State of Ohio Class A Drinking Water Operator Certification Program

Session Two: Supplemental Materials

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CONTENTS

1. Disinfection

Overview of Disinfection

1) **Purpose of Disinfection –** The primary purpose is to protect Public Health. All major public water supplies and some major community water supplies are required to disinfect. However not all small community and non-community water systems are required to disinfect.

Disinfection is the process used to kill pathogenic bacteria, in a raw water supply.

Residual Disinfection is the process of maintaining a disinfectant level in the treated or finished water supply throughout a system to assure that re-growth of pathogenic microorganisms will not occur.

- Chemical treatment for well supplies as a minimum requires provision for disinfection.
- For wells that are considered not to be under the influence of surface waters or requiring other forms of treatment, disinfection using chlorine or one of its compounds, followed by 30 minutes of detention time, may be required.
  - An example of detention time would be: You have a tank that holds 150 gallons of water. With the tank empty you fill it at a rate of five gallons per minute. At that rate it will take 30 minutes to fill it. So, if you have a tank that holds 150 gallons of water and you are filling it at 5 gallons per minute you would have a 30 minute detention time.

2) Disinfection Processes and Descriptions

Disinfection Byproducts

Some people believe if a little is good, even more must be better. When it comes to chlorination, over-feeding may cause the formation of additional, harmful, byproducts.

- Some of these reactions between organic compounds and chlorine will form regulated disinfection byproducts including trihalomethanes (TTHMs) and haloacetic acids (HAA5). It is desirable to remove as much of these organic materials from the water as possible before disinfection with chlorine since the byproducts are carcinogenic.
- All water systems that apply chlorine as a disinfectant must analyze for THMs. The number of samples analyzed and frequency is a function of system size and water source.

Disinfection Demand

Demand is defined as anything in the source water that will react with the disinfectant (chlorine) and make it unavailable for disinfection. This includes iron, hydrogen sulfide, inorganics, and organic material.

Process Control

Process control refers to controlling the key parameters (chemical feed rates and application points, mixing time, detention time, etc.) to ensure proper water quality.

- Chemical feed of a disinfectant must be continuous and adequate.
- Again, if the dosage of the disinfectant is not sufficient to kill the pathogenic organisms, breakthrough or re-growth may occur in the distribution system.

Time

Time is an important factor. Specifically, contact time is important. Contact time is the amount of time in minutes deemed necessary for the applied chlorine to perform its disinfection function before the water is delivered to the first customer.

Chemical Disinfection

Chlorine Gas

Chlorine gas is a liquid form of pure chlorine. It is stored in cylinder under pressure. When it is withdrawn from the cylinder it comes out in the form of a gas. Large water systems typically use this type of disinfectant.

Hypochlorite – Liquid Chlorination

Hypochlorite generally is a compound of chlorine and either sodium or calcium. Available in solutions from 5% to 15% chlorine.

- Advantages
  - Hypochlorite is an effective disinfectant.
  - Hypochlorite is easy to use and apply and does not require special training for handling.
  - It is easy to monitor to determine whether there is a residual disinfectant in the distribution system.
- Disadvantages
  - Hypochlorite solution is prone to degrade over time as chlorine vaporizes from solution, reducing its chlorine content, making it less effective and requiring a higher feed rate of the weaker product.
  - It is an aggressive chemical that can corrode many materials it comes in contact with.
  - Hypochlorite can react with organics in either the raw water or finished water to form trihalomethane and haloacetic acids, which are known carcinogenics.
  - It can “off gas” in the feed system, resulting in operational problems.
  - Hypochlorite can form chlorate, which may have adverse health impacts

Disinfection Application

Chlorination Terminology

Demand

Chlorine Demand is the amount of chlorine use by iron, hydrogen sulfide and organic materials found in the raw water. It is the difference between the amount of chlorine applied to the water and the amount of free residual chlorine after a given contact time.

Residual

Free Chlorine residual is the amount of uncombined (free) chlorine remaining in the water after reactions with inorganic and organic material. This residual, plus the combined chlorine from other reactions that have slight disinfection capability, is the total residual available for maintaining the sanitary quality of the water.

Chlorine residual is the total of all compounds with disinfecting properties and any remaining free chlorine.

Chlorine Residual (mg/l) = **Combined Chlorine Forms** (mg/l) + **Free Chlorine** (mg/l)

The residual should contain free chlorine since it has the highest disinfecting ability.
The presence of measurable chlorine residual indicates that all chemical reactions have been satisfied and that sufficient chlorine is present to kill microorganisms.

