Small Water Systems
Course # 2001
State of Tennessee
Dept. of Environment & Conservation
Bureau of Environment
Fleming Training Center

#2001 Small Water Systems

Instructor: Amanda Carter
Fleming Training Center

Tuesday, February 6
8:30    Welcome and Roll Call
8:45    Water Sources and Treatment
9:15    Wells
9:45    Small Water Plants
11:00   Lunch
12:15   Disinfection
1:45    Safety

Wednesday, February 7
8:30    Pumps & Equipment Maintenance
10:00   Cross Connection Control
11:00   Lunch
12:15   Rules and Regulations
       Wellhead Protection
2:00    Laboratory

Thursday, February 8
8:30    Basic Math
11:00   Lunch
12:15   Applied Math
2:30    Exam and Course Evaluation
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Section 1

Water Sources
Water Sources and Treatment
Small Water System Operation and Maintenance
California State University: Sacramento

Water Supply Hydrology and the Hydrologic Cycle
- Hydrologic Water Cycle
- movement of water from the surface of the earth to the atmosphere and back
- Process of evaporation and transpiration
- Condensation forms water vapor droplets
- Precipitation returns water to earth
- Water penetrates ground via infiltration, percolation, and runoff
  - Surface runoff occurs when ground is saturated

Hydrologic Cycle
- Evaporation and Transpiration
  - Evaporation
    - the changing of liquid to gas (water to water vapor)
  - Water is constantly evaporating from the earth
  - Transpiration
    - the process in which water from the earth is absorbed by plants and transferred to the air through the leaves

Hydrologic Cycle
- Condensation and Precipitation
  - Condensation
    - occurs when water vapor condenses as it cools and forms tiny droplets of water or clouds
  - Precipitation
    - occurs when the droplets become too heavy to stay airborne
    - these droplets fall back to earth as rain, snow, sleet or hail

Hydrologic Cycle
- Infiltration and Percolation
  - As precipitation falls, it soaks into the ground
  - Infiltration
    - the movement of water through the soil
  - Some of the water goes back to the surface due to capillary action
    - the movement of water above a water surface
  - The rest percolates (continues downward) to the water table
Hydrologic Cycle

- Surface Runoff
  - When the soil can hold no more water, it flows downward over the ground surface
  - It flows into streams or lakes or, eventually, the ocean

Groundwater

- Water below the surface
- Hidden resource
- Provides 20% of water used in the US
- Has few contaminants
- Resultant of infiltration and percolation
- Relatively free from micro contamination
- Characterized by:
  - high TDS
  - Fe & Mn
  - high dissolved gases
  - radon, CH4, H2S
  - low dissolved oxygen
  - low color
  - high hardness
- Can be influenced by natural and human activities

Groundwater

- Sources
  - Aquifers
    - confined and unconfined
  - Springs
  - Half of the world’s groundwater resource is located within one mile of the ground surface
  - Other half is found in deep aquifers

Aquifers

Unconfined Aquifers

- Upper surface is free to rise and fall
- Water table wells
  - wells constructed to reach an unconfined aquifer
- Amount of water produced varies widely as water table rises and falls in relation to rainfall
- Indicates water table level of surrounding aquifer

Confined Aquifers

- Also known as Artesian Aquifer
- Permeable layer confined by an upper level and lower level of low permeability material
- Water recharge area usually higher than main part of aquifer
- Water is usually under pressure
  - Flowing artesian well
    - pressure causes water to rise above ground surface
  - Non-flowing artesian well
    - water doesn't rise to the surface
  - Piezometric surface
    - height that water rises
Aquifers

- Characteristics
  - Underground layer of gravel, sand, sandstone, shattered rock, or limestone
  - Impermeable layer of rock, clay or granite keeps water from sinking downward
  - Water table is upper surface of an aquifer

- Classified as water table or artesian and confined or unconfined

Aquifers Terms & Materials

- Porosity
  - amount of water the material will hold

- Hydraulic conductivity
  - how easily the water will flow through the aquifer material
  - Both determine how much the aquifer will yield

- Pumping rates are higher in coarser material and cost less

- less pumping head loss

- Consolidated aquifer formations consist of limestone and fractured rock and produce large quantities of water

Groundwater Movement Characteristics

- Movement of water is naturally downhill
- Rainfall percolates down to the water table
- Water moves slowly through soil which removes suspended particles
- Soil acts as a natural filtration process
- Dissolved pollutants cannot be removed
- Contaminants can be picked up
- Water table is never completely level

Springs

- Occur if water table intersects the ground surface
- Difficult to determine source of springs
- They should be considered contaminated until sanitary survey is conducted
- Flows vary considerably and are influenced by artesian pressures
- Enclose intake in a concrete spring box

Surface Water Characteristics

- Higher turbidity
- Suspended solids
- More color
- Microbial contamination
- Impurities in snow and rain
- Impurities from runoff
  - soluble formations such as limestone, gypsum, & rock salt affect characteristics

- Precipitation dissolves gases in atmosphere
- Dust and solids from industrial processes
- Usually soft, low in solids and alkalinity, and pH slightly below 7
- Usually corrosive
- Seasonal changes

Surface Water Supply and Operating Problems

- Contamination
- Loss of water source by evaporation & seepage
- Weather (rain and snowfall)
- Exposure to environmental changes
- Icing
- Rainfall intensity and droughts
- Soil composition
- Human influences
- More and varied treatment processes
Vocabulary

A. Aesthetic  H. Direct Runoff
B. Appropriate Rights  I. Drawdown
C. Aquifer  J. Evaporation
D. Artesian  K. Evapotranspiration
E. Capillary Fringe  L. Hydrologic Cycle
F. Contamination  M. Infiltration
G. Cross Connection

1. _____ The process by which water or other liquid becomes a gas.
2. _____ The porous material just above the water table that may hold water by capillarity in the smaller void spaces
3. _____ The seepage of groundwater into a sewer system, including service connections
4. _____ Attractive or appealing
5. _____ A natural, underground layer of porous, water-bearing materials (sand, gravel) usually capable of yielding a large amount or supply of water
6. _____ The process by which water vapor is released to the atmosphere from living plants
7. _____ The introduction into water of microorganisms, chemicals, toxic substances, wastes, or wastewater in a concentration that makes the water unfit for its next intended use
8. _____ The process of evaporation of water into the air and its return to earth by precipitation.
9. _____ Water rights to or ownership of a water supply that is acquired for the beneficial use of water by following a specific legal procedure
10. _____ A connection between a potable water and an unapproved water supply.
11. _____ Pertaining to groundwater, a well, or underground basin where the water is under a pressure greater than atmospheric and will rise above the level of its upper confining surface if given an opportunity to do so
12. _____ Water that flows over the ground surface directly into streams, rivers, or lakes
13. _____ The drop in the water table or level of water in the ground when water is being pumped from a well

Answers
1. J  8. L
2. E  9. B
3. M  10. G
4. A  11. D
5. C  12. H
7. F
Section 2

Wells
Importance of Groundwater

- Function of well is to intercept groundwater moving through aquifers and bring water to the surface
- Reasons for choosing groundwater source:
  - Generally available in all regions, though quantities may be limited
  - Less costly than surface treatment facilities
  - Less bacterial and viral contamination
  - Water quality parameters generally constant
  - Well suited to the needs of smaller communities

Water Cycle

- Hydrologic cycle is the continuous circulation of water on our planet
- Subsurface water - water that infiltrates the soil
  - Not all will become groundwater
  - Capillary action may pull water back to the surface
    - Will then be evaporated
  - Water may be absorbed by plant roots
    - Reenters atmosphere through transpiration
  - Infiltrated water may be drawn down to the zone of saturation – groundwater reservoir that supplies water to wells

Aquifers

- To qualify as an aquifer:
  - Porosity, area, & thickness to store adequate water supply
  - Sufficient specific yield to allow water to drain to a well
  - Hydraulic transmissivity to permit well to drain water from the aquifer fast enough to meet flow requirements
  - Specific yield – the volume of water that is affected by gravitational forces and can be removed from the soil
  - Porosity - a measure of the opening or voids (pores) in a particular soil

