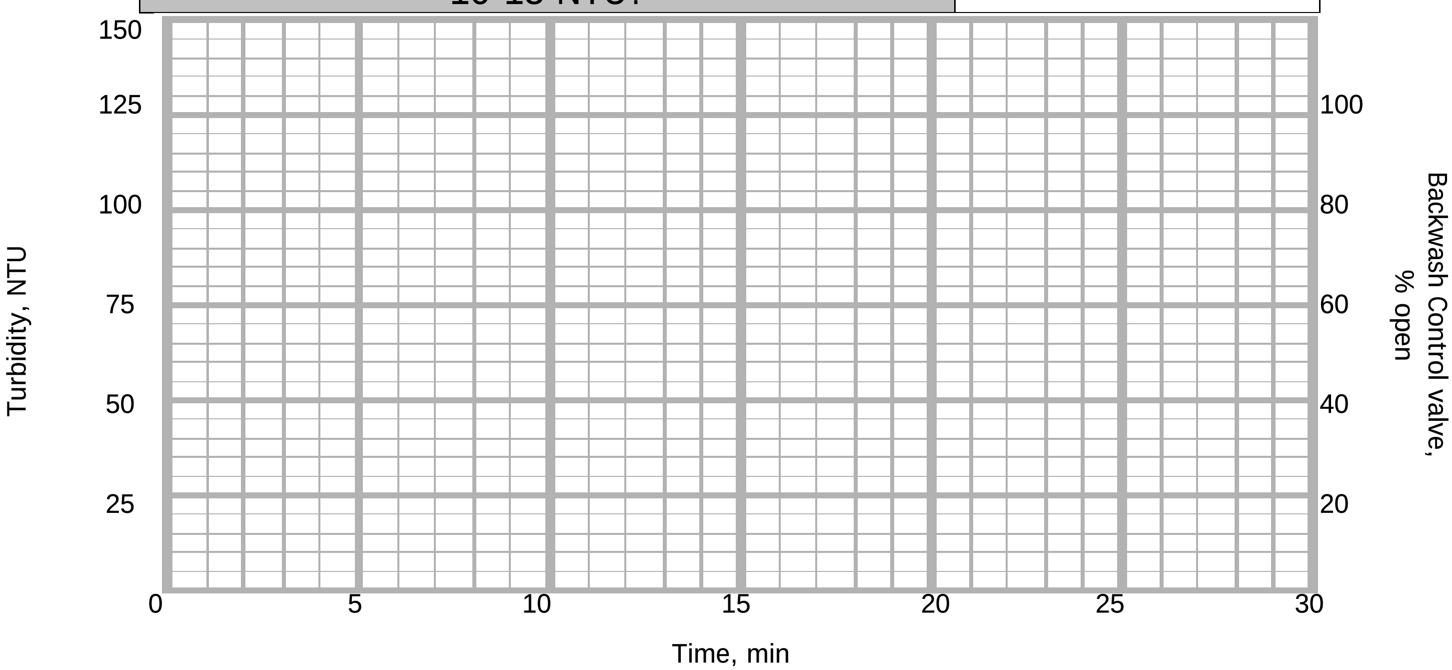
Backwash Water Turbidity Analysis

Time, min	Backwash Water Turbidity	Time, min	Backwash Water Turbidity
1		16	
2		17	
3		18	
4		19	
5		20	
6		21	
7		22	
8		23	
9		24	
10		25	
11		26	
12		27	
13		28	
14		29	
15		30	
What time did the backwash water fall between 10-15 NTU?			



Filter Number: ___________ Tester: ______________________________

Date: ___________________ Time: _______________________________

Gravel-layer Analysis

Gravel-layer Problems

- Indicators:
  - Dead areas
  - Boils
  - Excessive mud in one location
  - Media separation from the wall

Gravel-layer Analysis

- Equipment needed:
  - 5-ft ruler or steel rod
- This can be done at the same time you are getting media depths

Gravel-layer Analysis continued

- Procedure:
  - Filter bed dimensions need to be determined, draw a layout of filter bed
    - Divide filter in half length-wise
    - Divide those halves in half
    - Divide filter in half width-wise
    - Divide those halves in half also
  - Where the lines cross are your sampling areas, along with where the lines touch the sides and the corners

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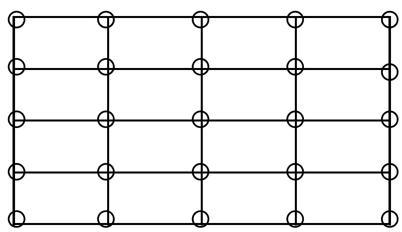
Gravel-layer Analysis continued

- 25 sampling points



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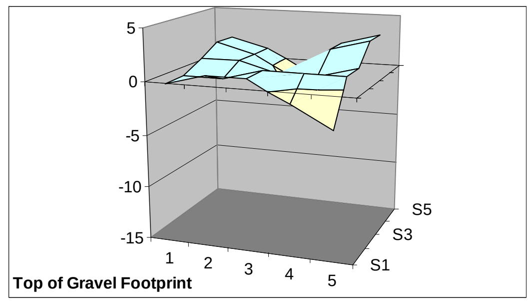
Gravel-layer Analysis continued



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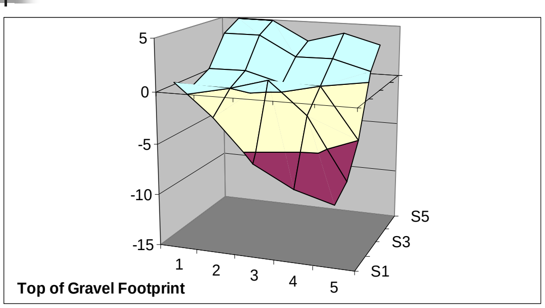
Gravel-layer Analysis continued



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Filtration Rate Analysis

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Filtration Rates Allowed in TN

- Rapid Sand Filters
  - 2.0 gpm/ft^2 for turbidity removal
  - 3.0 gpm/ft^2 for iron removal
- High Rate Filters
  - 4.0 gpm/ft^2 for turbidity and iron removal

State Design Criteria 4.2.1 a. 1 & 2

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Filtration Rate Analysis

- Also known as Hook Gauge
- Determines actual filtration rate in gpm/ft^2
- Determines the accuracy of the filtration rate flow meter
- Equipment needed:
  - Hook gauge – two hooks 6 inches apart
  - Stop watch
  - Tape measure
  - Calculator

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Filtration Rate Analysis continued

- Steps
  - Measure the length and width of the filter bed and basin
  - Place hook gauge in filter with the top hook well below the surface of the water
    - Make sure the hook gauge is level front to back and side to side
  - Close the influent valve, leaving the effluent valve open
    - Record meter's flow

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Filtration Rate Analysis continued

- Steps
  - Start the timer when the water breaks the surface of the first hook
  - Stop timer when the water breaks the surface of the second hook
  - Record time
  - Refill basin and repeat two more times

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Filtration Rate Analysis continued

- Number Crunch
  - Calculate the volume of the water that passed through the filter

$$volume,\ gal = (filter\ bay\ length,\ ft)(filter\ bay\ width,\ ft)(0.5\ ft\ depth)(7.48\ gal/\ ft^3)$$

  - Calculate the average time in minutes

$$avg.\ time,\ min = \frac{(Time_1 + Time_2 + Time_3)}{(3)(60\ \text{sec/ min})}$$

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Filtration Rate Analysis continued

- Number Crunch
  - Calculate the filter bed area

$$filter\ bed\ area,\ ft^2 = (bed\ length,\ ft)(bed\ width,\ ft)$$

  - Calculate filtration rate in gpm

$$\text{filtration rate, gal/min} = \frac{\text{volume, gal}}{\text{avg. time, min}}$$

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Filtration Rate Analysis continued

- Number Crunch
  - Calculate filtration rate in gpm/ft^2

$$\text{filtration rate, gpm/ ft}^2 = \frac{\text{filtration rate, gal/min}}{\text{filter bed area, ft}^2}$$

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Filtration Rate Analysis continued

- Is the calculated flow rate greater than the State's allowable rate?
  - Slow down the filtration rate
- Is the calculated flow rate equal to the flow meter?
  - If not, re-do hook gauge
  - If it is still off, the flow meter needs to be calibrated

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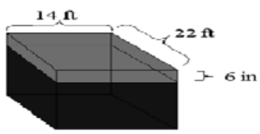
TDEC - Fleming Training Center

Filter Rate (Hook Gauge)

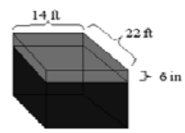
- A filter measures 22 ft by 14 ft. The influent is closed and the effluent is opened. The water level drops 6 inches in 120 sec, 124 sec and 128 sec during three tests. What is the filter rate in gpm/ft^2?