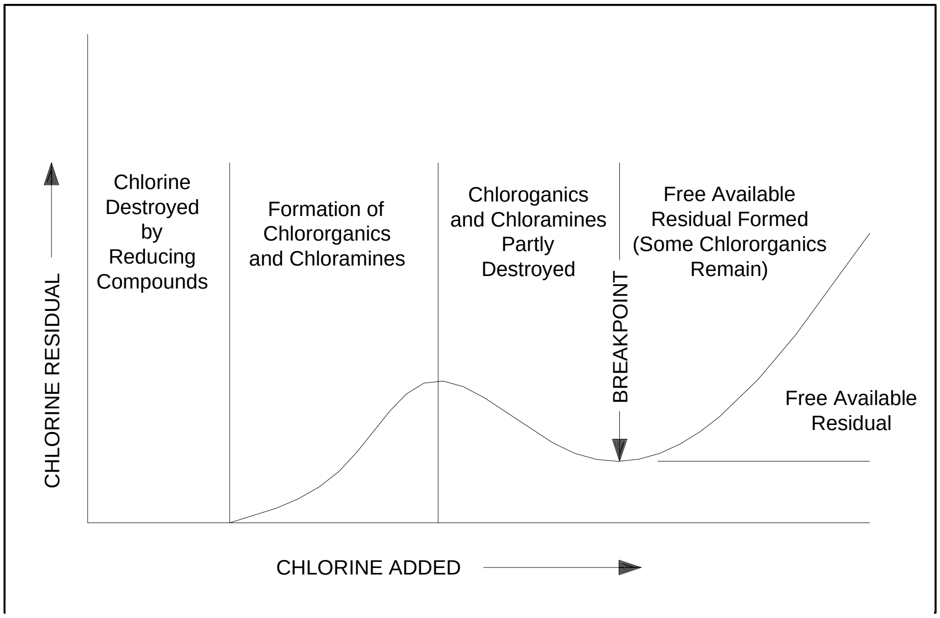
Dosage

Chlorine dose is the amount of chlorine needed to satisfy the chlorine demand plus the amount of chlorine residual needed for disinfection.

Chlorine Dose (mg/l) = **Chlorine Demand** (mg/l) + **Chlorine Residual** (mg/l)

Breakpoint Chlorination

Breakpoint chlorination is the addition of chlorine until all chlorine demand has been satisfied. It is used to determine how much chlorine is required for disinfection.



Breakpoint Chlorination Curve

Breakpoint Chlorination

In determining how much chlorine you will need for disinfection, remember you will be attempting to produce a certain chlorine residual in the form of FREE AVAILABLE RESIDUAL CHLORINE. Chlorine in this form has the highest disinfecting ability. BREAKPONT CHLORINATION is the name of this process of adding chlorine to water until the chlorine demand has been satisfied. Further additions of chlorine will result in a chlorine residual that is directly proportional to the amount of chlorine added beyond the breakpoint. Public water supplies are normally chlorinated PAST THE BREAKPOINT.

Take a moment here to look at the breakpoint chlorination curve in Figure 7.2. Assume the water being chlorinated contains some manganese, iron, nitrate, organic matter and ammonia. Now add a small amount of chlorine. The chlorine reacts with (oxidizes) the manganese, iron and nitrite. That's all that happens – no disinfection and no chlorine residual (Figure 7.2, points 1 to 2). Add a little more chlorine, enough to react with the organics and ammonia; CHLORORGANICS and CHLORAMINES will form. The chloramines produce a combined chlorine residual – a chlorine residual combined with other substances so it has lost some of its disinfecting strength. Combined residuals have rather poor disinfecting power and may cause tastes and odors.

With just a little more chlorine the chloramines and some of the chlororganics are destroyed (p9oints 3 to 4). Adding just one last amount of chlorine we get FREE AVAILABLE RESIDUAL CHLORINE – free in the sense that it has not reacted with anything and available in that it CAN and WILL react if need be. Free available residual chlorine is the best residual for disinfection. It disinfects faster and without the “swimming pool” odor of combined residual chlorine. Free available residual chlorine begins to form at the breakpoint; the process is called BREAKPOINT CHLORINATION. In water treatment plants today it is common practice to go “past the breakpoint”. This means that the treated water will have a low chlorine residual, but the residual will be a very effective disinfectant because it is in the form of FREE AVAILABLE RESIDUAL CHLORINE.

Measurement

The most common method used to measure chlorine residual is the DPD Colorimetric method.

DPD Colorimetric

- This method is a colorimetric used for waters that do not contain iodine-reducing substances. The basic method can be modified to measure monochloramine, dichloramine and free chlorine.