Overdraft

- Overdraft – pumping of water from aquifer in excess of the safe yield
- Overdraft can lead to the drained soils settling resulting in compaction and closing of pores
  - Subsidence of the land
Wellhead Protection

- Contamination can originate on the ground surface, in the ground above the well, or in the ground below the water table
  - Best method to guarantee continued supplies of clean groundwater is to prevent contamination
- Potential problems
  - Agriculture – pesticides, manure, nitrates
  - Gas stations – minor leaks, incidental spills
  - Fuel storage – underground tank failure, above ground tanks, buried & abandoned tanks
  - Photo labs, Dry cleaners, Furniture strippers, Medical Labs – solvents are very persistent
  - Septic systems – nitrates and other chemicals & solvents

Surface Features of a Well

- Openings in the top of the well allow for entrance or escape of air or gas
  - Provides access for adding gravel, taking water level readings, adding disinfectant or cleaning chemicals
  - Openings are second most important part of well
  - Well casing vent
    - Prevents vacuum forming during initial drawdown by allowing air to enter well
    - **Drawdown** – drop in water level in the ground when water is being pumped from a well
    - Prevents pressure buildup during recovery period by allowing air to escape
    - Minimum of 2 inches in diameter
    - Wells over 14 inches should have a dual vent
    - Should be 36 inches above finished surface of well lot

Well Surface Features

- Gravel tube
  - Required to monitor the gravel level and add level as needed
  - Typically 4 inches in diameter and tightly sealed
- Sounding tube
  - Used to determine water level and add disinfectant & cleaning agents
  - Minimum of 2 inches in diameter and tightly sealed
  - Well casing vent can be used as sounding tube
  - Disinfected roper or measuring tape is inserted into tube to the water level and the distance recorded
  - Can also use air pressure gauge – sounding line

Well Surface Features

- Pump pedestal
  - Concrete designed to support the full weight of the pumping unit
  - Constructed of continuously poured concrete to a minimum height of 18 inches above the finished elevation of the well lot
    - **Never** less than 12 inches
  - Minimum three inches of concrete around the outside of conductor casing grout seal
  - Should enclose top of grout seal a minimum of 12 inches deep
  - Steel reinforcement of the pedestal is recommended
- Pump motor base seal
  - Watertight seal between pump motor base and concrete pedestal
  - Latex rubber, neoprene rubber, or regular rubber gasket material
    - Cement grout should be avoided as seal

Air release and vacuum breaker valve

- If pump not equipped with foot valve, install this valve in the piping between the pump head and well discharge check valve
  - When pump is started, air will be expelled to the atmosphere instead of into the system
  - When pump is shutdown, air is admitted into the pump column allowing it to dewater into the well
  - Mount valve as close to check valve on top of discharge piping
  - Opening in top of valve must be equipped with downturned, screened assembly and protected from flooding
Well Surface Features

- **Sampling taps**
  - Pet cock valve fitted with a 3/8 (three eighths) inch copper line with the outlet turned down
  - No hose bib, faucet or threaded valve should be installed between pump and check valve to minimize contamination
- **Pump blowoff**
  - Use to remove pumped water containing sand picked up at beginning of pumping cycle
  - Waste line must be located above any known flood levels and protected against backpressure or backsiphonage
  - Do not connect directly to any sewer or storm drain

Well Surface Features

- **Well-casing vent (1)**
  - Allows air to enter well during drawdown to prevent vacuum conditions; vents excess air during well recovery period
- **Gravel Tube (2)**
  - Permits operator to see level of gravel and add gravel as needed
- **Sounding tube (3)**
  - Permits insertion of water level measuring device
  - Allows addition of chlorine or well cleaning agents

Well Surface Features

- **Air line water level measuring device (1)**
  - Aka Sounding line
  - Permits measurement of water level by means of air pressure measurements
- **Pump pedestal (2)**
  - Supports the weight of the pumping unit (concrete)
- **Pump motor base seal (3)**
  - Provides watertight seal between the motor base and the concrete support pedestal

Well Surface Features

- **Sampling taps (1)**
  - Permit sampling of pumped water
- **Air release and vacuum breaker valve (2)**
  - Permits discharge of air in column pipe during start-up and admits air during shutdown
- **Pump blowoff (drain line) (not shown)**
  - Removes first water (usually sandy) pumped at start up

Well Appurtenances
Valves

- Check valves
  - Prevents draining of system and keeps pressurized water from flowing back into the well
  - Flow reversal will not occur in pumps with a foot valve
  - Types: swing check, lift check, foot check, slant disc check, flap check, globe check, double disc check, and automatic control check

- Pump control valves
  - Diaphragm-type valve designed to eliminate pipeline surges when the pump is started and stopped (water hammer)
  - Types: normally open, normally closed
  - Both types hydraulically operated
  - Normally closed installed on main discharge line
  - Normally open installed in bypass line on discharge side

- Foot valves
  - Placed in the inlet to pump suction line
  - Maintains the prime of the pump
  - Prevents reversal of flow into the well when pump shuts off
  - Eliminates problems of air entering system

Flowmeters

- Used to measure the amount of water being pumped to the system
  - Should be at least 5 pipe diameters distance downstream from any pipe bend, elbow or valve
  - Should be at least 2 pipe diameters distance upstream from any pipe bend, elbow or valve
  - Should be calibrated in place
  - Types:
    - Positive displacement, propeller, turbine, orifice plate, electronic sensor
    - Propeller or turbine type with magnetic drive most common in well pump applications

Sand Traps and Sand Separators

- Sand should not be allowed to enter the distribution system
  - Reduced pump efficiencies, worn impellers, sanded water mains, excessive meter wear & plugging, customer complaints

- Sand traps
  - Large tank with series of baffles or chambers installed on discharge side of well pump
  - Costly and inefficient

- Sand separators
  - Uses centrifugal force to efficiently remove fine sand, scale, etc. from water
  - Can remove approximately 95% of large sand particles

More Appurtenances

- Tank coatings
  - Paints and coatings accepted by the Environmental Protection Agency (EPA) and/or the National Sanitation Foundation (NSF) for potable water contact are generally acceptable to the Department

- Surge suppressors
  - Installed on discharge side of booster pump to absorb shock waves in the water system and prevent water hammer

- Air and vacuum valves
  - Large venting orifice used to exhaust large quantities of air very rapidly

- Pressure relief valve
  - Installed on all hydropneumatic tanks to prevent water hammer

Air Chargers

- Add air to hydropneumatic system

- Hydraulic principle air charger
  - Uses water pressure of tank to force air into tank
  - Air is added to tank on upward compression stroke and releases water on downward exhaust stroke

- Air compressor air charger
  - When water level switch exceeds preset level, air gets pumped into the tank to push out water
  - Pump runs until pressure rises enough to open pressure switch OR the water level descend below preset level
**Well Maintenance and Rehabilitation**

Factors Affecting Maintenance of Well Performance

- Overpumping (aka overdraft)
  - Can damage aquifer and production capacity
  - Can lead to pumping air, water cascading into the well, sand pumping, excessive pump wear, reduced pump efficiency, sand locking

- Clogging or encrustation of screen
  - Well screens will filter sand out of water entering the well
  - Clogging/encrustation can limit number of available openings for water to move through
    - Encrusting waters usually alkaline
    - Most common cause of decrease in a well’s capacity
    - Carbonate, sulfate, and iron deposits most common causes of encrustation

- Corrosion or collapse of screen
  - Corrosion is a process that results in the gradual decomposition or destruction of metals
  - Typical corrosive water characteristics
    - Acidic (low pH)
    - High dissolved oxygen (DO)
    - High carbon dioxide (CO₂)
    - High total dissolved solids (TDS)
    - High hydrogen sulfide (H₂S)
    - High velocity water
    - Connection of dissimilar metals in water (galvanic corrosion)
  - Can enlarge screen openings allowing unwanted, larger particles through

