DISINFECTION

California State University: Sacramento

Water Treatment Plant Operation Vol. 1

Fleming Training Center | TN Department of Environment & Conservation

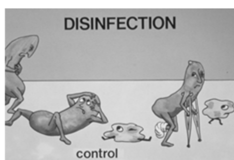
OBJECTIVES

- Safe Drinking Water Laws
- Factors Influencing Disinfection
- Agents of Disinfection
- Chlorine Residuals
- Chlorination Equipment
- Maintenance
- Measurement of Chlorine Residual
- Chlorine Safety Program
- Ultraviolet (UV) Systems
- Ozonation Systems

DISINFECTION VS. STERILIZATION

- Disinfection – the destruction of **pathogenic organisms**
  - To prevent waterborne disease outbreaks
  - Destroys only disease-causing organisms
- Sterilization – the destruction of **all organisms** in the water

Not all microorganisms are bad!



SAFE DRINKING WATER LAWS

- **US Environmental Protection Agency (USEPA)**
  - An agency of the United States federal government whose mission is to protect human and environmental health
- **Safe Drinking Water Act (SDWA)**
  - Established to protect the quality of drinking water in the U.S.
  - Authorizes EPA to establish minimum standards to protect tap water
    - Sets MCLs (maximum contaminant levels)for substances known to be hazardous to human health

SAFE DRINKING WATER LAWS

- **Surface Water Treatment Rule (SWTR)**
  - Purpose is to reduce illnesses caused by pathogens in drinking water including *Legionella*, *Giardia lamblia, and Cryptosporidium*
  - Applies to all public water systems (PWSs) using surface water sources or ground water sources under the direct influence of surface water (GWUDI)
    - Subpart H systems
  - Establishes maximum contaminant level goals (MCLGs) for viruses, bacteria and Giardia lamblia
  - Includes treatment technique (TT) requirements for filtered and unfiltered systems to protect against adverse health effects of exposure to pathogens

SAFE DRINKING WATER LAWS

- **Interim Enhanced Surface Water Treatment Rule (IESWTR)**
  - Applies to all public water systems using surface water, or GWUDI, that serve 10,000 or more persons
  - Sets a (MCLG) of zero for *Cryptosporidium*
  - Sets a 2-log (99%) *Cryptosporidium* removal requirements for systems that provide filtration
  - Requires that watershed protection programs address *Cryptosporidium* for systems that are not required to provide filtration
  - Requires sanitary surveys, conducted by states, for all surface water systems regardless of size
  - Requires systems to calculate levels of microbial inactivation to address risk trade-offs with disinfection byproducts

SAFE DRINKING WATER LAWS

- **Filter Backwash Recycling Rule (FBRR)**
  - Requires recycled filter backwash water to go through all processes of a system's conventional or direct filtration treatment
- **Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR)**
  - Targets additional Cryptosporidium treatment requirements to higher risk systems
  - Provides provisions to ensure that systems maintain microbial protection as they take steps to reduce the formation of disinfection byproducts

SAFE DRINKING WATER LAWS

- **Disinfectants and Disinfection Byproducts Rules (DBPR)**
  - Reduces drinking water exposure to disinfection byproducts
  - Applies to community water systems and non-transient non-community systems that add a disinfectant to the drinking water during any part of the treatment process
  - Stage 2 DBPR strengthens public health protection by tightening compliance monitoring requirements for Trihalomethanes (TTHM) and Haloacetic acids (HAA5).

AGENTS OF DISINFECTION

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PURPOSE OF PROCESS

- To destroy harmful organisms
- Physical disinfection
  - Removes the organisms from the water, or
  - Introduces motion that will disrupt the cells' biological activity and kill or inactivate them
- Chemical disinfection
  - Alter the cell chemistry causing microorganism to die
  - Most widely used is chlorine because it is easily obtained and leaves a measurable residual chlorine

PHYSICAL MEANS OF DISINFECTION

- Ultraviolet Rays (UV)
  - Rays must come in contact with each microorganism
  - Lack of measureable residual
- Heat
  - Rolling boil for 5 minutes
- Ultrasonic Waves
  - Sonic waves destroy microorganisms by vibration

CHEMICAL DISINFECTANTS

- Iodine
  - Limited to emergency use due to high cost and negative health effects
- Bromine
  - Very limited due to handling difficulties
- Bases (sodium hydroxide and lime)
  - High pH leaves a bitter taste in water
- Ozone
  - High costs, lack of chlorine residual, difficult to store, high maintenance requirements

CHEMICAL DISINFECTANTS

- Chlorine gas
  - Cl_2
  - 100% pure
  - gas
  - Liquid chlorine
- Calcium hypochlorite
  - $Ca(OCl)_2$
  - 65% pure
  - solid
  - HTH – high test hypochlorite
- Sodium hypochlorite
  - NaOCl
  - 5-15% pure
  - Liquid
  - Bleach

CHLORINE GAS (Cl_2)

- Properties of Chlorine
  - Greenish-yellow gas
  - 2.5 times heavier than air
  - Volume of gas will increase by almost 90% when temperatures rise
  - Liquid expands to 460 times the volume as a gas
  - Non-flammable but can support combustion

CHLORINE (Cl_2)

- Reaction with Water

$$\underset{}{Cl_2} + H_2O \rightarrow \underset{\text{hypochlorous acid}}{HOCl} + \underset{\text{hydrochloric acid}}{\overset{\text{Lowers pH}}{HCl}}$$

  - Free chlorine combines with water to form hypochlorous acid
    - Most effective disinfectant
    - Dissociates at higher pH (greater than 7)

$$\underset{\text{hypochlorous acid}}{HOCl} \rightarrow H^+ + \underset{\text{hypochlorite ion}}{OCl^-}$$

  - Hypochlorous acid has a much higher disinfection potential than hypochlorite ion
  - At pH = 7.5, of the chlorine present 50% will be HOCl and 50% will be OCl^-
  - At pH > 8.5 all chlorine present will be OCl^-

CHLORINE (Cl_2)

- Hydrogen sulfide and ammonia are inorganic reducing agents
  - Hydrogen sulfide reacts with chlorine to form sulfuric acid and elemental sulfur
    - Causes odor problems (rotten egg)
  - Ammonia reacts with chlorine to form chloramines
    - As ammonia concentration increases, the disinfectant power of chlorine decreases
  - Organics react with chlorine to form trihalomethanes (carcinogens)