Requirement for a DPD Colorimetric Test Kit

Ohio Administrative Code, Rule 3745-81-27 (C)(1)(a)

“. . . Residual disinfectant concentrations for free chlorine and combined chlorine may also be measured by using DPD colorimetric test kits. A DPD colorimetric test kit acceptable to the director is one that uses electronic measurement of the color development. It shall also have a digital display of the result. DPD colorimetric test kits with an analog display are not acceptable for use. An acceptable DPD colorimetric test kit shall have a method detection limit of 0.1 mg/l.” Effective Date: 6/28/03

Note: The test kit should have an upper range of 4.0 m./l.

Monitoring

Monitoring is required to assure that compliance is met with regulatory agencies for disinfection. The following table shows the microbial standards that must be adhered to by water suppliers.

Points of Application

Ground Water

Well Pump Discharge

- Well pump discharges that are not subject to influence by surface water, and do not require treatment for other constituents, need only be disinfected.

Clearwell Influent

- In many cases, the clearwell influent may be the filter effluent; however, in some water treatment plants, an intermediate process such as Granular Activated Carbon (GAC) absorption takes place to remove taste and odor and organics that still remain in the filtered water. For these plants, disinfection may not take place until the water leaves these process units and enters the clearwell.

Clearwell Effluent

- Clearwell effluent is monitored for chlorine residual.
- To assure that disinfectant residual is maintained in the transmission/ distribution system at satisfactory levels, additional disinfectant, such as chlorine, may be added at this point. For facilities that practice chlorination, the addition of ammonia may also be provided here.

Plant Effluent

- Plant effluent is subsequently monitored to assure that all water leaving the water treatment facility has adequate levels of disinfectant, either in the form of free chlorine residual or monochloramine.

Feed Pumps

- Feed pumps are used to apply various disinfectants to the water. Typical pumps for this type of service include:
    - Diaphragm pumps, which are generally available in several configurations. Each is a positive displacement type pump where the back and forth motion of a diaphragm in a chamber results in fluid, or chemical flow through the pump. In each pump type, the movement of the diaphragm is initiated differently.
    - Hydraulic pumps, which use hydraulic fluid to generate the back and forth motion of the diaphragm.
    - Peristaltic pumps, which uses a roller to squeeze liquid through a section of flexible tubing.
    - Solenoid pumps, which generates the back and forth motion of the diaphragm.

Typical chemicals used in the disinfectant process that are fed with these pumps include hypochlorite, chlorine dioxide and aqua ammonia.

System Operation

Normal Operation

Normal operation of the chlorine feed system requires regular observation of the facilities and equipment and a regular preventative maintenance program. Exact operating procedures will depend on the equipment installed, but the general procedure is as follows.

Container Storage Area

- Daily
  - Visually inspect the storage area.
  - Check for leaks.
- Weekly
  - Clean the building or storage area.
- Monthly
  - Exercise all valves.
  - Inspect flexible connectors and replace as necessary.
  - Perform scheduled preventative maintenance.

Chlorine Residuals

Chlorine Procedure

Chlorine Sample Test Procedure ("Hach" Pocket Colorimeter)

This procedure is written for the "Hach" Pocket colorimeter. Other chlorine testers have different procedures. Please consult the manufacturer's instructions for use.

Instructions marked below with an " * " (asterisk) are universal instructions, however.

Free Chlorine

1. *Run the sample tap for 2-5 minutes or longer, to ascertain that chlorine from the main water supply is flowing from the sample tap.
2. *Reduce the flow from the tap.
3. Fill a clean 10 mL test cell to the line with water from the sample tap.
4. Remove the colorimeter's protective cap.
5. Wipe the sample cell so that it is dry and clean.
6. Place the cell into the well on the colorimeter, making sure that the index mark faces to the front of the colorimeter.
7. Cover the cell with the instruments cap.

8. Press “ZERO”.
9. Wait for the colorimeter to register “0.00’ on the LCD display.
10. Remove the cell from the colorimeter.
11. Fill another sample cell with fresh sample to the 10 mL line.
12. Immediately add one free chlorine DPD powder packet to the sample.
13. Cap the cell and shake it for 10 seconds.
14. Immediately place the cell in the colorimeter’s well.
15. Cover the cell with the instrument’s cap.
16. Press “READ”.
17. Wait for the colorimeter to show the free chlorine results in mg/L.
18. Record the results as Free Chlorine in mg/L.

Total Chlorine

1. *Run the sample tap for 2-5 minutes or longer, to ascertain that chlorine from the main water supply is flowing from the sample tap.
2. *Reduce the flow from the tap.
3. Fill a clean 10 mL test cell to the line with water from the sample tap.
4. Remove the colorimeter’s protective cap.
5. Wipe the sample cell so that it is dry and clean.
6. Place the cell into the well on the colorimeter, making sure that the index mark faces to the front of the colorimeter.
7. Cover the cell with the instrument’s cap.
8. Press “ZERO”.
9. Wait for the colorimeter to register “0.00” on the LCD display.
10. Remove the cell from the colorimeter.
11. Fill another sample cell with fresh sample to the 10 mL line.
12. Immediately add one total chlorine DPD powder packet to the sample.
13. Cap the cell and shake it for 10 seconds.
14. On an accurate timer, time for 3-5 minutes
15. After 3-5 minutes place the cell in the colorimeter’s well.
16. Cover the cell with the instruments cap.
17. Press “READ”.
18. Wait for the colorimeter to show the total chlorine results in mg/L.
19. Record the results as Total Chlorine in mg/L.