- Biofouling
  - Bacterial growth is responsible for more than 80% of the blockages in wells and a major portion of corrosion
  - Biofilm is habitat of bacteria
  - Results in blockage, corrosion, or water quality problems

Field testing of deposits

- Black deposit: iron sulfide or manganese
- Dark to reddish brown: ferric iron oxide (soluble/dissolved)
- Bright yellow: sulfur
- Light tan deposit: mixture of calcium and magnesium carbonate
- Very light color to white: calcium carbonate
- Very heavy or dense deposit: predominately mineral
- Very light or low density deposit: biological or organic material

**Well Maintenance**

- Adequate recordkeeping is a must
  - Water level measurements before and after pumping
  - Flow rates
  - Water quality samples
  - Time length of pumping
  - Pump repairs
- Casing and screen maintenance
  - Material selection vital to life of well

**Casing and Screen Maintenance**

- Surging
  - Procedure used for opening pores in the screen and cleaning gravel pack
  - Common in new well development to purge sand around well screen
  - Effective at combating encrustation when used with acid treatment
Casing and Screen Maintenance

- High velocity jetting
  - Spraying water at a high velocity to backwash screen and reopen pores of the aquifer and remove sand around well screen
  - Jet should be 1-2 inches smaller than well casing diameter
  - 100-150 psi at 10-12 gpm

- Chlorine treatment
  - Shock treatment @ 100-200 mg/L
  - More effective than acid treatment removing biofilms and iron oxide deposits
  - Calcium hypochlorite or sodium hypochlorite
  - May be alternated with acid treatment

Polyphosphates

- Disperse silts, clays, and deposits of iron & manganese
- Dislodged solids easily removed by pumping

Acid treatment

- Used to loosen encrustation to remove from well and casing
- Hydrochloric acid or sulfamic acid
  - Dissolves calcium and magnesium carbonates
  - HCl – dissolves iron and magnesium hydroxides
- Use caution to not damage well materials
- Always add acid to water, never add water to acid
- Pump well to waste until well discharge pH has returned to normal

Acid Treatment

<table>
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<th>Characteristic</th>
<th>Slight</th>
<th>Moderate</th>
<th>High</th>
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<tr>
<td>Corrosiveness to metal</td>
<td>Phosphoric</td>
<td>Sulfamic</td>
<td>Hydrochloric</td>
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<td></td>
<td>Acid</td>
<td>Acid</td>
<td>Acid</td>
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<tr>
<td>Reactivity to:</td>
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<tr>
<td>• Carbonate Scale</td>
<td>Citric acid</td>
<td>Hydroxyacetic acid</td>
<td>Sulphamic acid, Hydrochloric acid, Phosphoric acid</td>
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<tr>
<td>• Sulfate Scale</td>
<td>Hydroxyacetic acid, Citric acid</td>
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<td>acid</td>
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<tr>
<td>• Fe/Mn Oxides</td>
<td>Sulphamic acid, Hydrochloric acid, Phosphoric acid</td>
<td>Sulphamic acid, Hydrochloric acid</td>
<td>acid</td>
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<tr>
<td>• Biofilm</td>
<td>Sulphamic acid, Hydrochloric acid, Phosphoric acid, Citric acid</td>
<td>Hydroxyacetic acid</td>
<td>acid</td>
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Troubleshooting

Analysis of Declines in Well Yields

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<th>Symptom</th>
<th>Cause</th>
<th>Corrective Action</th>
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<tr>
<td>Decline in drawdown with no change in specific capacity</td>
<td>Aquifer – groundwater level decline due to reduced recharge or overpumping</td>
<td>Increase spacing of new supply wells. Institute artificial recharge methods.</td>
</tr>
<tr>
<td>Decline in specific capacity with no change in drawdown</td>
<td>Well – screen blockage; reduction in open hole by sediment</td>
<td>Clean well with surge block or other means. Acid wash to dissolve encrustations.</td>
</tr>
<tr>
<td>No change in drawdown and no change in specific capacity</td>
<td>Pump – wear of impeller or other moving parts</td>
<td>Recondition/replace motor or parts</td>
</tr>
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Analysis of Changes in Water Quality

<table>
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<tr>
<th>Quality Change</th>
<th>Cause</th>
<th>Corrective Action</th>
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<tbody>
<tr>
<td>Biological</td>
<td>Movement of polluted water from surface through pipe liner and inside of pipe</td>
<td>Seal space and mound dirt around well</td>
</tr>
<tr>
<td>Chemical</td>
<td>Movement of polluted water into well from land surface</td>
<td>Seal space; extend casing to a deeper level</td>
</tr>
<tr>
<td>Physical</td>
<td>Migration of rock particles into well through screen or from water bearing fractures; Collapse of well screen or rupture of well casing</td>
<td>Remove pump and redevelop well Replace screen; install smaller casing inside original casing</td>
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Wells 15
Well Pumps and Service Guidelines

- Two basic groups
  - Positive displacement pumps – deliver same volume of water against any head
    - Piston or diaphragm
  - Dynamic pumps – deliver water with the volume varying inversely with the head
    - The greater the head the less the volume or flow
    - Centrifugal, jet, and air-lift
- Shallow well pump – installed above a well and takes water by suction lift
- Deep well pump – installed in well with inlet submerged below pumping level
  - Can be used in any type of well

Types of Pumps

- Centrifugal pumps
  - Raises water by centrifugal created by impeller in a casing; water passes through a channel or diffuser vanes
  - Volute-type pumps
    - No diffuser
    - Lower velocity with higher pressures
  - Turbine-type pumps
    - Most common for wells
    - Impeller surrounded by diffuser vanes that transform velocity head to pressure head
- Deep Well Turbine Pumps
  - Standard
    - Driven through rotating lineshaft connected to electric motor on top of well
      - Oil lubricated or water lubricated
  - Submersible
    - Similar to standard deep well turbine except motor is mounted below pump
- Jet pumps
- Piston pumps
- Rotary pumps

Well Pumps

- Column pipe
  - Connects to bottom of surface discharge head, extends down into well, and connects to the top of the well pump
  - Delivers water under pressure from well pump to surface
  - Keeps lineshaft and shaft enclosing tube assembly in straight line
- Right-angle gear drives
  - Can replace electric motor on top of well
  - Can be used with electric motor as a standby or for emergency purposes

Selecting a pump
- Must know required capacity, location & operating conditions, and total head
- Service guidelines
  - Deep well turbine, oil lubricated pumps have electric oiler system that includes an adjusting needle and sight glass
  - Oil drip rate depends on well column length
  - Should never be less than 5 drops of oil per minute
- Motors
  - Oil in bearing container changed annually
    - Be sure to use proper oil
    - Greased bearings require weekly attention during heavy pumping season
    - Do NOT over grease bearings, will cause overheating
Disinfection of Wells and Pumps

New Wells
- For well disinfection procedures, follow AWWA A100
  - AWWA A100 says to follow AWWA C654
- Equipment and material should be sprayed with 200 mg/L chlorine just prior to installation
- After installation of equipment
  - Treat water in well casing to provide residual of 50 mg/L
  - Circulate chlorinated water within casing and well column
  - Pump well to waste to remove chlorinated water

Disinfection After Equipment Installation
- Treating water in well casing
  - Must have 50 mg/L chlorine residual in entire volume of water
  - Calcium hypochlorite (HTH)
    - Dribble down the casing vent and at least 30 minutes shall pass to allow the tablets to fall through the water and dissolve
  - Sodium hypochlorite
    - Suspend tube through well casing vent to bottom of well
    - Withdraw tube as sodium hypochlorite solution pumped through tube
  - Well shall be surged at least 3 times
    - Improves mixing and induces contact of chlorine with adjacent aquifer
  - Chlorinated water shall sit at least 12 hours but less than 24 hrs