Volume, gal

V=(l, ft)(w, ft)(d, ft)(7.48 gal/ft^3)

V=(22 ft)(14 ft)(0.5 ft)(7.48 gal/ft^3)



V= 1151.9 gal

Average Time, min

120 sec, 124 sec and 128 sec

$$\text{Avg time, min} = \frac{sec_1 + sec_2 + sec_3}{(3)(60\ \text{sec/min})}$$

$$\text{Avg Time, min} = \frac{120+124+128}{(3)(60\ \text{sec/min})}$$

Avg Time, min = 2.0667 min

Sand Bed Area

A filter measures 22 ft by 14 ft.

Sand Area, ft^2 =(length, ft)(width, ft)

Sand Area, ft^2 = (22 ft)(14 ft)

Sand Area, ft^2 = 308 ft^2

Volume, gal = 1151.9 gal
Time, min = 2.0667 min
Area, ft^2 = 308 ft^2

Filter Rate, gpm/ft^2

$$\text{Filter rate, gpm (Hook Gauge)} = \frac{\text{volume, gal}}{\text{average time, min}}$$

$$\text{Filter rate, gpm} = \frac{1151.9\text{ gal}}{2.0667\text{ min}}$$

Filter rate, gpm = 557.4 gpm

Filtration Rate, gpm = 557.4 gpm
Volume, gal = 1151.9 gal
Time, min = 2.0667 min
Area, ft^2 = 308 ft^2

Filter Rate, gpm/ft^2

$$\text{Filter rate gpm/ft}^2 = \frac{\text{filter rate, gpm}}{\text{sand area, ft}^2}$$

$$\text{Filter rate, gpm/ft}^2 = \frac{557.4\text{ gpm}}{308\text{ ft}^2}$$

Filter rate, gpm/ft^2 = 1.8 gpm/ft^2

Filtration Rate Analysis Worksheet

Filter Bay Dimensions			
Length	ft	Width	ft
Filter Bed Dimensions			
Length	ft	Width	ft
Time to Drop 6 inches			
$Time_1$	sec		
$Time_2$	sec		
$Time_3$	sec		

Filtered Volume	
$vol, gal = (bay\ length, ft)(bay\ width, ft)(0.5\ ft\ drop)(7.48\ gal/ft^3)$	
$average\ time, min = \frac{Time_1 + Time_2 + Time_3}{(3)(60\ sec/min)}$	
$filter\ bed\ area, ft^2 = (bed\ length, ft)(bed\ width, ft)$	
$filtration\ rate, gpm/ft^2 = \frac{vol, gal}{(avg.\ time, min)(filter\ bed\ area, ft^2)}$	
Is this the allowable filtration rate for the State of TN?	

Rapid Sand Filters	
2.0 gpm/ft^2 for turbidity removal	3.0 gpm/ft^2 for iron removal
High Rate Filters	
4.0 gpm/ft^2 for iron and turbidity removal	

Filter Number: ___________ Tester: ______________________________

Date: __________________ Time: ______________________________

Filtration Math

1. A filter measures 28 feet by 20 feet. The influent is closed and the effluent is opened and the water drains down 6” in 120, 125, and 113 seconds. What is the filter-loading rate in gallons per minute per square foot (gpm/ft^2)?

2. The Randyville Water Plant treats an average of 5.18 MGD. The water is split equally to each of the 8 filters. Each filter basin measures 12 feet wide by 16 feet long and by 24 feet deep. Each filter bed measures 12 feet by 14 feet by 11 feet deep. The influent line to Filter 6 is closed while the effluent remains open. Using a hook gauge and a stopwatch, it is noted that the water level in the filter drops 6 inches in 80, 86, and 89 seconds. What is the filtration rate in gallons per minute per square foot (gpm/ft^2)?

3. The Chrisburg Water Plant treats an average of 7.2 MGD. The water is split equally to each of 8 filters. Each filter basin measures 12.5 feet wide by 16.5 feet long by 24 feet deep. Each filter bed measures 12.5 feet by 14 feet by 10 feet deep. The influent line to Filter 6 is closed while the effluent remains open. Using a hook gauge and a stopwatch, it is noted that the water level in the filter drops 6 inches in 69 seconds on test 1, 6 inches in 67 seconds on test 2 and 6 inches in 70 seconds on test 3. What is the filtration rate in gallons per minute per square foot (gpm/ft^2)?

4. Determine the filtration rate in gpm/ft^2 for a filter with a surface of 28 feet by 20 feet. With the influent valve closed, the water above the filter dropped 6 inches in 57, 56, and 60 seconds.

5. Determine the filtration rate in gpm/ft^2 for a filter bay that is 10 by 14 feet and the filter bed is 10 by 12 feet. The test was run three times. The times required for the water to drop 6 inches were 135, 132 and 129 seconds.

6. Determine the filtration rate in gpm/ft^2 for a filter bay that is 15 by 22 feet and the filter bed is 15 by 20 feet. The test was run three times. The times required for the water to drop 6 inches were 79, 85 and 80 seconds.

7. Determine the filtration rate in gpm/ft^2 for a filter bay that is 16 by 18 feet and the filter bed is 16 by 16 feet. The test was run three times. The times required for the water to drop 6 inches were 65, 62 and 64 seconds.

8. Determine the filtration rate in gpm/ft^2 for a filter bay that is 14 by 18 feet and the filter bed is 14 by 16 feet. The test was run three times. The times required for the water to drop 6 inches were 72, 75 and 76 seconds.

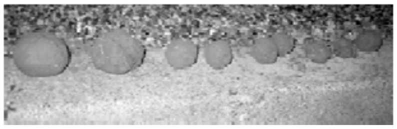
9. Determine the filtration rate in gpm/ft^2 for a filter bay that is 20 by 32 feet and the filter bed is 20 by 30 feet. The test was run three times. The times required for the water to drop 6 inches were 61, 59 and 58 seconds.

10. Determine the filtration rate in gpm/ft^2 for a filter bay that is 24 by 36 feet and the filter bed is 24 by 34 feet. The test was run three times. The times required for the water to drop 6 inches were 62, 60 and 59 seconds.

Answers:

1. 1.88 gpm/ft^2
2. 3.02 gpm/ft^2
3. 3.85 gpm/ft^2
4. 3.89 gpm/ft^2
5. 1.98 gpm/ft^2
6. 3.03 gpm/ft^2
7. 3.97 gpm/ft^2
8. 3.40 gpm/ft^2
9. 4.03 gpm/ft^2
10. 3.94 gpm/ft^2

Mudball Analysis



Mudballs

- Caused by grains of filter media covered with sticky floc material
  - If not effectively removed by backwashing, the grains clump together to form mudballs
- As they become larger, they sink into the filter bed and clog areas where they settle
- These areas become inactive, causing higher-than-optimal filtration rates in the remaining active areas and unequal distribution of backwash water

Mudballs continued

Two large mudballs

- Small, light mudballs usually consist of chemicals and feel “spongy”
- Heavy, dense mudballs consist normally of clay particles and are more rigid to the touch

Mudball Analysis

- Drain and isolate the filter
  - Good time to do this is when you are going to do core samples
  - Visually check filter media for mounds, cracks and separation from the wall
    - Due to mud retention from either poor backwash or surface wash not getting edges

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Mudball Analysis By Hand

- Lay plywood boards down on top of filter media
  - To avoid stepping onto media
- Pick a location and start digging with your hands
  - This creates a smaller hole as opposed to digging with a shovel
- Gently sift through media with your hands searching for mudballs

TDEC - Fleming Training Center 137

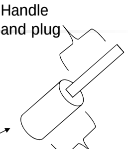
Mudball Analysis By Hand cont.

- As you are digging, look for separation of sand and anthracite
  - Measure depth of each separate media and make note of these depths
- Removal:
  - Manually
  - Soak the media in acidic water
- Backwash procedures will have to be modified to prevent accumulation of mudballs in the future

TDEC - Fleming Training Center 138

Mudball Analysis

- Equipment Needed:
  - No. 12 sieve (10 mesh)
  - Mudball sampling device
  - 1-gal resealable plastic baggies
  - 5-gal bucket
  - 250-mL graduated cylinder
    - 500-1,000-mL graduate cylinder may be needed if large mudballs are present



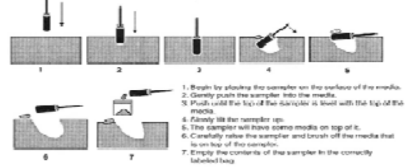
TDEC - Fleming Training Center 139

Mudball Analysis cont.

- Backwash filter
- Drain the water from the filter to a point below the media surface
- Select five sampling points at random
- Beginning with the first sampling point, push the mudball sampler 6 inches into the media

Mudball Analysis cont.