20. Calculate the combined chlorine by subtracting the free chlorine from the total chlorine.
21. Record the calculated value as Combined Chlorine mg/L.

High Levels of Chlorine

When chlorine levels are 2.0 mg/L or greater, when using dry DPD reagents, it is necessary to use a double dose of DPD reagent. This applies to both free and total chlorine. Use either two powder packets (meant for a 10 mL sample) or one powder packet (meant for a 25mL sample) or two doses of an automatic dispenser for each 10 mL of sample. For test instruments that use 25mL or larger samples, double the dose of dry reagent when chlorine levels are 2.0 mg/L or greater. It is also necessary to follow manufacturer's recommendations for high levels of chlorine. Most test kits have switchable ranges and use a well insert with smaller tubes for levels above 2.2 mg/L. With some brands of DPD reagent it may be necessary to double the dose for chlorine levels as low as 1.5 mg/L. You can check this in your laboratory by adding one packet of free chlorine reagent to a sample, test it and immediately add an additional packet. If the chlorine reading rises by 0.2 mg/L then you should use two packets.

Composite sample — A sample collected at a specific site, portions of which are collected at varied time intervals

Samples need to be representative of the water system. You should avoid:

- Fire hydrants
- Yard hydrants
- Mop sinks
- Drinking fountains
- Hose bibs

Be sure to remove:

- Strainers
- Aerators
- Hoses

2. Disinfection Safety

Skin Contact

- Immediately shower with large quantities of water.
- Remove protective clothing and equipment while in shower.
- Flush skin with water for at least 5 minutes.
- Call for medical assistance.
- Keep affected area cool.

Eye Contact

- Immediately shower with large quantities of water while holding eyes open.
- Call a physician immediately.
- Transfer promptly to medical facility.

(image courtesy of AWWA)

Hypochlorite Safety

Hypochlorite does not present the hazards that gaseous chlorine does and therefore is easier to handle. When spills occur, wash with large volumes of water. The solution is messy to handle. Hypochlorite causes damage to your eyes. And skin upon contact. Immediately wash affected areas thoroughly with water. Consult a physician if the area appears burned. Hypochlorite solutions are very corrosive. Hypochlorite compounds are nonflammable; however, they can cause fires when they come in contact with organics or other easily oxidizable substances.

[See, Small Water System Operation and Maintenance, Fourth Edition, p. 324, published by California State University, Sacramento, and the USEPA.].

3. Material Safety Data Sheet

Material Safety Data Sheet (MSDS)

- MSDS sheets are available from the chemical manufacturer/supplier for every chemical.
- The Treatment Plant Operator (TPO) should read and understand the MSDS for each chemical used in the plant. Additionally, the TPO should maintain a personal copy for all hazardous chemicals used.
- The MSDS contains a detailed assessment of chemical characteristics, hazards and other information relative to health, safety and the environment.
- Typical information included in an MSDS includes:
    - Product name and synonyms.
    - CAS number.
    - Manufacturer’s address and telephone number.
    - Components and contaminants.
    - Physical data.
    - Fire and Explosion hazard data.
    - Toxicity data.
    - Health hazard data, including exposure limits, effects of exposure and emergency and first aid procedures.
    - Reactivity data, including storage and disposal recommendations and conditions to avoid.
    - Spill or leak procedures.
    - Protective equipment.
    - First aid procedures.

An example of an MSDS is included in the supplemental materials.

4. Aesthetic Contaminants

Iron & Manganese

Common Sources of Iron and Manganese

Yellow springs, near Yellow Springs, Ohio, formed by iron-precipitating microflora (water from limestone)

- Rivers
  - Most iron and manganese is in the particulate form.
  - Levels can vary widely, primarily depending on turbidity levels.
- Reservoirs and Lakes
  - Lower levels of reservoirs and lakes may become anaerobic (depleted of oxygen due to a lack of mixing with the upper layers above the thermocline), which results in solubilization of some of the constituents of the bottom sediments, including iron and manganese.
  - Higher levels of iron and manganese may occur during periods of reservoir/lake turnover (inversion), typically due to the upper portion of the lake/reservoir sinking as the temperature becomes colder, which displaces the lower levels and brings more concentrated levels of iron and manganese closer to the surface.
  - If multiple raw water intake levels are available, it may be valuable to establish a depth water quality sampling program to aid in the decision–making process for what level of withdrawal to use.
- Groundwater
  - Water quality is generally relatively constant in individual wells, but the quality can vary greatly within the same aquifer or well field.
  - Iron and manganese are typically in the soluble state. Deciding which wells to use may depend not only on the quantity that a well can produce, but also on the levels of iron and/or manganese.
- In-plant sources
  - If settled solids in sedimentation basins are not removed frequently, anaerobic conditions may occur, resulting in the release of soluble iron and manganese that downstream filtration may not be able to remove.