Disinfecting Existing Wells
- Wells should be disinfected after repairs and/or parts replacement
  - Swab inside of well casing with non-foaming detergent
  - Add chlorine to provide 100 mg/L in water
    - Based of well diameter and water depth
  - Add chlorine through hose that is raised and lowered to reach all areas of well, including that portion above the water
  - Clean and disinfect pump and other equipment prior to lowering into well
  - Disinfect well using proper AWWA standards

Disinfection After Equipment Installation
- Circulating the chlorinated water
  - Make pressure tight connection (at least 2 inch diameter) from pump discharge to casing vent
  - Operate pump against throttled discharge
    - This will circulate some water through well while discharging the remainder
  - Test discharge water periodically for chlorine residual
    - When zero residual is measured, pump to waste for 15 minutes
  - Sample for bacteriological
  - Dispose of contaminated or highly chlorinated water properly

Disinfection After Equipment Installation
- Bacteriological evaluation (according to AWWA C654)
  - Collect 2 samples (duplicates) not less than 30 minutes apart
  - If any sample comes back total coliform positive
    - Pump well to waste for 15+ minutes, then take duplicate samples not less than 30 minutes apart
    - If still get positive
      - Re-chlorinate well using aforementioned steps OR
      - Take corrective action determined by qualified engineer
  - If repeated attempts to disinfect the well are unsuccessful, a detailed investigation to determine the cause or source of the contamination should be undertaken
Sand in Well Systems

Wells in alluvial formations are particularly susceptible to sand production. Nearly all wells will produce some sand. Problems caused by sand include:
- Equipment damage: pumps, plumbing fixtures, appliances, water meters, etc.
- Deposition in distribution leading to decreased carrying capacity
- Increased customer complaints

Solutions:
- Install sand separator
- Lower flow rate

Sand concentrations should not exceed 0.3 cu. ft./million gallons.

Flush large mains to resolve complaints on small mains. Must have sufficient velocity to remove sand during main flushing. Sand may not appear immediately when flushing, but once it does flushing should continue until sand is no longer evident.

Flushing Mains

- Sand in small diameter pipes is typically due to sand in larger mains supplying the water
  - Flush large mains to resolve complaints on small mains
- Must have sufficient velocity to remove sand during main flushing
- Sand may not appear immediately when flushing, but once it does flushing should continue until sand is no longer evident
# Vocabulary

| A. Alluvial | J. Head | S. Suction lift |
| B. Appurtenance | K. Hydrologic Cycle | T. Transmissivity |
| C. Aquifers | L. Overdraft | U. Transpiration |
| D. Available chlorine | M. Pet cock | V. Water hammer |
| E. Brake horsepower | N. Pore | W. Zone of saturation |
| F. Cone of depression | O. Porosity | |
| G. Drawdown | P. Prime | |
| H. Evaporation | Q. Sounding tube | |
| I. Foot valve | R. Specific yield | |

1. ____ a natural underground layer of porous, water-bearing materials usually capable of yielding a large amount or supply of water
2. ____ the process of evaporation of water into the air and its return to earth by precipitation
3. ____ the process by which water or other liquid becomes a gas
4. ____ the process by which water vapor is released to the atmosphere by living plants
5. ____ the soil or rock located below the top of the groundwater table
6. ____ a measure of the spaces or voids in a material or aquifer
7. ____ the quantity of water that a unit volume of saturated permeable rock or soil will yield when drained by gravity
8. ____ the measure of the ability to transmit (as in the ability of an aquifer to transfer water)
9. ____ a very small open space in a rock or granular material
10. ____ the pumping of water from a groundwater basin or aquifer in excess of the supply flowing into the basin
11. ____ the depression, roughly conical in shape, produced in the water table by the pumping of water from a well
12. ____ the drop in the water table or level of water in the ground when water is being pumped from a well.
13. ____ a pipe or tube used for measuring the depths of water
14. ____ a small valve or faucet used to drain a cylinder or fitting
15. ____ a special type of check valve located at the bottom end of the suction pipe on a pump; holds pump’s prime
16. ____ machinery, appliances, structures, or other parts of the main structure necessary to allow it to operate as intended, but not considered part of the main structure
17. _____ the result of opening or closing a valve too quickly causing a change in pressure that can lead to main damage
18. _____ action of filing a pump casing with water to remove the air
19. _____ a measure of the amount of chlorine available in chlorinated lime, hypochlorite compounds, and other materials that are used as a source of chlorine
20. _____ the vertical distance, or energy of water above a reference point; may be measured in feet or psi
21. _____ the negative pressure on the suction side of a pump
22. _____ the horsepower required at the top or end of a pump shaft; the energy provided by a motor or other power source
23. _____ relating to mud or sand deposited by flowing water; these deposits may occur after a heavy rain

Answers
1. C 13. Q
2. K 14. M
3. H 15. I
4. U 16. B
5. W 17. V
6. O 18. P
7. R 19. D
8. T 20. J
10. L 22. E
11. F 23. A
12. G
Section Review Questions

1. What is the purpose of a well?

2. What is the hydrologic cycle?

3. What does porosity measure?

4. Why are there openings in the top of a well?

5. What is the purpose of the well-casing vent?

6. How would you determine the distance down to the water level in a well?

7. What is the purpose of a check valve?

8. What is the purpose of pump control valves?

9. Why must flows be known when chemicals are being applied at a well pumping station?

10. What is the purpose of surge suppressors that are sometimes installed on the discharge side of a booster pump?

11. What is the purpose of and air release and vacuum breaker valve?
12. What is the purpose of an air charger?

13. List three major well maintenance problems.

14. How can overpumping an aquifer damage the aquifer?

15. Encrusting waters are usually (circle one) alkaline/acidic; while corrosive water are usually alkaline/acidic.

16. Why should the use of two or more different types of metals be avoided in a well?

17. What records should be kept regarding a well?

18. What is the purpose of surging?

19. How can the pores in a well screen and the gravel pack around the screen be cleaned?

20. How can encrustation be removed from the well casing and well?

21. How can bacterial growths and slime deposits be removed from well screens?

22. When the yield of a water well declines, what three factors should be investigated to determine the cause?
23. What are the two basic groups of well pumps and the difference between them?

24. When should a well be disinfected?

25. What would you do if repeated attempts to disinfect a well are unsuccessful?

26. Why does the disinfection of existing wells after well or pump repairs require special disinfection methods?

Section Review Questions – Answers

1. to intercept groundwater moving through aquifers and bring water to the surface for use by people

2. the continuous circulation of water on our planet; the process of evaporation of water into the air and its return to the earth by precipitation

3. the openings or voids in a particular soil; quantifies the amount of water that a particular soil type or rock can store

4. to permit the entrance or escape of air or gas and to provide access to the well for taking water level measurements, adding gravel, or for applying disinfection or well cleaning agents

5. to prevent vacuum conditions inside a well by admitting air into the well during the drawdown period when the well pump is first started; to prevent pressure buildup inside the well casing by allowing excess air to escape during the well recovery period after the well pump shuts off
6. inserting a measuring tape into the sounding tube, lowering it down the tube to the water level, and recording the distance; or, air pressure in a sounding line may be used

7. acts as an automatic shutoff valve when the pump stops to prevent draining of the system or the tank being pumped to, and to prevent pressurized water from flowing back down the pump column into the well

8. to eliminate the pipeline surges when the pump is started and stopped

9. in order to calculate the correct chemical feed rate

10. to absorb shock waves in the water system and prevent their transmittal through the line; to prevent water hammer

11. to exhaust large quantities of air very rapidly from a deep well pump column when the pump is started, and to allow air to re-enter the pump column and prevent a vacuum from developing when the pump stops

12. adding air to hydropneumatic tanks

13. overpumping and lowering of the water table
clogging or collapse of a screen or perforated section
corrosion or encrustation

14. by reducing storage and production capacity of groundwater systems

15. alkaline; acidic

16. corrosion is usually greatest at the points of contact of the different metals or where they come closest to contact; galvanic corrosion