- Tilt the mudball sampler back until it is horizontal with the filter bed
- Lift the mudball sampler, keeping it horizontal
- Empty into a baggie
- Repeat this steps for remaining sampling spots, placing all samples into same bag



Mudball Analysis cont.

- Put water in 5-gal bucket until about half-full
- Lower the No. 12 sieve into the water until nearly submerged
- Put sampled media into sieve, handful at a time
- Carefully raise and lower the sieve into the water to wash media through the mesh

Mudball Analysis cont.

- Continue placing handfuls of media, lowering and raising sieve until all media has been sieved
- Gently wash any mudballs collected to one side of the sieve

Mudball Analysis cont.

- Fill 250-mL graduated cylinder to the 200-mL mark
  - May need 500 to 1000-mL graduated cylinder if you have large mudballs
- Gently transfer the mudballs from the sieve to the graduated cylinder
- Read and record new volume

TDEC - Fleming Training Center 144

Mudball Analysis cont.

- Number crunch:

$$\text{Media Sample Vol, mL} = \frac{(0.785)(D^2)(H)(N)(3{,}785\,mL/gal)}{231\,in^3/gal}$$

Where:
D = diameter, in
H = height of sampler, in
N = number of samples taken

$$\text{Media Sample Vol, mL} = \frac{(0.785)(3^2)(6)(5)(3{,}785\,mL/gal)}{231\,in^3/gal} = 3472.6\,mL$$

TDEC - Fleming Training Center 145

Mudball Analysis cont.

- Number crunch:

$$\text{Mudball Volume, mL} = \text{Final Cylinder Vol, mL} - \text{Initial Cylinder Vol, mL}$$

$$\%\ \text{Mudballs} = \frac{(\text{Mudball Vol, mL})(100)}{\text{Media Sample Vol, mL}}$$

TDEC - Fleming Training Center 146

Mudball Analysis cont.

% Mudballs	Filter Bed Condition
0.0 – 0.1	Excellent
0.1 – 0.2	Very good
0.2 – 0.5	Good
0.5 – 1.0	Fair
1.0 – 2.5	Fairly bad
2.5 – 5.0	Bad
Greater than 5.0	Very bad

TDEC - Fleming Training Center 147

Mudball Analysis cont.

- Easy mudball removal
  - Use of strainer basket during a low-rate backwash
  - Break up of mudballs by using a rake
  - Passing media through large sieves that will let media less than 1 inch pass through

Mudball Analysis cont.

- More difficult mudball removal
  - Injection of high-pressure air or water into media to bring mudballs to the surface
  - Chemical addition to break up mudballs
  - Removal of media and cleaning or replacing it
    - Replacing does not fix the problem, backwash procedures need to be re-evaluated

Mudball Analysis Worksheet

Coring Device Diameter	in	Coring Device Depth	in

Mudball Volume	
Initial Cylinder Reading (V1)	mL
Final Cylinder Reading (V2)	mL
Mudball Volume (V1 – V2)	mL
$Media\ Sample\ Vol,\ mL = \frac{(0.785)(D^2)(H)(N)(3{,}785\ mL/gal)}{231\ in^3/gal}$ Where: D = diameter, in H = height of sampler, in N = number of samples taken	mL
$\%\ \text{Mudballs} = \frac{(\text{Mudball Vol., mL})(100)}{\text{Media Sample Vol., mL}}$	%

Circle the range that corresponds to the value you got						
0.0– 0.1 Excellent	0.1 – 0.2 Very Good	0.2 – 0.5 Good	0.5 – 1.0 Fair	1.0 – 2.5 Fairly Bad	2.5 – 5.0 Bad	Greater than 5.0 Very Bad

Filter Number: ___________ Tester: ______________________________

Date: ___________________ Time: _______________________________

Mudball Math

1. Mudball samples were taken with a sampler that has a 3 in diameter and is 6 inches deep. The 250-mL graduated cylinder was filled up to the 200-mL mark with water. The mudballs were placed in the graduated cylinder and the water rose to the 235 mL mark. What is the percent of mudballs if 5 samples were taken?

2. Mudball samples were taken with a sampler that has a 3 in diameter and is 6 inches deep. The 500-mL graduated cylinder was filled up to the 300-mL mark with water. The mudballs were placed in the graduated cylinder and the water rose to the 425 mL mark. What is the percent of mudballs if 5 samples were taken?

3. Mudball samples were taken with a sampler that has a 3 in diameter and is 6 inches deep. The 250-mL graduated cylinder was filled up to the 200-mL mark with water. The mudballs were placed in the graduated cylinder and the water rose to the 247 mL mark. What is the percent of mudballs if 5 samples were taken?

Answers:

1. 1.0%
2. 3.6%
3. 1.4%

Acid-Soluble Mineral Analysis

Also known as Carbonate Precipitation Analysis

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Presence of Acid-Soluble Minerals

- Calcium carbonate or manganese dioxide may "cement" the filter particles together
  - Increases media weight
  - Decreases bed expansion
  - Reduces filter effectiveness
- Can use muriatic acid to dissolve calcium carbonate, but it may also damage concrete filter bay
  - Have example from a water plant on procedure

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Presence of Acid-Soluble Minerals continued

- Equipment needed
  - Balance
  - Drying oven
  - Dessicator
- Sample can be what is left in 5 gallon bucket from mudball analysis

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Presence of Acid-Soluble Minerals continued

- AWWA B100-01 outlines analysis
  - Performed by immersing a known weight of filter media in 1:1 hydrochloric acid until the acid-soluble materials are dissolved, then determining the weight loss

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Presence of Acid-Soluble Minerals continued

- 5.3.1 Acid solubility test
  - Wash sample with distilled water and dry at 110 ± 5°C to a constant weight
  - Cool in dessicator no more than 30 minutes
  - Weigh 200 grams dried sample to nearest 0.1 % of weight of sample
  - Place sample in beaker and add enough 1:1 HCl to immerse sample, but not less than volume indicated on next slide

Presence of Acid-Soluble Minerals continued

Max. Particle Size in Sample		Min. Sample Wt	Min. 1:1 HCl vol.
mm	in	gram	mL
63.0	2 ½	4,000	7,000
37.5	1 ½	250	800
25.4	1	250	800
19.0	¾	250	800
12.5	½	250	800
9.5	$^3/_8$ and smaller	100	320

Presence of Acid-Soluble Minerals continued

- 5.3.1 Acid solubility test
  - Allow to stand in 1:1 HCl at room temperature for at least 30 minutes after fizzing stops
  - Wash sample with distilled water several times and dry at 110 ± 5°C to a constant weight
  - Cool in dessicator no more than 30 minutes
  - Weigh dried sample to nearest 0.1 % of weight of sample
  - Report loss in weight as acid-soluble material

Acid-Soluble Mineral Analysis Worksheet

Weigh Measurements			
Initial Sample Weight	grams	Final Sample Weight	grams
Calculations			
Carbonate Weight = Initial Weight, grams - Final Weight, grams			grams
$\text{Percent Carbonate} = \frac{\text{(Carbonate Weight, grams)(100)}}{\text{Initial Weight, grams}}$			grams
Additional Comments			

Filter Number: ___________ Tester: ______________________________

Date: ___________________ Time: _______________________________

Sieve Testing Procedure

Effective Size &
Uniformity Coefficient

Uniformity Coefficient and Effective Size

- From the design specifications, find out what the uniformity coefficient and effective size was supposed to be for each type of media
  - Gravel
  - Sand
  - Coal

Uniformity Coefficient

- The lower the uniformity coefficient, the more uniform the size of the media
- The more uniform the media size, the slower the head loss buildup of a filter
- Sand
  - Not greater than 1.7
- Anthracite
  - Not greater than 1.85

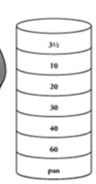
Uniformity Coefficient continued

- Time consuming test
  - Takes 2-3 days
- The ratio of particle diameters as determined by sieve analysis
- It is a measure of how well or poorly sorted the sediment is

Effective Size

- The smaller the media, the lower the effluent turbidity
- But less run time as well
- Sand
  - 0.35 mm to 0.55 mm
- Anthracite
  - 0.8 mm to 1.2 mm

Determination of Uniformity Coefficient & Effective Size



- Apparatus needed:
  - No. 200 sieve
  - Set of sieves
    - Numbers 3½, 10, 20, 30, 40, 60, lid and receiver
  - Drying oven
    - Set at a controlled temperature of 105-110°C
  - Set of metal pans for drying and weighing samples
  - A balance of 250 gram capacity and accurate to 0.01 gram

Determination of Uniformity Coefficient & Effective Size cont.

- Drain and isolate filter
- Determine sampling sites
  - 3-4 sites for a representative sample
- Enter filter and stand on plywood
- Place coring device (metal pipe ~1.5 inches in diameter) into media and push down until you come to resistance or hear the crunch of gravel
- Place hand on top of coring device to provide suction

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Determination of Uniformity Coefficient & Effective Size cont.