Common Treatments

- Compared to the removal of other inorganics, such as calcium and magnesium, iron is not easy to remove from source waters.
- Oxidation and coagulation are effective pretreatment processes for removal of some inorganics prior to filtration.

- Oxidation involves converting soluble iron (Fe II) and soluble manganese (Mn II) to the precipitated (solid) compounds ferric hydroxide ($Fe(OH)_3$) and manganese dioxide (MnO_2), respectively. Depending on the source and turbidity level of the raw water, oxidation may be followed by coagulation, flocculation, sedimentation, and filtration.
- Ion exchange, appropriate for groundwater only, is suitable when iron is less than 10 mg/L, and low production volumes are required.
- Sequestration, which is not so much a removal process as it is a stabilization of iron and manganese using polyphosphates (sometimes silicates) to prevent precipitation, is limited to iron levels of 1.0 mg/L or less, and manganese levels of 2.0 mg/L or less, or both combined of 2.0 mg/L or less.

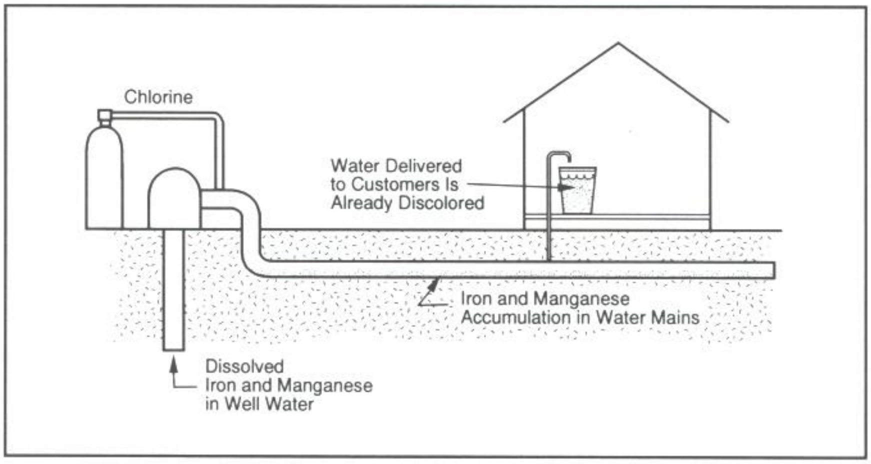
Filtration

Aeration

- Aeration, such as is accomplished with a tray aerator; the process flow is exposed to a very large amount of air. This process is typically used in conjunction with carbon dioxide removal, and is appropriate for groundwater application only. Because oxygen saturated water is corrosive, using aeration in the oxidation process can prove to be a disadvantage.

Chlorine

- Chlorine can be in the form of chlorine gas, sodium hypochlorite, and calcium hypochlorite. It is possible that if chlorine is used as the oxidizer before filtration TTHMs can be formed. Another disadvantage to using chlorine as the oxidant is that ferric chloride is formed during the oxidation process. During the greensand filtration process (discussed later in this module) the ferric chloride reacts with the potassium permanganate thus consuming it.



Iron and manganese oxidized by addition of chlorine

Filtration

- Granular media, primarily for filtration of iron and manganese, can be used in pressure filters (tanks).
- Two types of granular media used for iron and manganese removal are presented below: manganese greensand and anthrasand.

Greensand

- Greensand is typically used for groundwater sources containing levels of iron and/or manganese that require treatment.
- Processed from glauconite greensand by saturating the surface with manganous ions, the media utilizes the natural ion exchange properties of greensand.
    - Following saturation, the media is soaked in a strong oxidizing solution that converts the manganous ions to a hard black manganese dioxide coating.
    - The coating makes up about 4 mg per 1000 mg of greensand.
    - It is easy to detect when the media coating is stripped because the underlying greenish color of the glauconite sand will be uncovered.
    - Stripping can be avoided by using the continuous regeneration process. After the oxidation process, potassium permanganate ($KMnO_4$) is added before it enters the greensand bed. The $KMnO_4$ will oxidize any trace amounts of soluble iron and manganese and should be added so that a slight excess remains. This slight excess is reduced to a manganese oxide by the

  greensand. These oxides will precipitate on the greensand, maintaining a continuous regeneration. Over dosing of $KMnO_4$ will produce pink water while under dosing will produce brownish water.