17. water level measurements in the well before and after pumping; flow rates; water quality samples; length of time pumping; accurate data on pump repairs and causes

18. to open pores in the screen and for cleaning the gravel pack around the screen

19. high velocity jetting
20. acid treatment

21. chlorine treatments

22. the aquifer, the well, and the pump

23. positive displacement pumps - deliver the same volume of water against any head
dynamic pumps - deliver water with the volume or flow varying inversely with the head

24. following development, testing for yield, and before the test pump is removed from the
well, or when there is evidence of contamination

25. a detailed investigation to determine the cause or source of the contamination should
be undertaken

26. during repair work, deposits of slime, bacterial growth, and other debris are dislodged
from the inside surfaces of the well pump column pipe; these deposits can be smeared
on the inside surfaces of the well casing which will require swabbing of the inside of the
well casing
Section 3

Small Water Plant Operation
SMALL WATER TREATMENT PLANTS
California State University: Sacramento
Small Water System Operation and Maintenance

SURFACE WATERS
- Raw water storage
- Diversion works
- Flow measurement
- Disinfection
- Coagulation
- Flocculation
- Settling
- Filtration
- Corrosion Control
- Treated Water Storage
- High service pumps

SURFACE WATER
- Raw Water Storage
  - Slows influent water quality changes
  - Maintain production during source shutdown
- Diversion Works
  - Diversion dam, bar & trash screens, intake pipe/structure, pumps, water conveyance piping, flow control valves
- Flow measurement
  - Should indicate instantaneous flow and total flow
  - Install wye strainer upstream to prevent clogging
- Disinfection
  - Chlorine is recommended disinfectant
  - Prechlorination minimizes organic growth in treatment units
- Coagulation
  - Chemical feed with rapid mix to create microfloc
- Flocculation
  - Slowly mixing water to create larger settleable floc (macrofloc)
- Settling
  - Allows suspended matter to separate from water by gravity
- Filtration
  - Removes remaining suspended matter after sedimentation
- Corrosion control
  - Water stability to minimize corrosion and scaling
- Treated water storage
  - Reservoirs allow treated water to be stored to meet peak demands and provide water during outages
- High service pumps
  - Draws finished water from storage and supply it under pressure

GROUNDWATER
- Iron and manganese control (Fe and Mn)
  - Controlled by oxidation – converting the dissolved form to the insoluble form
  - e.g. liquid ferrous iron (Fe^{2+}) to solid ferric iron (Fe^{3+})
  - Feed oxidizing agent (e.g. chlorine or potassium permanganate) with oxygen to oxidize iron and manganese and form the insoluble (precipitated) form
  - Remove precipitates with sedimentation and/or filtration
- Softening
  - Hardness due to calcium and magnesium ions (Ca and Mg)
  - Softening achieved by ion exchange or chemical precipitation (lime-soda ash softening)
PACKAGING PLANTS

- Most commonly used for filtration of turbid water and removal of dissolved iron and manganese
- Includes all treatment equipment, pumps, chemical feeders, and controls
  - May choose instead to select a custom designed package plant with materials supplied by different manufacturers
- Advantages
  - Design and equipment have already proven effective
  - All bugs eliminated giving purchaser a high degree of confidence and performance
  - No plant is completely automatic - still requires maintenance, repair, and occasional process control changes.

COAGULATION & FLOCCULATION

COAGULATION

- Chemical reaction when coagulating chemical is added to water
  - Most common is aluminum sulfate (alum)
- Coagulant reacts physically with fine particles of suspended matter in the water
  - Colloidal particles have a net negative charge causing them to repel each other
    - Zeta Potential
  - Coagulant neutralizes negative charge to destabilize particles allowing them to come together
    - Van Der Waals force
  - Reaction occurs within 2-5 seconds of chemical application

COAGULATION OPTIMIZATION

- Is the pH after addition of the coagulant the same as when good coagulation occurs?
  - Daily pH records should be maintained
- Is adequate alkalinity present for coagulation reaction?
  - Consider increasing alkalinity to have at least 30 mg/L remaining after chemical reaction complete by adding lime
- Is chemical feeder supplying correct dosage of coagulant?
  - Dry chemical – collect sample of chemical for selected amount of time to compare to set feed rate
  - Solution chemical – use site tube to measure actual feed rate versus set rate
COAGULATION OPTIMIZATION

• Does the chemical feeder inject a steady chemical feed into the water?
  • Want consistent pulses vs long interval slug
• Is chemical injector distributing coagulant throughout flow of water?
  • Injectors with multiple-feed orifices better than single orifice
• Is violent rapid mixing provided just after chemical if feed?
  • Install mechanical mixer or relocate injection point to zone of turbulent flow
• Is a coagulant aid needed?
  • Polymer or weighting agent

FLOCCULATION

• Process of slow, gentle mixing of the water to bring smaller floc particles together to form macrofloc
• Mixing must be strong enough to encourage floc formation without settling, but not so strong to break floc apart
• Mechanical mixing
  • Consists of slowly rotating paddles
  • Mixing becomes progressively more gentle as water flows through flocculation basin
  • Preferred method due to flexibility to maintain mixing regardless of flow rate and adjustable agitation rates

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FLOCCULATION OPTIMIZATION

• Correct any deficiencies in the coagulation process
• Check degree of mixing – neither too violent nor too gentle
• Adequate mixing time
  • Do actual flow rates exceed design flow?
• Minimize short circuiting through basin
• Adjust plant to run on a more continuous basis and minimize frequent on/off operation

SEDIMENTATION

• Factors affecting flocculation
  • Degree of mixing
    • Too gentle – particles will not be brought into contact with one another and larger floc will not form
    • Too violent – floc will be torn apart (sheared) preventing size large enough to settle out independently
  • Time
  • Minimum 30 minutes with 45 minutes recommended
  • Minimize short circuiting – water travelling through basin is less than designed time
  • Add baffles or compartments – three recommended
  • Number of particles
    • Clean water is harder to treat due to decreased collisions between particles

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SEDIMENTATION

• Process of holding water in quiet, low-flow condition to allow for settling of suspended particles by gravity
• Tank has four zones
  • Inlet zone – water entering tank distributed across tank with a slow uniform flow velocity
    • Aka influent zone
  • Settling zone – water flows slowly through tank allowing suspended particles to settle out
  • Sludge zone – area where settled material lands in bottom of tank
  • Outlet zone – water is collected in weirs or launders and flows to tank outlet
    • Aka Effluent zone

ZONES OF SEDIMENTATION TANK

WEIR LAUNDER

Factors affecting sedimentation

• Time – minimum 4 hours for conventional sedimentation
  • Maybe reduced to 1 hour with tube or plate settlers
• Suspended matter characteristics – denser material settles faster than light, fluffy particles
  • Determined by coagulation/flocculation process
• Short-circuiting – long narrow tank more effective than short, wide tank
• Tank inlet/outlet arrangement – minor changes can cause drastic changes in settling efficiency
  • Inlet should distribute water evenly both horizontally and vertically while avoiding high velocities and eddy currents
  • Outlet should collect water uniformly and near the surface

Factors affecting sedimentation

• Surface overflow rate – lower rate is better than a higher rate
  • Aka surface loading rate (SLR)
  • Should be between 0.25 – 0.38 gpm/ft²
• Currents in tank – caused by flow inertia, wind action, temperature differences, and poor design
  • Can cause short-circuiting, resuspend settled particles
• Water temperature – particles settle faster in warm water than in cold water
  • Cold water is more viscous and creates more resistance
• Wind – can cause currents and turbulence decreasing settling

Check coagulation/flocculation process operation

• Decrease rate of flow to lower surface overflow rate and flow velocity
• Improve inlet conditions to reduce velocity, distribute flow uniformly, create uniform flow velocities
  • If more than one tank used, ensure flow divided equally across tanks
• Improve outlet conditions to eliminate velocities
• Remove accumulated sludge
• Cover tank to minimize currents caused by wind and weather
• Recycle sludge to inlet to increase number of particles in water
SEDIMENTATION