- Slowly raise coring device out of media, still with hand on top to provide suction
- Lay aluminum foil sheet down on plywood
- Gently tip the end of the coring device so the contents are slowly emptied across the length of the aluminum foil
- Separate the sand and anthracite at the interface

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Determination of Uniformity Coefficient & Effective Size cont.

- Repeat these steps for the next samples
- Label two bags, one for sand and one for anthracite

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Determination of Uniformity Coefficient & Effective Size cont.

- Begin with about a 100-gram sample of sand
  - Repeat for anthracite as well
- Dry in 105-110ºC oven for two hours
- Weigh dry sand sample (WD)
- Label and weigh metal sample pans, and set aside

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Determination of Uniformity Coefficient & Effective Size cont.

- Fill sand sample container with tap water, shake and decant wash water through No. 200 sieve
- Wash material retained on sieve back into sample container
- Repeat several times until wash water is clear

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Determination of Uniformity Coefficient & Effective Size cont.

- Dry sand again in 105-110oC oven for two hours
- Weigh dry washed sand (WDS) and subtract from dry weight to determine weight of fines
- Wt. of fines = WD - WDS

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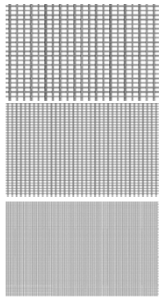
Determination of Uniformity Coefficient & Effective Size cont.

- Arrange a set of sieves from largest opening to smallest
- Shake stacked sieves, vibrating, jogging, and jolting them to keep the sand in continuous motion for two minutes
- Shake each sieve individually over a clean tray to make sure all the sand has passed through and is distributed by size



Determination of Uniformity Coefficient & Effective Size cont.

- Pour the sand off each sieve into labeled, weighed pans
- Weigh and determine the sample weight (WS) by subtracting the weight of the pan
- Determine the percent passing for each sieve by:
  - % of material retained on the sieve = $\frac{\text{WS x 100\%}}{\text{WDS}}$

Determination of Uniformity Coefficient & Effective Size cont.

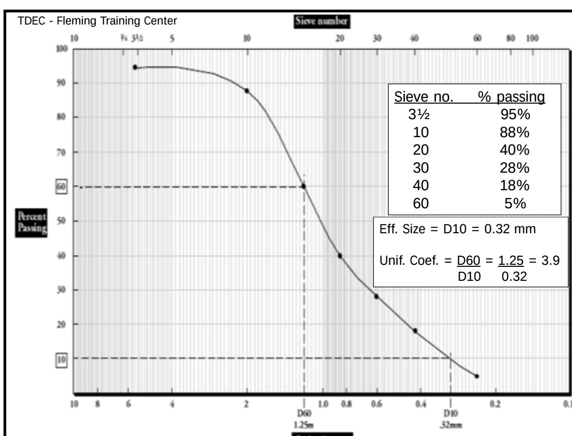
- % passing = % passing the next largest on sieve - % retained sieve
- An example calculation of percent passing each sieve for a 120 gram sample is summarized on the next slide

Sand Particle Size Analysis: Calculating Percent Passing Selected Sieves

Sieve number	Sieve size	Sample weight	% retained	% passing	% passing next larger sieve
3.5	5.6	6.0	5	95	100
10	2.0	8.4	7	88	95
20	0.85	57.6	48	40	88
30	0.425	14.4	12	28	40
40	0.425	12.0	10	18	28
60	0.25	15.6	13	5	18
Pan	-----	6.0	5	-----	5
Total Weight	-----	120.0			

Determination of Uniformity Coefficient & Effective Size cont.

- Graph the percent passing results on semi-log paper
- From the graph, find the Effective Size as D10, where only 10% of the sample is a smaller size
- Also from the graph, find D60, where 60% of the sample is a smaller size
- The Uniformity Coefficient is D60/D10



Floc Retention Analysis

Retained Floc

- Some retained floc should remain
  - Too clean – turbidity spikes
  - Too dirty – mudball formation will occur
  - Just enough – very few turbidity spikes will occur
- All depths of the media should retain a turbidity value of 30-60 NTU

Floc Retention Analysis

- Some "dirt" should remain in filter
  - This floc retention profile is a way to determine how much "dirt" stays in the filter and at what depths
- AWWA video says to do this annually, but you should do this quarterly to see if seasonal changes affect your filters

Floc Retention Analysis cont.

- Equipment Needed:
  - 24-36 1-gallon resealable plastic bags
  - Coring device
  - 100-mL graduated cylinder
  - Pint jar – "mason" or "jelly" jar
  - 50-mL beaker
  - Turbidimeter
  - 1-liter Erlenmeyer flask

Floc Retention Analysis cont.

- Performed twice on a filter
  - Once before backwashing and
  - Once after backwashing

Floc Retention Analysis cont.

- Procedure
  - Prepare 2 sets of plastic bags
    - 7 with "Before Backwash"
    - 7 with "After Backwash"
    - Each set needs media depths written on them as well:
      - 0-2 inches
      - 2-6 inches
      - 6-12 inches
      - 12-18 inches
      - 18-24 inches
      - 24-30 inches
      - 30-36 inches, just in case

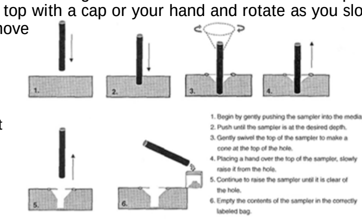
Floc Retention Analysis cont.

- Sample Collection Procedure
  - Select at least three sampling sites
    - Not in the same area
    - Try to get a good composite
  - Completely drain the filter
  - Lay down plywood and enter the filter

Floc Retention Analysis cont.

- Sample Collection Procedure
  - Push the coring device down into the filter, turning as you push down to the desired depth
  - Once the coring device has reached the desired depth seal the top with a cap or your hand and rotate as you slowly remove

Rotating it widens the hole so that it won't cave in



Floc Retention Analysis cont.

- Sample Collection Procedure
  - Break the seal and deposit the media into the appropriate bag for that depth
  - Repeat this process in the same hole for each sample depths
  - Then repeat this whole process in at least two other areas
    - You should have 3 areas sampled at depth of 0-2 inches in one bag, 2-6 inches, etc.

Floc Retention Analysis cont.

- Sample Collection Procedure
  - Backwash the filter
  - Repeat again, except this time place core samples in bags labeled "After Backwash"

Floc Retention Analysis cont.

- Sample Analysis Procedure
  - Mix each bag thoroughly and then arrange in order of depth with before and after backwash separated
  - Weigh out approximately 50 grams of media
    - Approximately 50-mL
  - Place into "jelly" jar

Floc Retention Analysis cont.

- Sample Analysis Procedure
  - Add 100-mL of tap water
    - Use same 50-mL beaker, filled twice to get 2:1
  - Cap and shake vigorously for 1 minute
  - Decant the turbid water into a 1000-mL flask
  - Repeat the steps of adding 100-mL tap water, shaking and decanting until you have a total of 500-mL

Floc Retention Analysis cont.

- Sample Analysis Procedure
  - Thoroughly mix the 500-mL of turbid water and take a turbidity reading
  - Multiply the reading by 2 in order to calculate the turbidity reading for a 100 gram sample
  - Repeat this procedure for each sample for both sets of before and after backwash at each depth
  - Record and plot results

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Floc Retention Analysis cont.

Turbidity	Filter Bed Condition
0-30 NTU	Media too clean, not well ripened
30-60 NTU	Media clean, slightly ripened; optimal filter performance
60-120 NTU	Slightly dirty media, well ripened, should perform well
120-300 NTU	Dirty media, well ripened; re-evaluate backwash procedure
300-600 NTU	Dirty media, possible mudballs
600-1200 NTU	Very dirty media, many mudballs
> 1200 NTU	Extremely dirty; chemical cleaning of media or replacement

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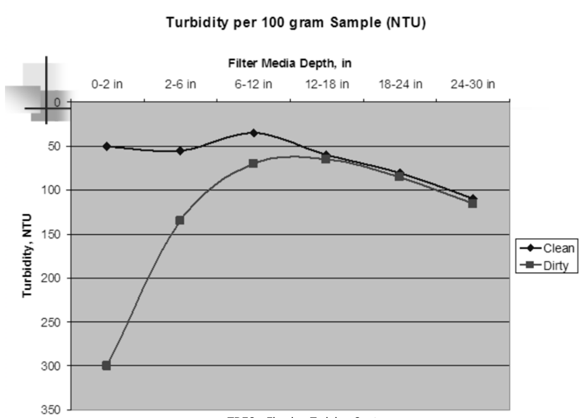

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Floc Retention Analysis cont.