- Greensand filters typically have an anthracite media cap (12 inch to 24 inch depth) that serves to remove iron, thereby reducing fouling and clogging of the greensand.
  - Anthracite has been found to be more effective than sand for iron removal, even when the same size of media is used; anthracite apparently has an adsorption capacity for iron.
  - The maximum hydraulic loading rate for anthracite media is up to 4 times greater than for sand, 8 gpm/sq ft versus 2 gpm/ sq ft.
  - There is a relationship between the loading rate, area of the filter, and the amount of water to be treated for iron and manganese removal.
- Greensand depth typically ranges between 16 inches and 24 inches.
- Greensand capacity is as follows:
  - Capacity for manganese: 5,000 mg per ft^3 of greensand.
  - Capacity for iron: 10,000 mg per ft^3 of greensand.
- Soluble manganese removal primarily occurs by autocatalytic adsorption on the manganese dioxide (MnO_2)-coated media, followed by oxidation of the adsorbed soluble manganese on the media; this process of manganese removal is suitable when iron and manganese levels in the source water are less than 1.0 mg/L.
- Manganese that was previously removed and oxidized on the greensand has an adsorption capacity for soluble manganese, thereby keeping the greensand continuously regenerated
  - Adsorbed soluble manganese is subsequently oxidized by the continuous feeding of an oxidant (preferably chlorine) to form manganese dioxide (MnO_2).
  - Only chlorine is required for oxidation.
- Filter backwash is required when headloss reaches a predetermined endpoint, or when iron and/or manganese begin to break through the filter.
  - The freeboard, the space above the filter media, allows for the media bed expansion during the backwash process.
  - Air wash is important in conjunction with water wash.
  - Insufficient backwashing causes the thickness of the filter media to increase. This can cause problems such as: decreased flow through the filter media, failure to remove additional insoluble iron and manganese, and loss of media during the backwash process.
  - Excessive backwash flow rate can also cause loss of filter media.
  - Backwash waste water can be collected for reuse and the settled precipitates sent to a sanitary sewer or drying bed.
- Advantages to using manganese greensand are plentiful.
  - It has the optimum grain size and shape to retain oxidation and precipitation products of iron and manganese.

  - No on-site batch chemical preparation is required to form a manganese dioxide media coating.
  - Media reconditioning is generally not required because the coating is firmly attached to the greensand.
  - Manganese dioxide coating is not removed during backwash.
  - No detention time is required for oxidation prior to filtration.
  - Greensand acts as an oxidation-reduction (redox) buffer, adsorbing a slight overdose of potassium permanganate, and continuing (temporarily) to remove iron and manganese if an underdose of oxidant should occur.
  - Greensand is not proprietary.
- Of course, there are some disadvantages to manganese greensand.
  - Minimum pH required is 6.2
  - If prefilter pH adjustment is required, the pH should not be adjusted above 6.8 to 7.0 to prevent the formation of non-filterable iron colloidals.
  - The small effective size (ES) of the media grains results in high cleanbed headloss.
  - The media has limited oxidative capacity.
  - Exhausted media must be regenerated with potassium permanganate.
  - High pressure drops, in excess of 8 psi, should be avoided in order to minimize media fracturing.
  - Raw water silica levels of 10 mg/L or more require feeding of sodium aluminate to prevent stripping of the greensand coating.

Other Treatments

Treatment at the Source

- Groundwater treatment involves air injection into the well for oxidation of soluble iron and manganese.

5. Water Quality Analyses

Monitoring the Effectiveness of Oxidation Processes

Iron and Manganese

- Typical sample sources are from raw water and filtered effluent.
    - The purpose of sampling raw water is to determine the dose of oxidant(s) required, based on iron and manganese analyses.
    - The purpose of sampling filtered water is to determine the effectiveness of the oxidation/filtration process, including oxidant dose and particle capture on the filter media.
- Soluble (grab) samples require that the sample be filtered immediately upon collection (before any soluble portion of the metal has a chance to oxidize from exposure to air) through an extremely small porosity filter medium, preferably a membrane ultrafilter, to assure that the metals in the filtered portion are truly in the soluble state and not just colloidal.
- Only the soluble fraction of the total iron and manganese levels creates an oxidant demand.
    - Identifying the soluble concentrations of these metals helps to determine the oxidant dose.
- Both the soluble and total metals samples should be preserved with nitric acid to pH less than 2.