HYPOCHLORITE DISINFECTANTS

- Hypochlorite as a disinfectant achieves the same result as chlorine gas
- May be applied in two forms:
  - Sodium hypochlorite (NaOCl)
  - Calcium hypochlorite (CaOCl)
- Only difference between disinfecting with chlorine gas vs hypochlorite is the side reactions of the end products
  - Chlorine gas tends to lower the pH (HCl)
  - Hypochlorite tends to raise the pH (NaOH or $Ca(OH)_2$)

HYPOCHLORITE (OCl^-)

- Reactions with Water
  - May be applied in the form of calcium hypochlorite ($Ca(OCl)_2$) or sodium hypochlorite (NaOCl)

$$Ca(OCl)_2 + H_2O \rightarrow \underset{\text{hypochlorous acid}}{HOCl} + \underset{\text{calcium hydroxide}}{Ca(OH)_2}$$

$$NaOCl + H_2O \rightarrow \underset{\text{hypochlorous acid}}{HOCl} + \underset{\text{sodium hydroxide}}{NaOH}$$

  - Raises pH due to OH^- ion
  - If is $Ca(OCl)_2$ injected at the same point as sodium fluoride, a severe crust can form at injection point

CHLORINE DIOXIDE (ClO_2)

- May be used as a primary disinfectant
  - Not affected by ammonia
  - Very effective disinfectant at higher pH levels
  - Reacts with sulfide compounds to help remove and eliminate their characteristic odors
  - Can control phenolic tastes and odors where chlorine would intensify them
  - Generated on-site by the reaction of chlorine and sodium chlorite

CHLORINE DIOXIDE (ClO_2)

- Reaction in Water

$$\underset{\text{chlorine dioxide}}{2ClO_2} + H_2O \rightarrow \underset{\text{chlorate ion}}{ClO_3^-} + \underset{\text{chlorite ion}}{ClO_2^-} + \underset{\text{hydrogen ion}}{2H^+}$$

- Reactions with Impurities in Water
  - Inorganic compounds
    - Highly effective in oxidizing iron & manganese
  - Organic compounds
    - Does not react with organics in water leaving little danger of THM formation

CHLORINE RESIDUALS

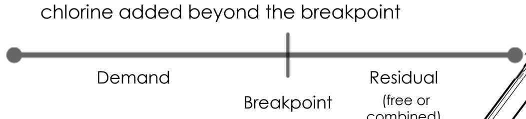
CHLORINATION

- Disinfection Action
  - Chlorine demand - the point where the reaction with organic and inorganic materials (aka reducing agents) stops
  - Chlorine residual – the total of all the compounds with disinfecting properties plus any remaining free chlorine
  - Chlorine dose – the amount of chlorine needed to satisfy the chlorine demand and the amount of chlorine residual needed for disinfection

Dose = Demand + Residual

BREAKPOINT CHLORINATION

- The 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



  - Dose = Residual + Demand

    OR
  - Demand = Dose - Residual

TOTAL RESIDUAL CHLORINE (TRC)

Total Residual Chlorine = Combined Residual + Free Residual

Combined Residual = Total Residual Chlorine – Free Residual

BREAKPOINT CHLORINATION

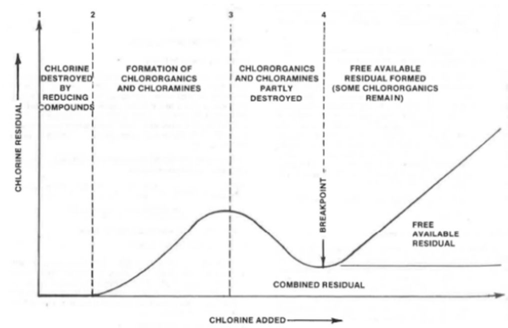


Fig. 7.2 Breakpoint chlorination curve

CHLORAMINATION

- Chloramines have been used as an alternative disinfectant for over 80 years
- An operator's decision to use chloramines depends on several factors
- However, chloramination alone is <u>not an approved method</u> of disinfection in the state of Tennessee
  - TN requires a Free Chlorine Residual
  - Chloramination produces a combined chlorine residual

CHLORINE RESIDUAL

- Chlorine is effective in controlling biological agents and eliminating coliform bacteria
- To ensure adequate control of coliform aftergrowth, a minimum free chlorine residual of 0.2 mg/L in the distribution system is required
  - A lack of this residual could indicate the presence of a heavy contamination

CRITICAL FACTORS AFFECTING CHLORINATION

- Effectiveness of upstream treatment processes
- Injection point and method of mixing
- Temperature
  - The higher temp, the more rapid the disinfection
- Dosage and type of chemical
  - The higher the dose, the faster the disinfection
- pH
  - The lower the pH, the better the disinfection
- Contact time
  - Longer contact time has better disinfection
- Concentration
  - Chlorine residual

MOST IMPORTANT

CT VALUES

"kill" is proportional to C x T

- Destruction of organisms depends on the concentration of chlorine added (C) and the amount of time the chlorine is in contact with the organisms (T)
- Inversely proportional
  - If one is decreased, the other must be increased to ensure that "kill" remains the same

POINTS OF CHLORINE APPLICATION

- Prechlorination
  - Application of chlorine ahead of any other treatment processes
  - Benefits
    - Control of algal and slime growths
    - Control of mudball formation
    - Improved coagulation
    - Reduction of tastes and odors
    - Increased chlorine contact time
    - Increased safety factor in disinfection of heavily contaminated waters
  - Disadvantages
    - High chance of creating disinfection by-products

POINTS OF CHLORINE APPLICATION

- Postchlorination
  - Application of chlorine after the water has been treated but before it enters the distribution system
  - Primary point of disinfection
- Rechlorination (booster chlorination)
  - Practice of adding chlorine in the distribution system
  - Common when distribution system is long or complex
- Wells
  - Good practice whenever wells are used for public water supplies

POINTS OF CHLORINE APPLICATION

- Distribution Mains
  - After initial installation and any repairs
- Tanks and Reservoirs
  - To resolve specific problems
  - After initial installation, repairs, maintenance, repainting, and cleaning
- Water Supply Systems
  - i.e. Small water systems

FACTORS INFLUENCING DISINFECTION

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FACTORS INFLUENCING DISINFECTION

- pH
  - Chlorine disinfects faster at pH of 7 than at pH > 8
  - Hypochlorous acid disassociates at a higher pH
- Temperature
  - Higher temperature means more efficient disinfection
  - Longer contact time required at lower temperatures
  - Chlorine will dissipate faster in warmer waters
- Microorganisms
  - Number and type greatly influence disinfection effectiveness
  - Cysts and viruses can be very resistant to disinfection