- From the previous graph
  - It appears the top couple of inches is catching the most particles
  - Most of the filtration occurred in the anthracite layer
  - Sand layer was not cleaned well during backwash

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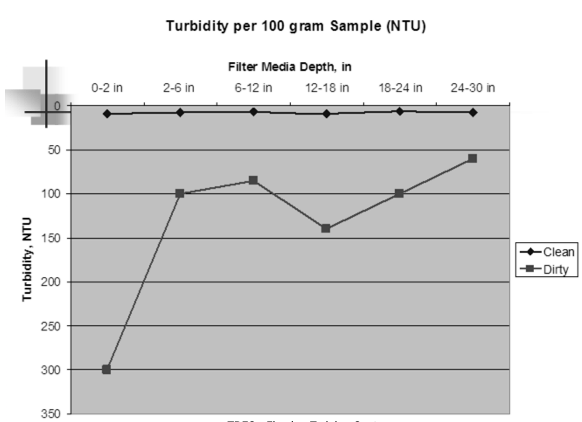

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Floc Retention Analysis cont.

- From the previous graph
  - Operator over-washed the filter
  - Common problem

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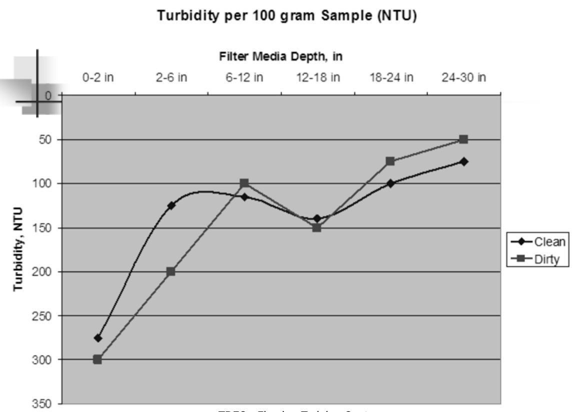

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Floc Retention Analysis cont.

- From the previous graph
  - Poor backwash

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Floc Retention Analysis cont.

- You want most of your particles removed during backwash
  - Filter should be cleaned and ripened
  - Filter can be too clean or too dirty with improper backwash

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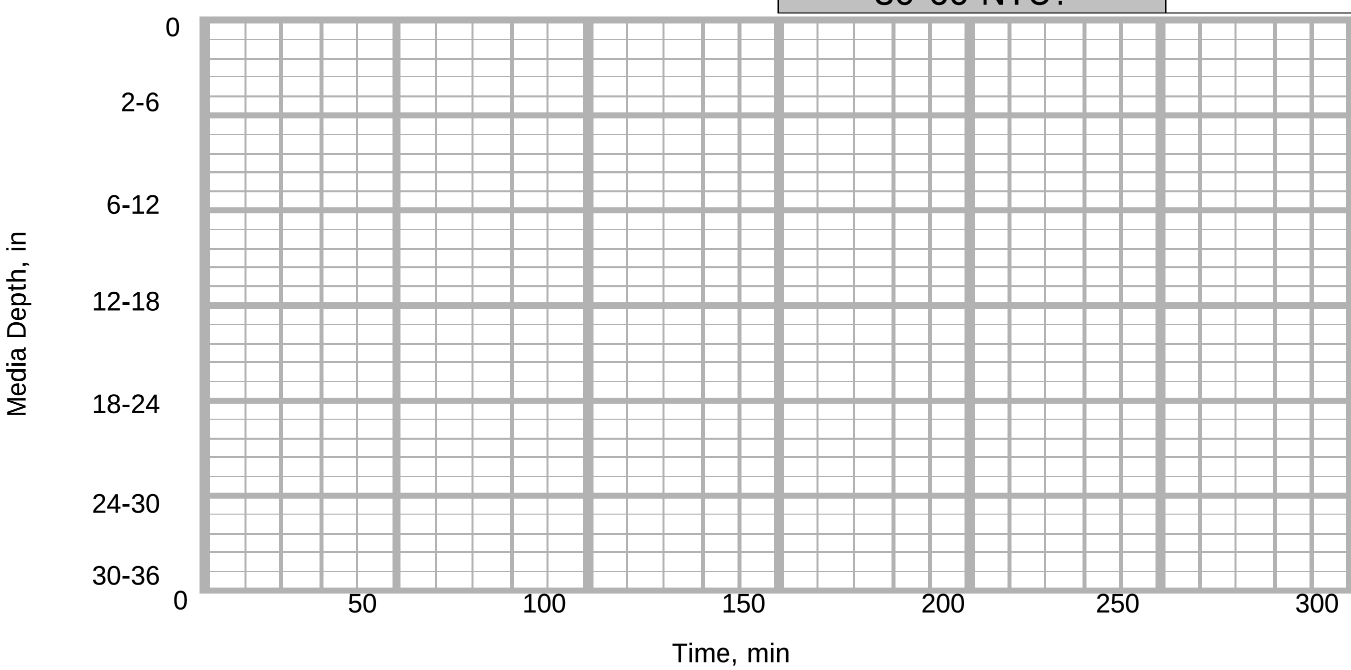
Floc Retention Profile

Before Backwash				After Backwash			
Core Sampler Depth, in	Turbidity	X	Floc Retention, NTU	Core Sampler Depth, in	Turbidity	X	Floc Retention, NTU
0-2		2		0-2		2	
2-6		2		2-6		2	
6-12		2		6-12		2	
12-18		2		12-18		2	
18-24		2		18-24		2	
24-30		2		24-30		2	
30-36		2		30-36		2	
Total Retained Floc				Total Retained Floc			
Average Retained Floc				Average Retained Floc			
				Is this in the range of 30-60 NTU?			



Filter Number: ___________ Tester: ______________________________

Date: __________________ Time: ______________________________

Disinfection

- Once filter surface is broken, filter bed must be disinfected
- If filter is dosed at 50 mg/L and let sit for 12-24 hours, it will remove mudballs, mud deposits, bacterial growth, iron and manganese deposits on filter walls and within media itself

Disinfection cont.

- AWWA Standard C653-03
  - This applies to disinfection of filter basins and gravel, silica sand, anthracite and other mixed media materials ***except*** granular activated carbon (GAC)
  - If GAC is part of the filter media, special care should be taken to protect the GAC from contamination

Disinfection cont.

- AWWA Standard C653-03
  - The entire filter basin should be filled up to the maximum water level and disinfected by one of two methods:
    - Chlorine injected into backwash water
    - Chlorine injected into filter influent while filtering to waste

Disinfection cont.

- AWWA Standard C653-03
  - Chlorine injected into backwash water
    - Enough chlorine injected to produce at least 25 mg/L free chlorine residual throughout entire filter
    - Chlorinated water shall be allowed to stand in the filter for at least 12 hours
    - Collect samples at the end of 12 hours, free residual chlorine shall not fall below 15 mg/L or else disinfection needs to be repeated

Disinfection cont.

- AWWA Standard C653-03
  - Chlorine injected into filter influent while filtering to waste
    - Enough chlorine injected to produce at least 25 mg/L free chlorine residual throughout entire filter
      - Turn on filter to waste to get through filter
    - When water with at least 25 mg/L free chlorine residual chlorine reaches the filter-to-waste, the flow of water shall be stopped
    - Filter shall be held for at least 12 hours

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Disinfection cont.

- AWWA Standard C653-03
  - After 12 hour contact time
    - Samples should be collected from the top and bottom of the unit to ensure the free chlorine residual readings measure the lowest chlorine level existing in the unit at the end of the 12-hour period
      - May have to dose at 50-100 mg/L to get residual of 15 mg/L after 12 hours
    - If satisfactory levels of chlorine residuals are obtained, the filter shall be run to waste or backwashed thoroughly to remove highly chlorinated water

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Disinfection cont.

- AWWA Standard C653-03
  - Bacteriological sampling
    - After chlorination and before filter placed back into service, two or more samples shall be taken from the unit not less than 30 minutes apart and shall be tested for the presence of coliform
      - 50% have to be negative, therefore take at least 3 samples, if one is positive, then more than 50% were negative

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Disinfection cont.

- AWWA Standard C653-03
  - Bacteriological sampling
    - If none of the samples show the presence of coliform, the unit may be placed back into service
    - If positive, take repeat at least 24 hours apart until consecutive samples are negative
    - Or disinfect again and resample

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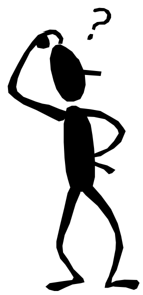
Now What?



- Many tests can be done
- What order should they be done?

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Order of Tests

- Set up hook gauge
- Establish a fixed point for bed expansion measurements
- Take the initial bed measurement
- Wash plywood sheets with strong hypochlorite solution

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Order of Tests cont.