- High rate settlers (tube or plate settlers) increase settling efficiency in sedimentation basins
  - Provides surface area for particles to settle on

Tube Settler
Plate Settler

FILTRATION

- Process of passing water through a porous bed of material to remove suspended matter from the water
- Two types
  - Gravity filter – water enters tank near the top and flows downward through media under force of gravity
    - Slow sand filter – uses biological process as well as physical straining
  - Pressure filter – water is forced through enclosed tank through filter media under pressure created by an external force

FILTER MEDIA LAYERS

FILTRATION MODES

- Conventional filtration
  - Used with highly variable raw water quality and large volumes of water are required
  - Filtration accomplished by straining and adsorption
  - Includes coagulation, flocculation, & sedimentation prior to filtration
- Direct filtration
  - Used with waters low in turbidity, color, plankton, & coliforms
  - Includes coagulation & flocculation prior to filtration
    - Sedimentation step is omitted
  - This method must be approved by State
  - These filters are cleaned by backwashing

- Diatomaceous earth (precoat) filtration
  - DE is added as a slurry to water being treated and collects on a screening device
  - Water is filtered by passing it through the screening device coated in DE
  - Used where very high particle removal efficiencies required
  - Can be operated as gravity or pressure filter
- Slow sand filtration
  - Particles removed by straining, adsorption, and biological action
  - Majority of particulate removal in top few inches of sand
  - Filter cleaned by remove the top 2 inches of filter media
Filtration Media

- Anthracite – hard coal prepared by crushing coal and sieving to get proper size
  - Effective size of 0.8 mm to 1.2 mm with a uniformity coefficient not greater than 1.85
  - 1.5 times heavier than water

- Sand – should be hard material like quartz that will not erode or easily dissolve in water
  - Effective size of 0.35 mm to 0.55 mm and a uniformity coefficient not greater than 1.70
  - 2.5 times heavier than water

In 30 inch dual media filter, anthracite should be 18-20 inches deep and sand should be 10-12 inches deep.

- Garnet – group of hard, reddish, glassy mineral sands with high density used at bottom of filter
  - When added, this makes filter a multimedia filter

- Underdrain – under filtering media
  - Supports filter media and prevents media passing through bottom of filter
  - Collects filtered water and conveys water from filter
  - Uniformly distributes backwash water across filter bed
    - Most important function

Filtration Rates

- Slow sand filters – max 2 gpm/ft²
  - Assumed Log Removals by Filtration Method
    - Giardia = 2.0 log removal
    - Viruses (crypto) = 2.0 log removal

- High rate filters – max 4 gpm/ft²
  - Assumed Log Removals by Filtration Method
    - Giardia = 2.5 log removal
    - Viruses (crypto) = 2.0 log removal
  - Includes
    - Rapid sand filters
    - Dual media filters
    - Multimedia filters

Filtration

- Filter continuously removes suspended matter while in operation
  - Matter clogs openings and decreases flow through filter
  - Head loss will gradually build up

- When terminal head loss is achieved, filter must be cleaned
  - Backwash – reversal of flow direction through filter to flush collected dirt out of media
    - Filter bed expands allowing media grains to scrub against each other and knock off dirt particles
    - Want to leave the filter cleaner but not too clean
      - Ripen filter (filter to waste) before placing filter back in service

- Backwashing frequency varies from facility to facility
  - Based on time, flow, head loss, and/or effluent turbidity
  - Consistency is key – have a good SOP

  - Bed should be expanded to at least 50% its normal depth
    - Not so much that media overflows into troughs
  - Minimum backwash rate = 18.75 gpm/ft²
  - Surface wash or subsurface wash required

  - Good backwashing increases filter run lengths, finished water production, finished water quality, etc
  - Poor backwashing increases finished turbidity, mudball formation, filter short circuiting

Filter Optimization

- Optimize coagulation, flocculation and sedimentation
  - Settled water turbidity should not exceed 5.0 ntu

- Ensure filtration rate is not higher than designed
  - Backwash filter effectively to prevent mudballs

- Operate filter to minimized rapid filter rate changes
  - Eliminate on/off operation

- Inspect media condition frequently
  - Look for loss in depth, mudballs, caking, surface cracks, and mounding or unevenness
FILTER OPTIMIZATION

• Observe filters during backwash and filtering periods to determine condition of underdrain
  • Gravel disturbance and broken underdrains will allow media to pass through in finished water during filtration
  • Mounded media, sand boils, or evidence of uneven upward flow during backwash indicates underdrain issues
• Provide accurate flow and headloss gauges
• Consider feeding a polymer filter aid
Small Plants – Vocabulary

A. adsorption  H. jar test
B. alkalinity   I. mudballs
C. clear well   J. precipitate
D. coagulation  K. short-circuiting
E. diatomaceous earth  L. slurry
F. flocculation  M. trihalomethanes
G. garnet       N. wye strainer

1. _____ a screen shaped like the letter Y; water flows through upper part of Y and debris is trapped by screen at the fork
2. _____ derivatives of methane in which three halogen atoms are substituted for three of the hydrogen atoms; often formed during chlorination by reactions with natural organic materials in the water
3. _____ the clumping together of very fine particles into larger particles (microfloc) caused by the use of chemicals
4. _____ a reservoir for the storage of filtered water of sufficient capacity to prevent the need to vary the filtration rate with variations in demand; also used to provide chlorine contact time for disinfection
5. _____ capacity of water to neutralize acids; caused by water’s content of carbonate, bicarbonate, and hydroxide.
6. _____ laboratory procedure in which varying dosages of coagulant are tested in a series of jars under identical conditions
7. _____ the gathering together of fine particles after coagulation to form larger particles called macrofloc by a process of gentle mixing
8. _____ a condition that in tanks or basins when some of the flowing water entering a tank or basin flows along a nearly direct pathway from the inlet to the outlet
9. _____ an insoluble, finely divided substance that is a product of a chemical reaction within a liquid
10. _____ a fine, siliceous earth composed mainly of the skeletal remains of diatoms
11. _____ a water mixture or suspension of insoluble matter
12. _____ the gathering of a gas, liquid, or dissolved substance on the surface or interface zone of another material

13. _____ a group of hard, reddish, glass, mineral sands made up of silicates of base metals

14. _____ material, approximately round in shape, that forms in filters and gradually increases in size when not removed by the backwashing process

Vocabulary -Answers
1. N  8. K  
3. D  10. E  
4. C  11. L  
5. B  12. A  
Small Plants Review Questions

1. How does the storage of raw water in lakes, ponds, or reservoirs help the water treatment plant operator?

2. What information does an operator obtain from a flowmeter?

3. How can a flowmeter be protected?

4. Groundwaters may require what types of treatment?

5. What is the influence of temperature on the coagulation process?

6. How can the alkalinity of the water being treated be increased?

7. What is flocculation?

8. What happens if the flocculation mixing is too strong or too weak?

9. What is the purpose of settling?

10. Short-circuiting is influenced by what factors?

11. How does temperature influence particle settling?
12. Why is sludge recycled to the inlet of the settling tank?

13. What is included in the suspended matter removed by filtration?

14. Why do anthracite and sand stay separated during and after backwashing?

15. What is a mixed media (multimedia) filter?

16. Under what conditions will mudballs form in filters?
Small Plants Review Questions – Answers

1. by slowing the rate of change in water quality due to rainstorms and other factors

2. the instantaneous rate of flow as well as the total quantity of water that has flowed through it

3. by a fine screen or wye strainer installed upstream from the meter to prevent clogging or damage by trash or rocks

4. disinfection, iron and manganese control, and softening

5. the warmer the water, the faster the coagulation chemical reactions

6. by adding lime or soda ash prior to coagulation

7. a process of slow, gentle mixing of the water to encourage the tiny floc in the flocculation basin, but the mixing must not be so strong that it breaks apart the floc particles already formed

8. mixing must be strong enough to prevent premature settling of floc in the flocculation basin, but no so strong that it breaks apart the floc particles already formed