FACTORS INFLUENCING DISINFECTION

- Turbidity
  - Excessive turbidity greatly reduces disinfection efficiency
- Reducing Agents
  - Any substance that will readily donate or give up electrons
    - *Reduces the chlorine concentration*
  - 3 primary reducing agents
    - Inorganic Matter
    - Organic Matter
    - Bacteriological

FACTORS INFLUENCING DISINFECTION

- Reducing Agents
  - Inorganic matter
    - Ammonia can combine with disinfectant chemical to form side compounds
  - Inorganic reducing agents
    - Hydrogen sulfide gas (H_2S)
    - Ferrous ion (Fe^{2+})
    - Manganous ion (Mn^{2+})
    - Ammonia (NH_3)
    - Nitrite ion (NO_2^-)

FACTORS INFLUENCING DISINFECTION

- Reducing Agents
  - Organic Matter
    - Organics can consume great amounts of disinfectants while forming unwanted compounds such as disinfection by-products
    - Reactions with organics and other reducing agents will significantly reduce the amount chemical available for disinfection

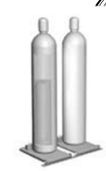
CHLORINATION EQUIPMENT

CHLORINE GAS STEEL (150 LB) CYLINDER

- Move cylinders with a properly balanced hand truck
- Can be rolled in a vertical position
- Always replace the protective cap when moving a cylinder
- Keep cylinders away from direct heat and direct sun
- Transport and store cylinders in an upright position
- Store empty cylinders separate from full cylinders
  - Never store near turpentine, ether, anhydrous ammonia, finely divided metals, hydrocarbons, or other materials that are flammable
- Remove outlet cap from cylinder and inspect outlet threads
- Test chlorine cylinders at 800 psi every 5 years

CHLORINE GAS STEEL (150 LB) CYLINDER

- Contains 100 to 150 pounds
- Fusible plug is placed in the valve below the valve seat
  - Safety device to prevent buildup of excessive pressures
  - Melts at 158°-165°F (70°-74°C)



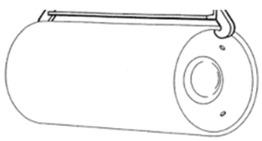
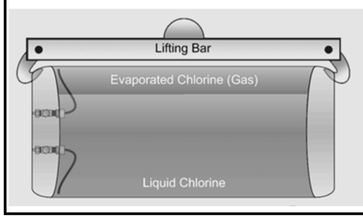
CHLORINE GAS TON TANKS

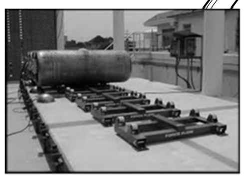
- Loaded weight of about 3,700 pounds
- Openings for fusible plugs and valves
  - 2 operating valves
  - 6 fusible plugs (3 on each end)

CHLORINE GAS TON TANKS

- Ship ton tanks by rail in multiunit cars, truck or semitrailer
- Handle ton tanks with a suitable lift clamp or in conjunction with a hoist or crane
- Lay ton tanks on their sides
- Do not stack
- Separate tanks by 30 inches for access in case of leaks
- Place ton tanks on trunnions that are equipped with rollers
  - In case of a leak, tank can be rolled so that the leaking chlorine escapes as a gas not a liquid
- Use locking devices to prevent ton tanks from rolling while connected

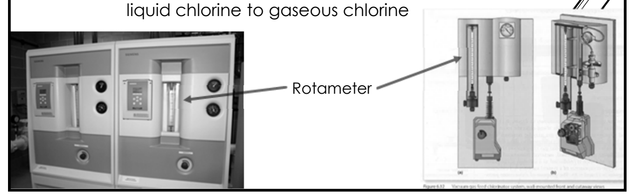
CHLORINE GAS TON TANKS

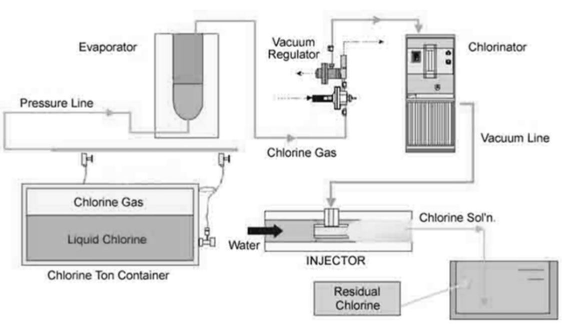


REMOVING CHLORINE FROM TON TANKS

- Must be placed on their sides with valves in vertical positions to allow either chlorine gas or liquid to be removed
  - Top valve to remove chlorine gas
  - Bottom valve to remove liquid chlorine
    - Must use an evaporator – water bath that converts liquid chlorine to gaseous chlorine



REMOVING CHLORINE FROM TON TANKS



CHLORINE GAS RAILROAD CAR

CHLORINATORS (CHLORINE GAS)

- Chlorine gas may be removed from chlorine containers by a valve and piping arrangement
- Chlorine gas is controlled, metered, and introduced into a stream of injector water, and then is conducted as a solution to the point of application
- Safety
  - Protective clothing: gloves and rubber suit
  - Self-contained pressure-demand air supply system (SCBA)
  - Chlorine leak detector and exhaust fan set at floor level
    - Warning device located outside chlorine room

CHLORINATOR FLOW PATH

- Within the chlorinator, gas passes through spring a loaded regulator valve that maintains the operating pressure
- Rotameter indicates the rate of gas flow
  - Rate controlled by orifice
- Gas then moves to the injector where it is dissolved in water
- Mixture leaves the chlorinator as a chlorine solution (HOCl) ready for application

CHLORINATOR FLOW PATH

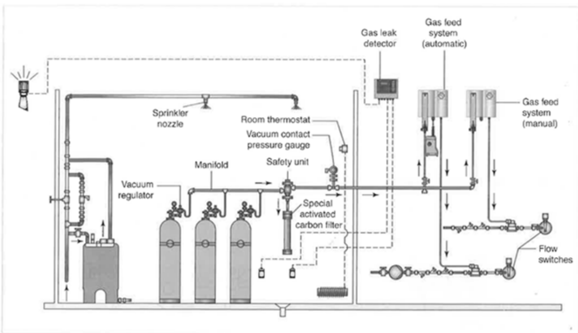
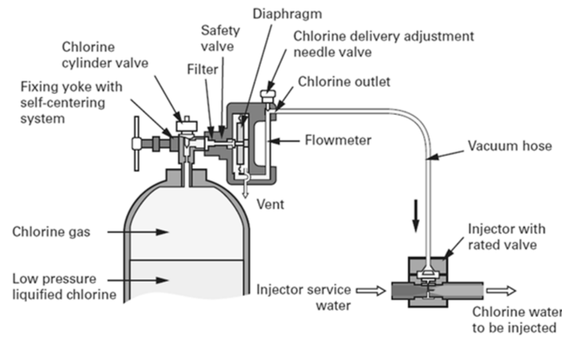


Figure 6.11 Typical vaccum-fed gas chlorinator installation.