- Drain filter
  - Run hook gauge (drop test)
  - Look for uneven drainage, cracks, mounding
  - Do not let filter dry out before next steps
- Set up ladders for safely entering and exiting the filter bay
- Lay down plywood to avoid standing on media

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Order of Tests cont.

- Measure levelness of troughs
- Take media depth measurements randomly throughout filter bed
- Take “Before Backwash” core samples for floc retention analysis
- Remove all people and equipment
- Lower hook gauge below troughs

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Order of Tests cont.

- Slowly start backwash to refill filter
  - Observe distribution of backwash water
  - Look for boils, mudballs

Order of Tests cont.

- While the filter is being backwash:
  - Take samples for backwash water turbidity analysis
  - Take second measurement for bed expansion
  - Perform rise test for backwash water flow rate
    - Afterward raise again to repeat drop test later

Order of Tests cont.

- After backwash, drain filter again
  - Run hook gauge (drop test)
  - Look for uneven drainage, cracks, mounding
  - Do not let filter dry out before next steps
- Set up ladders for safely entering and exiting the filter bay
- Lay down plywood to avoid standing on media

Order of Tests cont.

- Take “After Backwash” core samples for floc retention analysis
- Take samples for mudball analysis
- Remove all people and equipment
- Backwash again
- Disinfect
- Run samples in lab

References

- *Filter Evaluation Procedures for Granular Media*, 1st Edition. 2003. AWWA
- *AWWA Standard B100-01*
- *Filter Evaluation and Optimization*, TAUD – John Shadwick

Acid Washing and Disinfecting Dual Media Filters

Each filter shall be acid washed and disinfected annually for proper maintenance of filter media. Proper PPE should be worn while handling Hydrochloric acid, Hydrogen Peroxide, Calcium Hypochlorite and Sodium Hypochlorite (respirators, chemical resistant gloves and apron).

Acid Washing:

Note: Before any work on a filter begins, be sure to check that the effluent valve is in the closed position and is placed in the off position.

1. Follow the backwashing procedures for a Manual backwash, except when you ramp the wash water back down to zero open the rewash valve and let the filter level go back down to about 0.7 – 0.9 feet on top of the filter. **Collect media sample after initial backwash. Record time.**
2. While running the air sour to mix the acid with filter media add 15 to 20 gallons of 31% Hydrochloric acid or until the water on top of the filter reaches a pH of 1.8 to 1.9, document the results. Let the air scour mix the acid for 1 hour.
3. **Record beginning and end times.**
4. Wash the filter again so that the pH is elevated back up to normal (6.5 – 7.0) and document the results (pH prior to disinfection) and time spent in air scour acid wash.
5. Once pH is adjusted back around 7.00, drop the water level on top of the filter to 1.00 foot.
6. Add 12 pounds of 65% HTH (Calcium Hypochlorite) (**this number is not exact and should be adjusted accordingly with varying water levels on top of the filters**) or 10 gallons of 12.5% Sodium Hypochlorite to the filter to achieve 200ppm total chlorine residual.
7. Turn air scour back on.
8. Check the total chlorine residual in the filter then let the filter air scour for 30 minutes to disinfect. **Record total chlorine residual and start and end times for the disinfection.**
9. After 30-minute disinfection, wash the filter again until the chlorine residual is back down to normal and collect the bacteriological sample. **Record the chlorine residual before collecting the bacteriological sample.**
10. Put the filter into rewash until it seasons and turbidity reaches 0.20NTU. Record the total backwash water used for the entire process. Make note of the filter media depth in comparison to the red indicating tile on the filter bed wall. **Make sure all information is clearly stated on filter disinfection form.**

Acid Washing and Disinfecting Record

Acid Wash			
31% Hydrochloric Acid			
pH dropped to		pH prior to disinfection	
Air Scour for 1 hour			
Begin Time	AM PM	End Time	AM PM

Disinfection			
Slug Chlorination			
Required Chlorine Dose			ppm or mg/L
Contact Time			hours
Begin Time	AM PM	End Time	AM PM

Calculations	
$\text{Volume} = \frac{(\text{Filter Area, } ft^2)(3.5\ ft)(7.48 gal/ft^3)}{1{,}000{,}000}$ *3.5 = Water + Filter Media Depth*	MG
$\text{HTH, lbs} = \frac{(\_\_\_\_\_\_\ mg/L)(\_\_\_\_\_\_\ MG)(8.34\ lbs/gal)}{(\_\_\_\_\_\_)\%\text{Chemical Purity, as decimal}}$	lbs
$\text{Bleach, gal} = \frac{(\_\_\_\_\_\_\ mg/L)(\_\_\_\_\_\_\ MG)}{(\_\_\_\_\_\_)\%\text{Chemical Purity, as decimal}}$	gal

Lab Results			
Actual chlorine content initial (after chlorine was added)			m/L
Chlorine residual prior to pulling Bac'T sample			m/L
Bac'T sample Results		Bac'T Sample Date & Time	AM PM
Total Backwash Water Used		Date & Time put back into service	AM PM

Filter Number: ___________ Tester: ______________________________

Date: ___________________ Time: ______________________________

Bed Expansion Math

1. While evaluating a filter, a bed expansion test was performed. During the backwash the filter bed rose 4 ¼ inches. The average media depth was 30 inches. Calculate the bed expansion in percent.

$$\frac{(4.25)(100)}{30} = 14\%$$

2. While evaluating a filter, a bed expansion test was performed. During the backwash the filter bed rose 6 ½ inches. The average media depth was 31 inches. Calculate the bed expansion in percent.

$$\frac{(6.5)(100)}{31} = 21\%$$

3. While evaluating a filter, a bed expansion test was performed. During the backwash the filter bed rose 8 inches. The average media depth was 36 inches. Calculate the bed expansion in percent.

$$\frac{(8)(100)}{36} = 22\%$$

4. Filter 5 at a water plant has an average media depth of 29 inches. The bed expanded by 8 inches during backwash. What is the bed expansion in percent?

$$\frac{(8)(100)}{29} = 28\%$$

5. Filter 2 at a water plant has an average media depth of 28 inches. The bed expanded by 4 inches during backwash. What is the bed expansion in percent?

$$\frac{(4)(100)}{28} = 14\%$$

6. Filter 16 at a water plant has an average media depth of 32 inches. The bed expanded by 10 inches during backwash. What is the bed expansion in percent?

$$\frac{(10)(100)}{32} = 31\%$$

7. Calculate the filter bed expansion if the average media depth is 33 inches and the bed expansion is 5.5 inches.

$$\frac{(5.5)(100)}{33} = 17\%$$

8. Calculate the filter bed expansion if the average media depth is 34 ½ inches and the bed expansion is 7 inches.

$$\frac{(7)(100)}{34.5} = 20\%$$

9. Calculate the filter bed expansion if the average media depth is 28 inches and the bed expansion is 9 inches.

$$\frac{(9)(100)}{28} = 32\%$$

10. Calculate the filter bed expansion if the average media depth is 31 inches and the bed expansion is 5 inches.

$$\frac{(5)(100)}{31} = 16\%$$

Backwash Math

1. A filter measures 28 feet by 20 feet. The backwash cycle is started and the water rises 6" in 12, 13, and 13 seconds. What is the backwash rate in gallons per minute per square foot (gpm/ft^2)?

vol. = (28 ft)(20 ft)(0.5 ft)(7.48) = 2094.4 gal

time = $\frac{12s + 13s + 13s}{(3)(60)}$ = 0.2111 min

area = (28 ft)(20 ft) = 560 ft^2

gpm/ft^2 = $\frac{2094.4 \text{ gal}}{(0.2111 \text{ min})(560 \text{ ft}^2)}$ = **17.72 gpm/ft^2**

2. The Randyville Water Plant treats an average of 5.18 MGD. The water is split equally to each of the 8 filters. Each filter basin measures 12 feet wide by 16 feet long and by 24 feet deep. Each filter bed measures 12 feet by 14 feet by 11 feet deep. Filter 6 is taken offline to backwash. Using a hook gauge and a stopwatch, it is noted that the water level in the filter rises 6 inches in 14, 16, and 15 seconds. What is the backwash rate in gallons per minute per square foot (gpm/ft^2) and how many gallons were used if the filter was backwashed for 9 minutes?

vol. = (12 ft)(14 ft)(0.5 ft)(7.48) = 628.32 gal

time = $\frac{14s + 16s + 15s}{(3)(60)}$ = 0.25 min

area = (12 ft)(14 ft) = 168 ft^2

gpm/ft^2 = $\frac{628.32 \text{ gal}}{(0.25 \text{ min})(168 \text{ ft}^2)}$ = **14.96 gpm/ft^2**

vol. = (14.96 gpm/ft^2)(168 ft^2)(9 min) = **22,619.5 gal**

3. The Chrisburg Water Plant treats an average of 7.2 MGD. The water is split equally to each of 8 filters. Each filter basin measures 12.5 feet wide by 16.5 feet long by 24 feet deep. Each filter bed measures 12.5 feet by 14 feet by 10 feet deep. Filter 6 is taken offline to backwash. Using a hook gauge and a stopwatch, it is noted that the water level in the filter rises 6 inches in 12 seconds on test 1, 6 inches in 11 seconds on test 2 and 6 inches in 14 seconds on test 3. What is the backwash rate in gallons per minute per square foot (gpm/ft^2)?