Free Chlorine Residual

- Typical sample sources are filtered influent (or applied) and filtered water.
- A chlorine residual of 0.5 mg/L to 1.0 mg/L should be maintained in the filter effluent to assure complete oxidation of soluble iron and manganese.
    - DPD or amperometric titration can be used for measuring chlorine residuals.
        - DPD is a commonly used reagent/method for measuring chlorine residuals in the field and at small facilities.
        - Amperometric titration is more accurate for measuring chlorine residuals, and is commonly used at larger facilities.
- The sample must be analyzed immediately, as chlorine can off gas from solution.

Analytical Equipment

- Field test kits that might be used include:
    - Portable colorimeter is used for iron and manganese, color, and free chlorine-DPD.
    - Portable spectrophotometers are used for analyzing iron and manganese, color, free chlorine-DPD, and permanganate residual.

Free Chlorine-DPD

6. Hardness

Secondary Contaminants

- MCL’s for these contaminants are not enforceable; however, most water treatment plant operators still monitor and record these parameters.
- The secondary contaminants most commonly monitored by the water treatment plant operator include color, corrosivity, aluminum, chlorides, iron, manganese, odor, pH, and total dissolved solids.

Hardness

- Excessively hard water produces scale formation inside water conveyance pipes and pumps, resulting in progressively degraded performance.
- Hot water increases the tendency of water to produce scale, which seriously degrades domestic, commercial, and industrial hot water system performance and lifespan.
- Excessive hardness reduces the effectiveness of soaps and detergents.

7. ION EXCHANGE SOFTENING

Definitions

Hardness, Total – the presence of divalent metallic cations (primarily calcium and magnesium) in water due to the dissolution of minerals in geologic formations by natural waters. Although there is no specific hardness level that defines at what point a water is considered hard, there is a general understanding that a water having a total hardness less than 75 mg/L (as $CaCO_3$) is considered soft, and above 150 mg/L (as $CaCO_3$) is considered hard.

Hardness, Calcium – that portion of total hardness due only to calcium.

Hardness, Carbonate – that portion of total hardness which is chemically equivalent to alkalinity; the dissolution by water of calcium and magnesium from minerals containing carbonate and bicarbonate are the predominant source of carbonate hardness.

Hardness, Magnesium – that portion of total hardness due to magnesium ions.

Hardness, Noncarbonate – that portion of total hardness in excess of alkalinity; the dissolution of calcium and magnesium compounds of sulfate and chloride, or silicates in water are the predominant source of noncarbonate hardness. Noncarbonate hardness equals the total hardness minus the carbonate hardness.

Regeneration – chemical process by which a chemically-coated filter media (e.g. ion exchange media) is returned or restored to a productive treatment condition.

Total Dissolved Solids (TDS) – surrogate for ionic strength in water, consisting mainly of dissolved inorganic salts. Since dissolved ions serve as a weak conductor of an electric current, there is a relationship between TDS and conductivity. Although this relationship is site specific, typically it is in the range of 55% to 70% of the conductivity reading.

Common Treatments for Hardness

Ion Exchange Softening

- The Ion exchange process is a common alternative to Lime and Soda Ash for softening water. Water from all natural sources contains dissolved minerals such as calcium and magnesium which cause water hardness.
- The Ion exchange process removes theses minerals which softens the water treated by this process.
- The Ion exchange process uses a resin as the medium by which the ions of calcium and magnesium are exchanged for sodium ions.
- The early types of resins used in the ion exchange process were zeolites, which are silica compounds. In the early days the process was called "Zeolite" softening. It is still sometimes called this today.
- The naturally occurring zeolites have an exchange capacity of around 2,800 grains per cubic foot of media. The synthetic resins manufactured today have as much as 35,000 grains per cubic foot removal capacity.

Advantages, disadvantages, and operating points of the ion exchange process

- The ion exchange process has a much lower initial cost and smaller space requirements than those for the lime and soda ash process.
- Ion exchange units can easily be operated by automatic control, thereby requiring a minimal operating staff.
- The only chemical required in most ion exchange applications is salt. This chemical is safe and easy to handle. There is relatively little danger of serious contamination of the water supply through equipment failure or improper operation if salt is used.
- The problem of disposing of the regeneration waste from the ion exchange process is highly variable. In some instances, disposal is very simple at some locations, whereas at other it may be extremely difficult.
- The ion exchange process is not frequently used to treat surface waters. If it is full conventional treatment must be used first to prevent turbidity and algae from fouling the resin.
- The ion exchange process removes all hardness from the water thereby making the water more corrosive. By blending a portion of completely soft water with hard water, a water having any desired hardness can be produced.