CHLORINATORS PARTS



CHLORINATORS PARTS

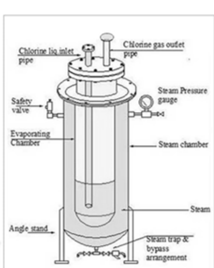
- Injector – portion of chlorination system that feeds chlorine solution into pipe under pressure
  - Creates vacuum to operate chlorinator
- Check valve assembly – prevents water from back-feeding as the water moves through ejector
- Rate valve – controls the flow rate at which chlorine gas enters the chlorinator
- Diaphragm assembly – regulates chlorinator vacuum which can be used to adjust feed rate

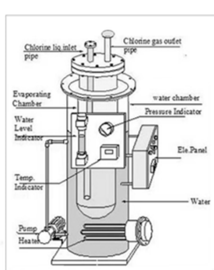
CHLORINATOR PARTS

- Rotameter – device used to measure the flow rate of gases and liquids
  - Gas or liquid flows up a tapered, calibrated tube with a ball/float that rises or falls with the flow rate

CHLORINATOR PARTS

- Evaporator – converts liquid chlorine to gaseous chlorine for use by chlorinators





REMOVING CHLORINE FROM CYLINDERS

- Whenever performing any work or maintenance on chlorine cylinders, a self-contained breathing apparatus (SCBA) should be worn or at least readily available
- Greater than maximum feed rate will result in freezing and a decreased rate of delivery
  - 50 lb cylinder = 40 lb/day
  - Ton cylinder = 400 lb/day
    - With evaporator = 9,600 lb/day
- Frosting may cause gas to condense to liquid which could plug the chlorine supply lines

HYPOCHLORITE CONTAINERS

- Plastic containers commonly used for storage of bleach or HTH solution
- Should be large enough to hold 2-3 days' supply
  - Fresh solution should be prepared every 2-4 days
  - Sodium hypochlorite will lose 2-4% concentration per month at room temperature
  - Recommended shelf life of 60-90 days

HYPOCHLORINATORS

- A piece of equipment used to feed chlorine solutions (bleach)
- Consists of chemical solution tank, diaphragm-type pump, power supply, water pump, pressure switch, water storage tank

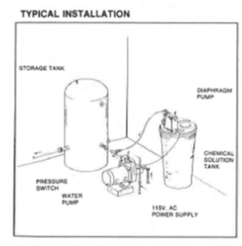


Fig. 7.7 Typical hypochlorinator installation

HYPOCHLORINATORS

- 2 methods of feeding
  - Directly pumped into water
  - Pump through an ejector (injector)
    - Draws in additional water for dilution of solution

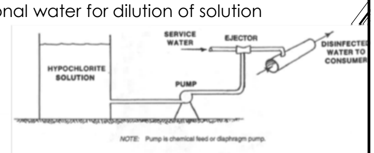


Fig. 7.11 Hypochlorinator injector feed system

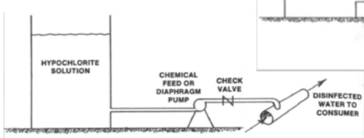
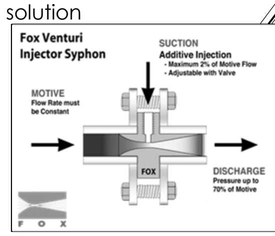


Fig. 7.10 Hypochlorinator direct pumping system

HYPOCHLORINATOR PARTS

- Mix tank – to mix water and bleach into solution
- Day tank – tank designed to hold enough chemical solution for one day or one shift
- Eductor – device that draws in additional water for dilution of the hypochlorite solution
  - aka ejector or injector



HYPOCHLORINATOR SYSTEM

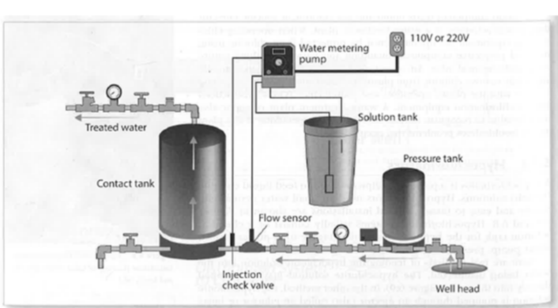


Figure 6.8 Proportional-feed flow meter hypochlorinator system (Adapted from Clean Water Systems and Stores, Inc.)

MEASUREMENT OF CHLORINE RESIDUAL

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METHODS OF MEASURING CHLORINE RESIDUAL

- Amperometric titration
- Colorimetric tests (DPD)

- All subpart H systems (surface water systems and groundwater systems under the influence of surface water) must provide disinfection
- All subpart H systems must collect residual chlorine sample at the same frequency and location as total coliform samples

AMPEROMETRIC TITRATION

- A means of measuring concentrations of certain substances in water based on the electric current that flows during a chemical reaction

AMPEROMETRIC TITRATION

1. Place a 200 mL sample of water in titrator
2. Start the agitator
3. Add 1 mL of pH 7 buffer
4. Titrate with phenylarsene oxide solution (PAO)
5. End point is reached when one drop will cause a deflection on the microammeter and the deflection will remain
6. # mL of PAO used in titration is equal to mg/L of free chlorine residual

COLORIMETRIC TEST (DPD)

- A method of measuring the chlorine residual in water
- N,N-diethyl-p-phenylene-diamine
- "False positive" can occur when sample contains a combined chlorine residual

COLORIMETRIC TEST (DPD)

- The residual may be determined by either titrating
  or comparing a developed color with color standards

1. Collect a sample
   - Typically 10 mL or 25 mL
2. Zero instrument with sample blank
3. Add color reagent
4. Read colored sample in spectrophotomer or colorimeter

MAINTENANCE

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CHLORINE LEAKS

- Chlorine leak can be smelled at concentrations as low as 0.3 ppm
  - Detectors can detect 1ppm or less
- Always work in pairs when looking for and repairing leaks
- If leak is large, all persons in adjacent areas should be warned and evacuated

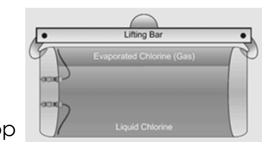
CHLORINE LEAKS

- Any new or repaired system should be cleaned, dried, and tested for leaks
- Ammonia solution on a piece of cloth held near a chlorine leak will produce a white vapor
  - Use concentrated ammonia solution of 28-30% ammonia
  - A squeeze bottle filled with ammonia water to dispense vapor may also be used
- If leak is in the equipment, close the valves at once