vol. = (12.5 ft)(14 ft)(0.5 ft)(7.48) = 654.5 gal

time = $\frac{12s + 11s + 14s}{(3)(60)}$ = 0.2056 min

area = (12.5 ft)(14 ft) = 175 ft^2

gpm/ft^2 = $\frac{654.5 \text{ gal}}{(0.2056 \text{ min})(175 \text{ ft}^2)}$ = **18.19 gpm/ft^2**

4. Determine the backwash rate in gpm/ft^2 for a filter with a surface of 28 feet by 20 feet. The backwash cycle started and the water rose 6 inches in 15, 16, and 16 seconds.

vol. = (28 ft)(20 ft)(0.5 ft)(7.48) = 2094.4 gal

time = $\frac{15s + 16s + 16s}{(3)(60)}$ = 0.2611 min

area = (28 ft)(20 ft) = 560 ft^2

gpm/ft^2 = $\frac{2094.4 \text{ gal}}{(0.2611 \text{ min})(560 \text{ ft}^2)}$ = **14.32 gpm/ft^2**

5. Determine the backwash rate in gpm/ft^2 for a filter bay that is 10 by 14 feet and the filter bed is 10 by 12 feet. The test was run three times. The backwash cycle started and the water rose 6 inches in 17, 16, and 16 seconds.

vol. = (10 ft)(12 ft)(0.5 ft)(7.48) = 448.8 gal

time = $\frac{17s + 16s + 16s}{(3)(60)}$ = 0.2722 min

area = (10 ft)(12 ft) = 120 ft^2

gpm/ft^2 = $\frac{448.8 \text{ gal}}{(0.2722 \text{ min})(120 \text{ ft}^2)}$ = **13.74 gpm/ft^2**

6. Determine the backwash rate in gpm/ft^2 for a filter bay that is 15 by 22 feet and the filter bed is 15 by 20 feet. The test was run three times. The backwash cycle started and the water rose 6 inches in 18, 17, and 20 seconds

vol. = (15 ft)(20 ft)(0.5 ft)(7.48) = 1122 gal

time = $\frac{18s + 17s + 20s}{(3)(60)}$ = 0.3056 min

area = (15 ft)(20 ft) = 300 ft^2

gpm/ft^2 = $\frac{1122 \text{ gal}}{(0.3056 \text{ min})(300 \text{ ft}^2)}$ = **12.24 gpm/ft^2**

7. Determine the backwash rate in gpm/ft^2 for a filter bay that is 16 by 18 feet and the filter bed is 16 by 16 feet. The test was run three times. The backwash cycle started and the water rose 6 inches in 11, 10, and 9 seconds

vol. = (16 ft)(16 ft)(0.5 ft)(7.48) = 957.44 gal

time = $\frac{11s + 10s + 9s}{(3)(60)}$ = 0.1667 min

area = (16 ft)(16 ft) = 256 ft^2

gpm/ft^2 = $\frac{957.44 \text{ gal}}{(0.1667 \text{ min})(256 \text{ ft}^2)}$ = **22.44 gpm/ft^2**

8. Determine the backwash rate in gpm/ft^2 and the amount of water used if they backwashed for 12 minutes for a filter bay that is 14 by 18 feet and the filter bed is 14 by 16 feet. The test was run three times. The backwash cycle started and the water rose 6 inches in 18, 17, and 20 seconds

vol. = (14 ft)(16 ft)(0.5 ft)(7.48) = 837.76 gal

time = $\frac{18s + 17s + 20s}{(3)(60)}$ = 0.3056 min

area = (14 ft)(16 ft) = 224 ft^2

gpm/ft^2 = $\frac{837.76 \text{ gal}}{(0.3056 \text{ min})(224 \text{ ft}^2)}$ = **12.24 gpm/ft^2**

backwash vol. = (12.24 gpm/ft^2)(224 ft^2)(12 min) = **32,901 gal**

9. Determine the backwash rate in gpm/ft^2 and the amount of water used if they backwashed for 14 minutes for a filter bay that is 20 by 32 feet and the filter bed is 20 by 30 feet. The test was run three times. The times required for the water to rose 6 inches were 13, 12 and 15 seconds.

vol. = (20 ft)(30 ft)(0.5 ft)(7.48 gal) = 2244 gal

time = $\frac{13s + 12s + 15s}{(3)(60)}$ = 0.2222 min

area = (20 ft)(30 ft) = 600 ft^2

gpm/ft^2 = $\frac{2244 \text{ gal}}{(0.2222 \text{ min})(600 \text{ ft}^2)}$ = **16.83 gpm/ft^2**

backwash vol. = (16.83 gpm/ft^2)(600 ft^2)(14 min) = **141,372 gal**

10. Determine the backwash rate in gpm/ft^2 and the amount of water used if they backwashed for 9 minutes for a filter bay that is 24 by 36 feet and the filter bed is 24 by 34 feet. The test was run three times. The times required for the water to rose 6 inches were 14, 15 and 16 seconds.

vol. = (24 ft)(34 ft)(0.5 ft)(7.48) = 3051.84 gal

time = $\frac{14s + 15s + 16s}{(3)(60)}$ = 0.25 min

area = (24 ft)(34 ft) = 816 ft^2

gpm/ft^2 = $\frac{3051.84 \text{ gal}}{(0.25 \text{ min})(816 \text{ ft}^2)}$ = **14.96 gpm/ft^2**

backwash vol., gal = (14.96 gpm/ft^2)(816 ft^2)(9 min) = **109,866 gal**

Filtration Math

1. A filter measures 28 feet by 20 feet. The influent is closed and the effluent is opened and the water drains down 6" in 120, 125, and 113 seconds. What is the filter-loading rate in gallons per minute per square foot (gpm/ft^2)?

$$\text{vol.} = (28\text{ ft})(20\text{ ft})(0.5\text{ ft})(7.48) = 2094.4\text{ gal}$$

$$\text{time} = \frac{120\text{s} + 125\text{s} + 113\text{s}}{(3)(60)} = 1.9889\text{ min}$$

$$\text{area} = (28\text{ ft})(20\text{ ft}) = 560\text{ ft}^2$$

$$\text{gpm/ft}^2 = \frac{2094.4\text{ gal}}{(1.9889\text{ min})(560\text{ ft}^2)} = \boxed{1.88\text{ gpm/ft}^2}$$

2. The Randyville Water Plant treats an average of 5.18 MGD. The water is split equally to each of the 8 filters. Each filter basin measures 12 feet wide by 16 feet long and by 24 feet deep. Each filter bed measures 12 feet by 14 feet by 11 feet deep. The influent line to Filter 6 is closed while the effluent remains open. Using a hook gauge and a stopwatch, it is noted that the water level in the filter drops 6 inches in 80, 86, and 89 seconds. What is the filtration rate in gallons per minute per square foot (gpm/ft^2)?

$$\text{vol.} = (12\text{ ft})(16\text{ ft})(0.5\text{ ft})(7.48) = 718.08\text{ gal}$$

$$\text{time} = \frac{80\text{s} + 86\text{s} + 89\text{s}}{(3)(60)} = 1.4167\text{ min}$$

$$\text{area} = (12\text{ ft})(14\text{ ft}) = 168\text{ ft}^2$$

$$\text{gpm/ft}^2 = \frac{718.08\text{ gal}}{(1.4167\text{ min})(168\text{ ft}^2)} = \boxed{3.02\text{ gpm/ft}^2}$$

3. The Chrisburg Water Plant treats an average of 7.2 MGD. The water is split equally to each of 8 filters. Each filter basin measures 12.5 feet wide by 16.5 feet long by 24 feet deep. Each filter bed measures 12.5 feet by 14 feet by 10 feet deep. The influent line to Filter 6 is closed while the effluent remains open. Using a hook gauge and a stopwatch, it is noted that the water level in the filter drops 6 inches in 69 seconds on test 1, 6 inches in 67 seconds on test 2 and 6 inches in 70 seconds on test 3. What is the filtration rate in gallons per minute per square foot (gpm/ft^2)?

$$\text{vol.} = (12.5\text{ ft})(16.5\text{ ft})(0.5\text{ ft})(7.48) = 771.375\text{ gal}$$

$$\text{time} = \frac{69\text{s} + 67\text{s} + 70\text{s}}{(3)(60)} = 1.1444\text{ min}$$

$$\text{area} = (12.5\text{ ft})(14\text{ ft}) = 175\text{ ft}^2$$

$$\text{gpm/ft}^2 = \frac{771.375\text{ gal}}{(1.1444\text{ min})(175\text{ ft}^2)} = \boxed{3.85\text{ gpm/ft}^2}$$

4. Determine the filtration rate in gpm/ft^2 for a filter with a surface of 28 feet by 20 feet. With the influent valve closed, the water above the filter dropped 6 inches in 57, 56, and 60 seconds.