9. to remove as much of the floc and other suspended material as possible before the water flows to the filter

10. (1) the shape and dimensions of the tank, and (2) the inlet and outlet arrangements of the tank

11. the warmer the water, the faster the particles settle

12. to increase the number of particles in the water and improve flocculation of the settling particles

13. mainly particles of floc, soil, and debris; but also living organisms such as algae, bacteria, viruses, and protozoa

14. sand is 2.5 times heavier than water and anthracite is 1.5 times heavier than water
15. a mixed media filter contains three layers of media: garnet, sand, and anthracite

16. mudballs form if backwashing does not effectively clean the media
Section 4

Disinfection
Disinfection

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

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
- USEPA (US Environmental Protection Agency)
  - Responsible for setting drinking water standards
- SDWA (Safe Drinking Water Act)
  - Sets MCLs (maximum contaminant levels) for substances known to be hazardous to human health
- SWTR (Surface Water Treatment Rule)
  - Requires disinfection for all surface water supply systems to protect against exposure to viruses, bacteria, and Giardia

Factors Influencing Disinfection
- pH
  - Chlorine disinfects faster at pH of 7 than at pH > 8
  - Hypochlorous acid dissociates 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

Safe Drinking Water Laws
- IESWTR (Interim Enhanced Surface Water Treatment Rule)
  - Increase public protection from illness caused by Cryptosporidium
- DPBR (Disinfection By-Products Rule)
  - Limits amount of certain potentially harmful disinfection by-products that may remain in drinking water after treatment
- LT2ESWTR (Long Term to Enhanced Surface Water Treatment Rule)
  - Builds upon earlier rules to reduce illness linked with Cryptosporidium
FACTORS INFLUENCING DISINFECTION

- Turbidity
  - Excessive turbidity greatly reduces disinfection efficiency
- 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 of chemical available for disinfection
- Inorganic matter
  - Ammonia can combine with disinfectant chemical to form side compounds

FACTORS INFLUENCING DISINFECTION

- Reducing Agents
  - Any substance that will readily donate electrons
  - Demand for chlorine by reducing agents must be met before chlorine becomes available to accomplish disinfection
- Inorganic reducing agents
  - Hydrogen sulfide gas (H_2S)
  - Ferrous ion (Fe^{2+})
  - Manganous ion (Mn^{2+})
  - Ammonia (NH_3)
  - Nitrite ion (NO_2^-)

PROCESS OF DISINFECTION

PURPOSE OF PROCESS

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

AGENTS OF DISINFECTION

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

AGENTS OF DISINFECTION

- 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 residual, difficult to store, high maintenance requirements
**Agents of Disinfection**

- Chemical Disinfectants
  - Chlorine -- $\text{Cl}_2$
    - 100% pure gas
  - Calcium hypochlorite -- $\text{Ca(OCl)}_2$
    - 65% pure solid
  - HTH -- high test hypochlorite
  - Sodium hypochlorite -- $\text{NaOCl}$
    - 5-15% pure liquid
    - Bleach

**Chlorine ($\text{Cl}_2$)**

- 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
  - Can support combustion

- Reaction with Water
  
  \[
  \text{Cl}_2 + \text{H}_2\text{O} \rightarrow \text{HOCI} + \text{HCl}
  \]

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

**Hyochlorite (OCl⁻)**

- Reaction with Water
  
  \[
  \text{Ca(OCl)}_2 + \text{H}_2\text{O} \rightarrow \text{HOCI} + \text{Ca(OH)}_2
  \]
  \[
  \text{NaOCl} + \text{H}_2\text{O} \rightarrow \text{HOCI} + \text{NaOH}
  \]

  - Raises pH due to OH⁻ ion
  - If Ca(OCl)₂ injected at the same point as sodium fluoride, a severe crust can form at injection point

**Chlorine Dioxide ($\text{ClO}_2$)**

- 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
  - Effective oxidizing agent with iron and manganese
  - Does not form carcinogenic compounds from treating organics
### 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

\[ \text{Dose} = \text{Demand} + \text{Residual} \]

### 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

\[ \text{Total chlorine dose} = \text{residual} + \text{demand} \]

### Chloramination

- Chloramines have been used as an alternative disinfectant for over 70 years
- An operator’s decision to use chloramines depends on several factors
- However, chloramination alone is not an approved method of disinfection in the state of Tennessee

### Chlorine Residual Testing

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

### Critical Factors

- **Effectiveness of upstream treatment processes**
- **Injection point and method of mixing**
- **Temperature**
  - The higher the 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
**CT VALUES**

“kill” is proportional to $C \times T$

- 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**

- **Precolorination**
  - 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

- **Postchlorination**
  - Application of chlorine after the water has been treated but before it enters the distribution system
  - Primary point of disinfection

- **Rechlorination**
  - 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

- **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

**OPERATION OF CHLORINATION EQUIPMENT**

- **HYPOCHLORINATORS**
  - A piece of equipment used to feed liquid chlorine solutions (bleach)
  - Consists of chemical solution tank, diaphragm-type pump, power supply, water pump, pressure switch, water storage tank
HYPOCHLORINATORS
- 2 methods of feeding
  - Directly pumped into water
  - Pump through an ejector (injector)
    - Draws in additional water for dilution of solution

CHLORINATORS
- 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 set at floor level
  - Warning device located outside chlorine room

CHLORINATORS PARTS
- Ejector – creates the vacuum that moves the chlorine gas (also called injector or eductor)
  - Fitted with Venturi valve
- 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 – connects directly to the inlet valve of the vacuum regulator

CHLORINE CONTAINERS
- Plastic
  - Commonly used for storage of hypochlorite 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

- Steel Cylinders
  - Safety for handling and storing
    - 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

- Contain 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 CONTAINERS

- **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)

- 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

REMOVING CHLORINE FROM CONTAINERS

- 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 lbs/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

- **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 - used to convert liquid chlorine to gaseous chlorine
CHLORINE LEAKS
- Chlorine leak can be smelled at concentrations as low as 3 ppm
  - Detectors can detect 1 ppm 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

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

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

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 (sulfuric acid) will make the leak larger
- Leak around valve stem can be stopped by closing the valve or tightening the packing gland/nut

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.
MEASUREMENT OF CHLORINE RESIDUAL

METHODS OF MEASURING CHLORINE RESIDUAL
- Amperometric titration
  - A means of measuring concentrations of certain substances in water based on the electric current that flows during a chemical reaction
  - 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 phenylarsine 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

- DPD tests
  - A method of measuring the chlorine residual in water
  - N,N-diethyl-p-phenylene-diamine
  - 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 spectrophotometer or colorimeter
  - “False positive” can occur when sample contains a combined chlorine residual

CHLORINE SAFETY PROGRAM

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

<table>
<thead>
<tr>
<th>Effect</th>
<th>CL concentration (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slight symptoms after several hours' exposure</td>
<td>1</td>
</tr>
<tr>
<td>Detectable odor</td>
<td>0.3-3.3</td>
</tr>
<tr>
<td>Noxiousness (harmful)</td>
<td>5</td>
</tr>
<tr>
<td>Throat irritation</td>
<td>15</td>
</tr>
<tr>
<td>Coughing</td>
<td>30</td>
</tr>
<tr>
<td>Dangerous from 1/2 to 1 hour</td>
<td>40</td>
</tr>
<tr>
<td>Death after a few deep breaths</td>
<td>1,000</td>
</tr>
</tbody>
</table>

Disinfection
CHLORINE PPE

- Every person should be trained in the use of self-contained 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.

FIRST-AID MEASURES

- 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.

FIRST-AID MEASURES

- 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 area thoroughly with water.
- Nonflammable, however can cause a fire when comes in contact with organics.