CHLORINE LEAKS

- If leak is in cylinder, use emergency repair kit
  - For 150 lb cylinder, Emergency Repair kit A
  - For ton cylinder, Emergency Repair kit B
  - For railroad car, Emergency Repair kit C

CHLORINE LEAKS



- If chlorine leaking as a liquid, rotate cylinder so leak is on top
  - Chlorine is escaping only as a gas
- If prolonged or unstoppable leak, emergency disposal should be provided
  - Chlorine may be absorbed into solutions of caustic soda, soda ash, or agitated hydrated lime
- Never put water on a chlorine leak
  - By-product (hydrochloric acid) will make the leak larger
- Leak around valve stem can be stopped by closing the valve or tightening the packing gland nut

CHLORINE LEAKS

- Leaks at valve discharge outlet can often be stopped by replacing the gasket or adapter connection
- Leaks at fusible plugs and cylinder valves usually require special handling and emergency equipment
- Pinhole leaks in the walls of cylinders can be stopped by using a clamping pressure saddle with a turnbuckle available in repair kits
  - Temporary fix
- A leaking container must not be shipped
- Do not accept delivery of containers showing evidence of leaking, stripped threads, etc.

CHLORINE SAFETY PROGRAM

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CHLORINE HAZARDS

- Chlorine gas is 2.5 times heavier than air
  - Extremely toxic
  - Corrosive in moist atmospheres
  - Very irritating to mucous membranes of the nose, throat, and lungs

Effect	Cl_2 concentration (ppm)
Slight symptoms after several hours' exposure	1
Detectable odor	0.3-3.5
Noxiousness (harmful)	5
Throat irritation	15
Coughing	30
Dangerous from ½ to 1 hour	40
Death after a few deep breaths	1,000

CHLORINE PPE

- Every person should be trained in the use of self-containing breathing apparatus (SCBA), methods of detecting hazards, and should know what to do in case of emergencies
- Clothing exposed to chlorine can be saturated with chlorine, which will irritate the skin if exposed to moisture or sweat
- Self-contained air supply and positive pressure breathing equipment must fit and be used properly
- Wear protective clothing to enter an area containing a chlorine leak
  - Chemical suit will prevent chlorine from contacting the sweat on the body and forming hydrochloric acid

MILD CHLORINE EXPOSURE

- Leave contaminated area
- Move slowly, breathe lightly without exertion, remain calm, keep warm, and resist coughing
- If clothing has been contaminated, remove as soon as possible
- If slight irritation, immediate relief can come from drinking milk

EXTREME CHLORINE EXPOSURE

- Follow established emergency procedures
- Always use proper safety equipment; do not enter area without self-contained breathing apparatus
- Remove patient from affected area immediately
- First-aid
  - Remove contaminated clothes
  - Keep patient warm and cover with blankets
  - Place patient in comfortable position on back
  - Administer oxygen if breathing is difficult
  - Perform mouth-to-mouth resuscitation if breathing seems to have stopped
  - If chlorine has got in eyes, flush with large amounts of water immediately (at least 15 minutes)

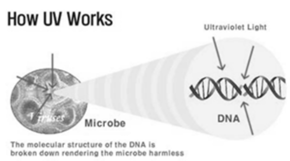
HYPOCHLORITE SAFETY

- Wash spills with large volumes of water
- Hypochlorite can damage eyes and skin upon contact
  - Immediately wash affected are thoroughly with water
- Nonflammable, however can cause a fire when comes in contact with organics

ULTRAVIOLET (UV) SYSTEMS

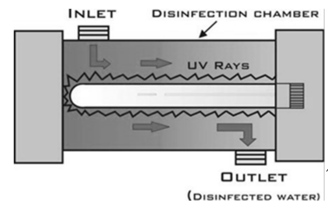
USES OF UV SYSTEMS

- Ultraviolet light – band of electromagnetic radiation just beyond the visible light spectrum
  - UV light absorbed by cells of microorganisms damages the genetic material to cease growth or reproduction



TYPES OF UV LAMPS

- Based on internal operating design
  - Low-pressure, low-intensity
  - Low-pressure, high-intensity
  - Medium-pressure, high-intensity



LOW PRESSURE UV LAMPS

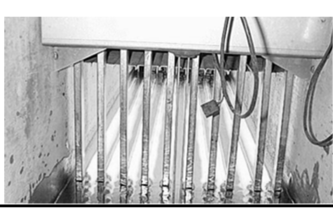
- Source of UV energy in majority of systems
- Last between 8,000 and 10,000 hours
- Operate between 40° and 60°F
- Generate light by transforming electrical energy into UV radiations
- Emits light at wavelength 253.7 nm
- Each lamp protected by quartz sleeve with watertight electrical connections

LOW PRESSURE UV LAMPS

- Lamp assemblies mounted in a rack(s) that are immersed in flowing water
- Can be enclosed in a vessel or in an open channel
  - Enclosed in vessels in pressure systems
- Placed either horizontal and parallel to flow or vertical and perpendicular to flow
- Number of lamps determines water depth in channel

SAFETY

- UV lamp can burn eyes
- Never look into uncovered parts of the UV chamber without protective glasses
- Lamps contain mercury vapor that will be released of lamp breaks



OPERATION

- Water level over lamps must be maintained to ensure all microorganisms are exposed and to prevent short circuiting
- Water level control device must be regulated by the operator to:
  - Minimize variation of the channel's water level
  - Maintain the channel's water level at a defined level
  - Keep the UV lamps submerged at all times
  - Prevent excessive water layer thickness above the top lamp row

OPERATION

- Light must be intense enough to penetrate pathogens' cell walls
  - Intensity affected by the condition of the UV lamps and the quality of the water
  - An old or dirty lamp has a reduced UV light intensity
  - High turbidity inhibits light transmission, reducing the disinfecting power in proportion to its distance from the light source
  - High TSS inhibits light transmission and shields bacteria protecting them from disinfection
- Low UV light intensity will produce a low level of disinfection

OPERATION

- UV Dose Calculation
  - Intensity of UV radiation and contact time determine the UV dose and, therefore, the effectiveness
  - Expressed as mJ/sq cm (milli-joules per square centimeter)
  - Use worse case intensity for calculation (farthest point from UV)
- Channel Volume Calculation
  - Refers to the irradiated volume of the UV reactor
    - Volume of bacteria exposed to UV radiation
  - Fixed calculation