Measurements commonly used to express water hardness in the Ion Exchange Process

- One grain per gallon = 17.12 mg/L
- One grain = 0.142 lb per 1,000 gallons
- 7,000 grains = 1 lb per gallon

Ion Exchange Softening Facilities

The ion exchange process requires the following basic components:

- Ion exchange materials (resin)
- Ion exchange units
- Salt storage tanks
- Brine-feeding equipment
- Device for blending hard and soft water

Ion Exchange Resins

- Natural Greensand composed of sodium aluminum silicate commonly called zeolite was once used.
- Today synthetic zeolites and organic polymers, known as polystyrene resins have now replaced natural zeolites.
- Polystyrene resins are most commonly used today because they have three to six times the exchange capacity of other materials.

Ion Exchange Units

- The tanks holding the resin resemble pressure filters.
- The units are normally of the vertical-downflow design.
- The units are provided with the following components:
  - Hard water inlet
  - Soft water outlet
  - Wash-water inlet and collector
  - Brine inlet and distribution system
  - Brine and rinse water outlet
  - Rate of flow controllers
  - Sample taps
  - Underdrain system, which also serves to distribute backwash water
  - Graded gravel support system (supports the resin).

Salt Storage Tanks

- Sized to hold enough brine for a 24 hour period of operation or three regenerations, whichever is greater.
- Made of salt resistant material, usually fiberglass.
- Rock salt transported in tanker trucks is usually the type of salt stored and used.

Brine Feeding Equipment

- Concentrated brine (about 25 percent) is diluted to approximately 10 per cent in order to be the most effective.
- A metering pump of hydraulic ejector is used to dilute the concentrated brine as it is applied the resin bed.
- The brine is very corrosive and special plastic or other salt resistant materials must be used for the pumps and piping.

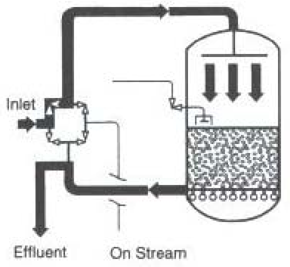
Blending Hard and Soft Water

- The normal range for water softening is 80 to 150 mg/L or 4.6 to 8.7 grains per gallon of hardness.
- Zero –hardness water is very corrosive to piping and plumbing systems.
- A by-pass valve or other device is commonly used to blend the soft and hard water at the discharge of the softener.

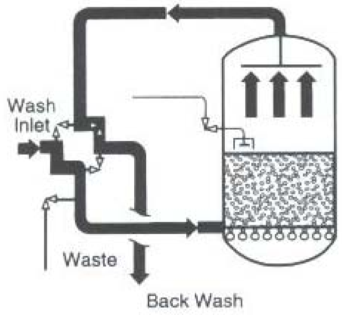
Operation of the Ion Exchange Process

There are four basic cycles used in the ion exchange process.

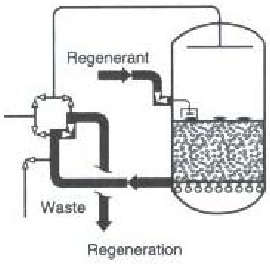
- Softening
- Backwash
- Regeneration
- Slow and fast rinse



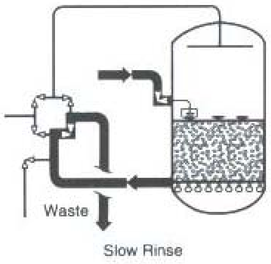
Softening. Influent water passes downward through the bed of ion exchange material to the effluent.



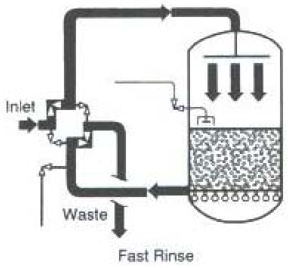
Backwash. Influent water is passed upward through the bed of ion exchange material to loosen the bed and remove suspended solids that may have been deposited in the bed during operation.



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



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



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

Courtesy of Infilco Degremont, Inc., Richmond, Va.

Four cycles in the ion exchange process

8. Disposal of Wastewater

- Discharged wastewater containing spent brine may total from 1.5 to 7 percent of the amount of water softened.
- Discharged wastewater may contain total dissolved solids concentration from 35,000 to 45,000 mg/L.
- Discharge may be sent to an approved wastewater treatment facility or require the issuance of a discharge permit from the governing regulatory authority.

9. Process Control Testing

The ion exchange process is a very simple process and requires a minimal amount of testing.

- Total hardness test
- Sodium test
- pH
- Chloride test (use to periodically check that rinsing after regeneration is adequate).

10. Record Keeping

Tracking of the following information should be performed daily.

- Total hardness and pH
- Daily water treated in gallons per day (gpd) or million gallons per day (mgd).
- Amount of water treated in each softening cycle, in gallons.
- Amount of backwash water, rinse water and brine used each day, in gallons.
- Amount of salt, in pounds or tons, added to the storage tank daily, weekly of monthly whichever applies.