$\text{vol} = (20\text{ ft})(28\text{ ft})(0.5\text{ ft})(7.48) = 2094.4\text{ gal}$

$\text{time} = \frac{57\text{s} + 56\text{s} + 60\text{s}}{(3)(60)} = 0.9611\text{ min}$

$\text{area} = (20\text{ ft})(28\text{ ft}) = 560\text{ ft}^2$

$\text{gpm/ft}^2 = \frac{2094.4\text{ gal}}{(0.9611\text{ min})(560\text{ ft}^2)} = \boxed{3.89\text{ gpm/ft}^2}$

5. Determine the filtration rate in gpm/ft^2 for a filter bay that is 10 by 14 feet and the filter bed is 10 by 12 feet. The test was run three times. The times required for the water to drop 6 inches were 135, 132 and 129 seconds.

$\text{vol.} = (10\text{ ft})(14\text{ ft})(0.5\text{ ft})(7.48) = 523.6\text{ gal}$

$\text{time} = \frac{135\text{s} + 132\text{s} + 129\text{s}}{(3)(60)} = 2.2\text{ min}$

$\text{area} = (10\text{ ft})(12\text{ ft}) = 120\text{ ft}^2$

$\text{gpm/ft}^2 = \frac{523.6\text{ gal}}{(2.2\text{ min})(120\text{ ft}^2)} = \boxed{1.98\text{ gpm/ft}^2}$

6. Determine the filtration rate in gpm/ft^2 for a filter bay that is 15 by 22 feet and the filter bed is 15 by 20 feet. The test was run three times. The times required for the water to drop 6 inches were 79, 85 and 80 seconds.

$\text{vol.} = (15\text{ ft})(22\text{ ft})(0.5\text{ ft})(7.48) = 1234.2\text{ gal}$

$\text{time} = \frac{79\text{s} + 85\text{s} + 80\text{s}}{(3)(60)} = 1.3556\text{ min}$

$\text{area} = (15\text{ ft})(20\text{ ft}) = 300\text{ ft}^2$

$\text{gpm/ft}^2 = \frac{1234.2\text{ gal}}{(1.3556\text{ min})(300\text{ ft}^2)} = \boxed{3.03\text{ gpm/ft}^2}$

7. Determine the filtration rate in gpm/ft^2 for a filter bay that is 16 by 18 feet and the filter bed is 16 by 16 feet. The test was run three times. The times required for the water to drop 6 inches were 65, 62 and 64 seconds.

$\text{vol.} = (16\text{ ft})(18\text{ ft})(0.5\text{ ft})(7.48) = 1077.12\text{ gal}$

$\text{time} = \frac{65\text{s} + 62\text{s} + 64\text{s}}{(3)(60)} = 1.0611\text{ min}$

$\text{area} = (16\text{ ft})(16\text{ ft}) = 256\text{ ft}^2$

$\text{gpm/ft}^2 = \frac{1077.12\text{ gal}}{(1.0611\text{ min})(256\text{ ft}^2)} = \boxed{3.97\text{ gpm/ft}^2}$

8. Determine the filtration rate in gpm/ft^2 for a filter bay that is 14 by 18 feet and the filter bed is 14 by 16 feet. The test was run three times. The times required for the water to drop 6 inches were 72, 75 and 76 seconds.

gal = (14 ft)(18 ft)(0.5 ft)(7.48) = 942.48 gal

$$\text{time} = \frac{72s + 75s + 76s}{(3)(60)} = 1.2389 \text{ min}$$

area = (14 ft)(16 ft) = 224 ft^2

$$\text{gpm/ft}^2 = \frac{942.48 \text{ gal}}{(1.2389 \text{ min})(224 \text{ ft}^2)} = \boxed{3.40 \text{ gpm/ft}^2}$$

9. Determine the filtration rate in gpm/ft^2 for a filter bay that is 20 by 32 feet and the filter bed is 20 by 30 feet. The test was run three times. The times required for the water to drop 6 inches were 61, 59 and 58 seconds.

gal = (20 ft)(32 ft)(0.5 ft)(7.48) = 2393.6 gal

$$\text{time} = \frac{61s + 59s + 58s}{(3)(60)} = 0.9889 \text{ min}$$

area = (20 ft)(30 ft) = 600 ft^2

$$\text{gpm/ft}^2 = \frac{2393.6 \text{ gal}}{(0.9889 \text{ min})(600 \text{ ft}^2)} = \boxed{4.03 \text{ gpm/ft}^2}$$

10. Determine the filtration rate in gpm/ft^2 for a filter bay that is 24 by 36 feet and the filter bed is 24 by 34 feet. The test was run three times. The times required for the water to drop 6 inches were 62, 60 and 59 seconds.

gal = (24 ft)(36 ft)(0.5 ft)(7.48) = 3231.36 gal

$$\text{time} = \frac{62s + 60s + 59s}{(3)(60)} = 1.0056 \text{ min}$$

area = (24 ft)(34 ft) = 816 ft^2

$$\text{gpm/ft}^2 = \frac{3231.36 \text{ gal}}{(1.0056 \text{ min})(816 \text{ ft}^2)} = \boxed{3.94 \text{ gpm/ft}^2}$$

Mudball Math

1. Mudball samples were taken with a sampler that has a 3 in diameter and is 6 inches deep. The 250-mL graduated cylinder was filled up to the 200-mL mark with water. The mudballs were placed in the graduated cylinder and the water rose to the 235 mL mark. What is the percent of mudballs?

Sampler Vol. $= \frac{(0.785)(3in)^2(6in)(5)(3785)}{231} = 3472.86$ mL

$235 - 200 = 35$ mL

$\frac{(35mL)(100)}{3472.86mL} = 1.0\%$ fairly bad

2. Mudball samples were taken with a sampler that has a 3 in diameter and is 6 inches deep. The 500-mL graduated cylinder was filled up to the 300-mL mark with water. The mudballs were placed in the graduated cylinder and the water rose to the 425 mL mark. What is the percent of mudballs?

$425 - 300 = 125$ mL

$\frac{(125mL)(100)}{3472.86 mL} = 3.6\%$ bad

3. Mudball samples were taken with a sampler that has a 3 in diameter and is 6 inches deep. The 250-mL graduated cylinder was filled up to the 200-mL mark with water. The mudballs were placed in the graduated cylinder and the water rose to the 247 mL mark. What is the percent of mudballs?

$247 - 200 = 47$ mL

$\frac{(47mL)(100)}{3472.86mL} = 1.4\%$ fairly bad

Answers:

1. 1.0%
2. 3.6%
3. 1.4%

Filter Math

Filter Dimensions:

Bay Length = 30 ft — Bed Length = 28 ft.

Bay Width = 24 ft — Bed Width = 24 ft

Media Depth Measurements:

28″	29″	28″
28″	30″	29″
31″	29″	29″
30″	28″	27″

avg. media depth = 28.83 in

Bed Expansion: 4 inches

Drop Test Times = 72 sec, 70 sec, 73 sec avg. time = 1.1944 min

Rise Test Times = 18 sec, 20 sec, 21 sec avg. time = 0.3278 min

What is the percent bed expansion; filtration rate in gpm and gpm/ft^2; the backwash rate in gpm and gpm/ft^2 and the amount of water if backwashed for 12 minutes?

$$\%\ \text{bed expansion} = \frac{(4)(100)}{28.83} = \boxed{13.87\%}$$

$$\text{filtration rate, gpm} = \frac{(30\,ft)(24\,ft)(0.5\,ft)(7.48)}{1.1944\,min} = \boxed{2254.5\,gpm}$$

$$\text{filtration rate, gpm/ft}^2 = \frac{2254.5\,gpm}{(28\,ft)(24\,ft)} = \boxed{3.35\,gpm/ft^2}$$

$$\text{backwash rate, gpm} = \frac{(28\,ft)(24\,ft)(0.5\,ft)(7.48)}{0.3278\,min} = \boxed{7667.1\,gpm}$$

$$\text{backwash rate, gpm/ft}^2 = \frac{7667.1\,gpm}{(28\,ft)(24\,ft)} = \boxed{11.4\,gpm/ft^2}$$

$$\text{backwash vol., gal} = (11.4\,gpm/ft^2)(28\,ft)(24\,ft)(12\,min) = \boxed{91{,}929.6\,gal}$$