OPERATION

- Routine Operations Tasks
  - Check UV monitors for UV transmission
  - Routinely clean the UV lamps
- Wiping Systems
  - Should be observed to ensure proper operation of the wiping action of a bank and the proper wiping cycle
- Monitoring Lamp Output Intensity
  - Lamp output declines with use
  - Lamps should be replaced with output no longer meets standards or burn out

OPERATION

- Monitoring Influent and Effluent Characteristics
  - Must maintain velocities and low turbidity levels
    - Suspended particles shield microorganisms from UV light
    - Flows should be somewhat turbulent to ensure exposure to all microorganisms, but controlled so that water is exposed for long enough for disinfection to occur
  - Bacteriological tests must be performed frequently since there is no residual left by UV
- Emergency Alarms
  - UV systems require extensive alarm systems to ensure complete disinfection

MAINTENANCE

- Routine Maintenance
  - Check UV monitor for reduction in lamp output
  - Monitor process for major changes
  - Check for fouling of the quartz sleeves
  - Check that all UV lamps are energized
  - Monitor reports to determine UV lamp replacement interval
  - Check quartz sleeves for discoloration
  - Dewater and hose down UV channel if algae and other attached biological growths form on walls and floor

MAINTENANCE

- Quartz Sleeve Fouling
  - Occurs when cations attach to protein and colloidal matter that crystallizes on the quartz sleeves
  - This will decrease the intensity of the UV light
- Sleeve Cleaning
  - Frequency depends on the quality of water being treated and treatment chemicals used
  - Best done by dipping bulbs an inorganic acid solution for 5 minutes
    - i.e. Nitric acid (50%) or phosphoric acid (5-10%)

MAINTENANCE

- UV lamps
  - Service life ranges from 7,500 – 20,000 hours
  - Depends on
    - Level of suspended solids
    - Frequency of on/off cycles
    - Operating temperature of lamp electrodes
  - Lamp output drops 30-40% in first 7,500 hours
  - Lamp electrode failure is most common cause of lamp failure
  - Do not throw used lamps in garbage can
    - Must be disposed properly due to mercury content

OZONATION SYSTEMS

Introduction to Water Treatment

Fleming Training Center
TN Department of Environment & Conservation

OZONE (O_3)

- Bluish toxic gas with pungent odor
- Alternative disinfectant
- Very strong oxidant and virucide (kills viruses)
- Must be generated on site
- Generated by passing an electrical current through pure oxygen

$$O_2 + \text{Energy} \rightarrow O + O$$

$$O + O_2 \rightarrow O_3$$

OZONE (O_3)

- Effectiveness of disinfection depends on
  - Susceptibility of the target organisms
  - Contact time
  - Concentration of the ozone
- Because ozone is consumed quickly, it must be exposed to the water uniformly
- Residual ozone measured by the iodometric method
- Dissolved ozone measured by Indigo test

EQUIPMENT

- Consists of 4 major parts
  - Air preparation unit
  - Electrical power unit
  - Ozone generator
  - Contactor

EQUIPMENT

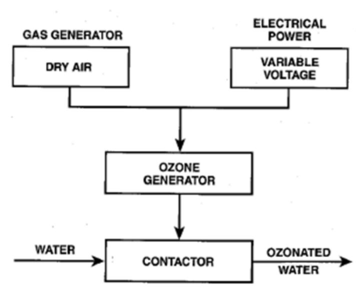


Fig. 7.47 Ozonation equipment

EQUIPMENT

Air preparation

- When air is used as the feed gas for an ozone generator, it must be extremely dry
- The preparation unit usually consists of a commercial air dryer with a dew point monitoring system
  - This is the most critical part of the system
- Air should be clean and dry with a dew point below -51°C (-60°F)

EQUIPMENT

Electrical Power Units

- Usually a very special electrical control system
- Most common unit provides low frequency, variable voltage
- For large installations, medium frequency, variable voltage is used
  - Reduces power costs
  - Allows for higher ozone output

EQUIPMENT

Ozone Generator

- Consists of a pair of electrodes separated by a gas space and a layer of glass insulation
- Air passes through the empty space
- Electrical discharge occurs across the gas space and ozone is formed

Oxygen from air + Electrical voltage → Ionized oxygen + Heat

O_2 + electricity → 2(O)

Ionized oxygen + Non-ionized oxygen → Ozone

$2(O) + 2(O_2) \rightarrow 2\ (O_3)$

EQUIPMENT

Ozone Contactor

- Mixing chamber for the ozone rich material and the water
- Ozone has a very short life
- Must be evenly and efficiently introduced to the water to be treated
  - Critical to the success of the system

EQUIPMENT

Types of Ozone Contactors

- Turbine mixers
- Injectors
- Packed columns
- Spray chambers
- Fine-bubble diffusion
  - Most common
  - Small bubbles rise through the tank transferring the ozone to the water

OZONE ADVANTAGES

- More effective than chlorine in destroying viruses
- No harmful residuals after ozonation
- No regrowth of microorganisms
- Removes color, tastes, and odors
- Oxidizes iron, manganese, sulfides and organics

OZONE LIMITATIONS

- Low dosage may not effectively inactivate some viruses, spores, and cysts
- Complex technology requiring complicated equipment
- Ozone if very reactive and corrosive require corrosion resistant materials
- Ozone is very irritating and possibly toxic
- The cost of treatment can be relatively high in capital and power costs
- Cannot be used as sole means of disinfectant in Tennessee due to Cl_2 residual requirements
- Can combine with bromide to form bromate
  - A carcinogen

APPLICATIONS OF OZONE

- Ozone may be used for more than just disinfection or viral inactivation
  - When used prior to coagulation
    - Treats Fe and Mn, helps flocculation, and removes algae
  - If applied before filtration
    - Oxidizes organics, removes color, and treats tastes and odors

MAINTENANCE

- Inspect electrical equipment and pressure vessels monthly
- Conduct a yearly preventive maintenance program
  - Should be done by a factory representative or an operator trained by the manufacturer
- Lubricate moving parts according to manufacturer's recommendations

SAFETY

- Ozone is a toxic gas and is a hazard to plants and animals
- When ozone breaks down in the atmosphere, the resulting pollutants can be very harmful
- Ozone contactors must have a system to collect ozone off-gas.
  - Ozone generating installations must include a thermal or catalytic ozone destroyer

Common Waterborne Diseases

Waterborne Disease	Causative Organism	Source of Organism in Water	Symptom
Gastroenteritis	*Salmonella* (bacteria)	Animal of human feces	Acute diarrhea and vomitting
Typhoid	*Salmonella typhosa* (bacteria)	Human feces	Inflamed intestine, enlarged spleen, high temperature - **FATAL**
Dysentary	*Shigella* (bacteria)	Human feces	Diarrhea - rarely fatal
Cholera	*Vibrio comma* (bacteria)	Human feces	Vomitting, severe diarrhea, rapid dehydration, mineral loss – high mortality
Infectious Hepatitis	Virus	Human feces, shellfish grown in polluted waters	Yellow skin, enlarged liver, abdominal pain – low mortality, lasts up to 4 months
Amoebic Dysentery	*Entamoeba* histolytica (protozoan)	Human feces	Mild diarrhea, chronic dysentery
Giardiasis	*Giardia lamblia* (protozoan)	Animal or human feces	Diarrhea, cramps, nausea and general weakness – not fatal, lasts 1-30 weeks
Crytosporidiosis	*Cryptosporidium* (protozoan)	Human and animal feces	Acute diarrhea, abdominal pain, vomiting and low-grade fever
Legionellosis	*Legionella pneomophila* and related bacteria		Acute respiratory illness

Fleming Training Center

Pipe Disinfection Formulas for 50 mg/L of HTH

If a pipe is of size not listed below, the following formula will give the calculations needed to find the amount of HTH needed, if the length of line is given:

Calculation Formula = $0.000026007(X)^2(L)$

L= the length of the line in feet,
X = the diameter in inches

Or, Use the following Chart, if Pipe Diameter is listed

DIAMETER (INCHES)	LBS OF HTH
6	0.000935(L)
8	0.00166(L)
10	0.0026(L)
12	0.00374(L)
14	0.00509(L)
16	0.00665(L)
20	0.01038(L)
C24	0.01495(L)

Contact Amanda Carter At Fleming Training Center

(615) 898-6507

Disinfection Vocabulary

A. Amperometric Titration
B. Bacteria
C. Breakpoint Chlorination
D. Carcinogen
E. Chlorination
F. Chlorine Demand
G. Chlorine Requirement
H. Chlorine Residual
I. Chlororganic
J. Colorimetric Measurement
K. Combined Available Chlorine
L. Combined Available Chlorine Residual
M. Combined Chlorine
N. Combined Residual Chlorination
O. DPD
P. Dew Point
Q. Disinfection
R. Eductor
S. Enteric
T. Free Available Residual Chlorine
U. HTH
V. Hydrolysis
W. Hypochlorination
X. Hypochlorite
Y. IDLH
Z. MPN
AA. Oxidation
BB. Oxidizing Agent
CC. Pathogenic Organisms
DD. Postchlorination
EE. Potable Water
FF. Prechlorination
GG. Precursor, THM
HH. Reagent
II. Reducing Agent
JJ. Reliquefaction
KK. Sterilization
LL. Titrate
MM. Total Chlorine
NN. Total Chlorine Residual
OO. Trihalomethanes
PP. Turbidity
QQ. Ultraviolet

_____ 1. The Most Probable Number of coliform group organisms per unit volume of sample water

_____ 2. Any substance which tends to produce cancer in an organism

_____ 3. A chemical reaction in which a compound is converted into another compound by taking up water.

_____ 4. Any substance that will readily donate electrons

_____ 5. The application of chlorine to water to produce combined available chlorine residual

_____ 6. A hydraulic devise used to create a negative pressure by forcing a liquid through a restriction, such as a Venturi.

_____ 7. Organic compounds combined with chlorine

_____ 8. Organisms capable of causing diseases in a host

_____ 9. The total concentration of chlorine in water, including the combined chlorine and the free available chlorine

_____ 10. Pertaining to a band of electromagnetic radiation just beyond the visible light spectrum; used to disinfect water

_____ 11. Addition of chlorine to water until the chlorine demand has been satisfied; additional chlorine beyond this point will result in a free chlorine residual

_____ 12. Immediately Dangerous to Life or Health; the atmospheric concentration of any toxic, corrosive or asphyxiant substance that poses and immediate threat to life or would cause irreversible or delayed adverse health effects

_____ 13. The amount of chlorine that is needed for a particular purpose

_____ 14. The addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound

_____ 15. The removal or destruction of all microorganisms

_____ 16. The cloudy appearance of water caused by the presence of suspended and colloidal matter

_____ 17. A pure chemical substance that is used to make new products or is used in chemical tests to measure, detect, or examine other substances

_____ 18. The application of hypochlorite compounds to water for the purpose of disinfection.

_____ 19. The sum of the chlorine species composed of free chlorine and ammonia

_____ 20. The total chlorine, present as chloramine or other derivatives, that is present in a water and is still available for disinfection and for oxidation of organic matter

_____ 21. The application of chlorine to water generally for the purpose of disinfection

_____ 22. The addition of chlorine at the headworks of the plant prior to other treatment processes mainly for disinfection and control of tastes, odors, and aquatic growths

_____ 23. That portion of the total available residual chlorine composed of dissolved chlorine gas, hypochlorous acid, and or hypochlorite ion remaining in water after chlorination.

_____ 24. A method of measuring the chlorine residual in water

_____ 25. An substance, such as oxygen or chlorine, that will readily add electrons

_____ 26. The return of a gas to the liquid state e.g. a condensation of chlorine gas to return it to its liquid form by cooling

_____ 27. The concentration of residual chlorine that is combined with ammonia, organic nitrogen, or both in water as a chloramine and is still available to oxidize organic matter and kill bacteria

_____ 28. The difference between the amount of chlorine added to water and the amount of residual chlorine remaining after a given contact time

_____ 29. Living organisms, microscopic in size, which usually consist of a single cell

_____ 30. The addition of chlorine to the plant effluent, following plant treatment, for disinfection purposes

_____ 31. The total amount of chlorine residual present in a water sample after a given contact time

_____ 32. Of intestinal origin, especially applied to wastes or bacterias

_____ 33. Water that does not contain objectionable pollution, contamination, minerals, or infective agents and is considered satisfactory for drinking

_____ 34. The temperature to which air with a given quantity of water vapor must be cooled to cause condensation of the vapor in the air

_____ 35. A means of measuring unknown chemical concentrations in water by measuring a sample's color intensity

_____ 36. A means of measuring concentrations of certain substances in water based on the electric current that flows during a chemical reaction

_____ 37. 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)

_____ 38. Natural organic compounds found in all surface and groundwaters that may react with halogens such as chlorine

_____ 39. Calcium hypochlorite. $Ca(OCl)_2$

_____ 40. The process designed to kill or inactivate most microorganisms in water, including essentially all pathogenic bacteria

_____ 41. The concentration of chlorine present in water after chlorine demand has been satisfied

_____ 42. Derivatives of methane in which three halogen atoms are substituted for three of the hydrogen atoms

_____ 43. Chemical compounds containing available chlorine

Answers

1. Z	12. Y	23. T	34. P
2. D	13. G	24. O	35. J
3. V	14. AA	25. BB	36. A
4. II	15. KK	26. JJ	37. LL
5. N	16. PP	27. L	38. GG
6. R	17. HH	28. F	39. U
7. I	18. W	29. B	40. Q
8. CC	19. M	30. DD	41. H
9. MM	20. K	31. NN	42. OO
10. QQ	21. E	32. S	43. X
11. C	22. FF	33. EE	

Disinfection
Review Questions

1. What are pathogenic organisms?

2. What is disinfection?

3. Drinking water standards are established by what agency of the United States government?

4. MCL stands for what words?

5. How does pH influence the effectiveness of disinfection?

6. How does the temperature of the water influence disinfection?

7. What two factors influence the effectiveness of disinfection on microorganisms?

8. List the physical agents that have been used for disinfection (chlorine is not a physical agent).

9. List the chemical agents other than chlorine that have been used for disinfection.

10. What is a major limitation to the use of ozone?

11. How is the chlorine dosage determined?

12. List two organic reducing chemicals with which chlorine reacts rapidly.

13. What does chlorine produce when it reacts with organic matter?

14. How do chlorine gas and hypochlorite influence pH?

15. How does pH influence the relationship between HOCl and OCl^-?

16. What is breakpoint chlorination?

17. List the two most common points of chlorination in a water treatment plant.

18. Under what conditions should waters not be prechlorinated?

19. What are the benefits of prechlorination?

20. List the major parts of a typical hypochlorinator system.

21. What are the two common methods of feeding hypochlorite to the water being disinfected?

22. What type of container is commonly used to store hypochlorite?

23. How large a supply of hypochlorite should be available?

24. What is the purpose of the fusible plug?

25. What is removed by the upper and lower valves of ton chlorine tanks?

26. Why are one-ton tanks placed on their sides with the valves in a vertical position?

27. If chlorine is escaping from a cylinder, what would you do?

28. How can chlorine leaks around valve stems be stopped?

29. How can chlorine leaks at the valve discharge outlet be stopped?

30. What properties make chlorine gas so hazardous?

31. What type of breathing apparatus is recommended when repairing chlorine leaks?

32. What first-aid measures should be taken if a person comes in contact with chlorine gas?

33. The UV light intensity that reaches the pathogens in the water is affected by what factors?

34. Routine maintenance of UV disinfection systems includes which tasks?

35. How often should quartz sleeves be cleaned?

36. The service life of UV lamps depends on which factors?

37. How can operators determine the proper way to dispose of used UV lamps?

38. Why is ozone generated on site?

39. The effectiveness of ozone disinfection depends on which factors?

Disinfection
Review Questions

1. Pathogenic organisms are disease-producing organisms
2. Disinfection is the selective destruction or inactivation of pathogenic organisms.
3. The US Environmental Protection Agency establishes drinking water standards.
4. MCL stands for Maximum Contaminant Level.
5. Most disinfectants are more effective in water with a pH around 7.0 than at a pH over 8.0.
6. Relatively cold water requires longer disinfection time or greater quantities of disinfectants.
7. The number and type of organisms present in water influence the effectiveness of disinfection on microorganisms.
8. (1) Ultraviolet rays (2) heat, and (3) ultrasonic waves
9. (1) Iodine (2) bromine (3) bases (sodium hydroxide and lime) (4) ozone
10. The inability of ozone to provide a residual in the distribution system
11. Dose = demand + residual
12. Hydrogen sulfide and ammonia
13. Suspected carcinogenic compounds (trihalomethanes)
14. Chlorine gas lowers the pH; hypochlorite increases the pH
15. The higher the pH the greater the percent of OCl^-
16. The addition of chlorine to water until the chlorine demand has been satisfied and further additions of chlorine result in a free available residual chlorine that is directly proportional to the amount of chlorine added beyond the breakpoint.
17. Prechlorination ahead of any other treatment processes and postchlorination after the water has been treated and before it enters the distribution system
18. When the raw waters contain organic compounds
19. (1) Control of algal and slime growths (2) control of mudball formation (3) improved coagulation (4) reduction of tastes and odors (5) increased chlorine

contact time (6) increased safety factor in disinfection of heavily contaminated water

20. Chemical solution tank for the hypochlorite, diaphragm-type pump, power supply, water pump, pressure switch, and water storage tank
21. (1) Pumping directly into the water (2) pumping through an ejector which draws in additional water for dilution of the hypochlorite solution
22. Plastic containers
23. A week's supply of hypochlorite should be available
24. The fusible is a safety device. The fusible metal softens or melts at 158-165^{o}F to prevent buildup of excessive pressures and the possibility of rupture due to fire or high surrounding temperatures.
25. The upper valve discharges chlorine gas, and the lower valve discharges liquid chlorine from ton chlorine tanks.
26. In this position, either chlorine gas or liquid chlorine may be removed.
27. Turn the cylinder so that the leak is on top and the chlorine will escape as a gas.
28. By closing the valve or tightening the packing gland nut. Tighten the nut or stem by turning it clockwise.
29. By replacing the gasket or adapter connection.
30. Chlorine gas is extremely toxic and corrosive in moist atmospheres.
31. A properly fitting self-contained air or oxygen supply type of breathing apparatus, positive/demand breathing equipment, or rebreather kits are used when repairing a chlorine leak
32. First aid measures depend on the severity of the contact. Move the victim away from the gas area, remove the contaminated clothes and keep the victim warm and quiet. Call a doctor and fire department immediately. Keep the patient breathing.
33. The UV light intensity that reaches the pathogens in the water is affected by the condition of the UV lamps and the quality of the water.
34. (1) Checking the UV monitor for significant reduction in lamp output (2) monitoring the process changes in normal flow conditions (3) checking for fouling of the quartz sleeves and the UV intensity monitor probes (4) checking the indicator light display to ensure that all of the UV lamps are energized (5)

monitoring the elapsed time meter, microbiological results, and lamp log sheet (6) checking the quartz sleeves for discoloration

35. Depends on the quality of the water being treated and the treatment chemicals used prior to disinfection
36. Depends on (1) the level of suspended solids in the water to be disinfected and the fecal coliform level to be achieved (2) the frequency of the on/off cycles (3) the operating temperature of the lamp electrodes
37. Contact the appropriate regulatory agency. Do not throw UV bulbs in trash because they contain mercury.
38. It is unstable and decomposes to elemental oxygen in a short time after generation.