DISINFECTION USING 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°F 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 if 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

- 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

- **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

- **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 monitors 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

- **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 in an inorganic acid solution for 5 minutes
  - i.e. Nitric acid (50%) or phosphoric acid (5-10%)

- **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
OZONE (O₃)
- 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
  \[ O₂ + \text{Energy} \rightarrow O + O \]
  \[ O + O₂ \rightarrow O₃ \]

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

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

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
  \[
  \text{Oxygen from air + Electrical voltage} \rightarrow \text{Ionized oxygen + Heat}
  \]
  \[
  \text{O}_2 + \text{electricity} \rightarrow 2\text{O} \]
  \[
  \text{Ionized oxygen + Non-ionized oxygen} \rightarrow \text{Ozone}
  \]
  \[
  2\text{O} + 2\text{O}_2 \rightarrow 2\text{O}_3 \]

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

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 is 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 Cl₂ 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
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

<table>
<thead>
<tr>
<th>DIAMETER (INCHES)</th>
<th>LBS OF HTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>0.000935(L)</td>
</tr>
<tr>
<td>8</td>
<td>0.00166(L)</td>
</tr>
<tr>
<td>10</td>
<td>0.0026(L)</td>
</tr>
<tr>
<td>12</td>
<td>0.00374(L)</td>
</tr>
<tr>
<td>14</td>
<td>0.00509(L)</td>
</tr>
<tr>
<td>16</td>
<td>0.00665(L)</td>
</tr>
<tr>
<td>20</td>
<td>0.01038(L)</td>
</tr>
<tr>
<td>C24</td>
<td>0.01495(L)</td>
</tr>
</tbody>
</table>

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 asphyxiating 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 bacteria

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

4. II 15. KK 26. JJ 37. LL
8. CC 19. M 30. DD 41. H
9. MM 20. K 31. NN 42. OO
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 $\text{OCl}^-$
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°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.
Section 5

Pumps
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
  - 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, screw pump, etc.

• Metering pumps
  - Most common type of solution feeder
  - Delivers precise volume of solution with each stroke or rotation
  - Typically have variable-speed motor that can be adjusted to control chemical flow
Positive-Displacement Pumps

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

Positive Displacement Pumps

- Peristaltic Pump
  - Fluid to be pumped flows through flexible tube inside a pump casing
  - Rotor inside turns and compresses the tube
  - Rotor forces fluid through tube

Screw Pumps

- 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

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

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.

Common Pump & Motor Connections

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

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

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.
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

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

- 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

#8: Examine wearing rings at regular intervals. When seriously worn, their replacement will greatly improve pump efficiency.

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 180ºF (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

Pumps Discharge

Bearings

Shaft

Impeller

Stuffing Box Casing

Or

Volute

Packing Gland

Wear Ring (missing)

Stuffing Box

Impeller

Stufing Box

Lantern Ring

Packing Gland

Shaft

Packing

Shaft
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

- 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

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

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.

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.

- 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
**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

**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)

**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

**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.

**Pump Safety: Wet Wells**

- Confined spaces
- Corrosion of ladder rungs
- Explosive atmospheres
- Hydrogen sulfide accumulation
- Slippery surfaces
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 (72°C).

**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
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 snugly 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 6

Cross Connection Control
Outline

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

Backflow Case Study

Human Blood in the Water System

Blood observed in drinking fountains at a funeral home

Hydraulic aspirator used to drain body fluids during embalming

Contamination caused by low water pressure while aspirator was in use

Kool-Aid Laced with Chlordane

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

During a new water meter installation chlordane was backsiphoned into water lines and became mixed with Kool-Aid

A dozen children and three adults became sick

Propane Gas in the Water Mains

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

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

Hundreds evacuated, two homes caught fire, water supply contaminated

EPA Study

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

459 incidents resulted in 12,093 illnesses

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

- Federal
  - Federal Safe Drinking Water Act
- State
  - Tennessee Safe Drinking Water Act
  - Statute
  - Regulation
- Local
  - Ordinance (City) or Policy (Utility)
  - Plumbing Code
  - Cross Connection Control Plan

Hydraulics and Pressure

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

Head Pressure

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

```
27 3/4” = 2.31 Feet of Head
```

Normal Flow

```
50 psi
45 psi
```

No Flow

```
50 psi
48 psi
```

Normal Flow

```
100 psi
85 psi
```
Reverse Flow - Backflow

- The undesirable reversal of flow of water or other substances into the potable water distribution supply

- Occurs due to:
  - Backpressure
  - Backsiphonage

Backpressure

- Pressure in downstream piping greater than supply pressure

- Backsiphonage

- Sub-atmospheric pressure in the water system

What is drawn into the water pipes if backsiphonage occurs?

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

What is drawn into the water pipes if backsiphonage occurs?

- Whatever is in the barrel...

Aspirator Effect

Backsiphonage may occur at this point

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

Cross-Connection

- An actual or potential connection between a potable water supply and any non-potable substance or source

- Cross-connection types:
  - Direct
  - Indirect

Direct Cross-Connection

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

Indirect Cross-Connection

- An indirect cross-connection is subject to backsiphonage only
### Indirect Cross Connection

- Submerged Inlet
- Low Inlet

### Low Inlet

**Direct Cross Connection?**

**Yes**

**No**

### Degree of Hazard

<table>
<thead>
<tr>
<th>Non-Health Hazard</th>
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</thead>
<tbody>
<tr>
<td>Low hazard</td>
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<tr>
<td>Will not cause illness or death</td>
</tr>
<tr>
<td><strong>Pollutant</strong></td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Health Hazard</th>
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</thead>
<tbody>
<tr>
<td>High hazard</td>
</tr>
<tr>
<td>Causes illness or death</td>
</tr>
<tr>
<td><strong>Contaminant</strong></td>
</tr>
</tbody>
</table>

### The Backflow Incident

For backflow to occur three conditions must be met:

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

### Five Means of Preventing Backflow

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

### Air Gap

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

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

Approved Air Gap Separation

Backflow Protection Against:
- Backsiphonage
- Backpressure
- Contaminant (health hazard)
- Pollutant (non-health hazard)

Reduced Pressure Principle Assembly

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

Air Gap Separation Limitations

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

Reduced Pressure Principle Assembly

**Normal Flow**
The two check valves loaded in the closed position mechanically keep the water flowing in one direction through the assembly.

The relief valve assembly is designed to maintain a lower pressure in the zone between the two checks than in the supply side of the unit which hydraulically keeps the water flowing in one direction through the assembly.

Water always flows from high pressure to low pressure.

Backflow Protection Against:
- Backsiphonage
- Backpressure
- Contaminant (health hazard)
- Pollutant (non-health hazard)

Double Check Valve Assembly (DC)

The double check valve backflow prevention assembly (DC) consists of two independently operating check valves installed between two tightly closing resilient seated shut-off valves and fitted with four properly located test cocks.

Similar to the RP, but has no relief port so it cannot maintain a lower pressure in the zone between the checks and nowhere for the water to go during a backflow incident or failure.

Since the water in a DC cannot leave the system during a backflow event or assembly failure then it is a higher risk and therefore cannot be used in a high hazard (contaminant) application.

If one check fails the other will continue to protect, but given enough time the second check will fail and backflow will occur.

Second check fouled during backpressure.

Backflow Protection Against:
- Backsiphonage
- Backpressure
- Pollutant only
Proper Installation for DC and RP

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


Proper Installation for DC and RP

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

Pressure Vacuum Breaker (PVB)

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

Pressure Vacuum Breaker (PVB)

- Incoming water pressure will compress the spring on the check and flow into the body
- As pressure builds up in the body it will compress the spring on the air valve and close it allowing water to travel downstream

Pressure Vacuum Breaker (PVB)

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

PVB Backsiphonage Condition
Installation of PVB

- PVB is not designed to protect against backpressure and cannot have any source of backpressure (including head pressure) downstream of the device
- Needs to be installed **12 inches** above the highest point downstream

Pressure Vacuum Breaker

- Acceptable installation not subject to backpressure

Pressure Vacuum Breaker

- Improper installation subject to backpressure

Pressure Vacuum Breaker

**Backflow Protection Against:**
- Backsiphonage Only
- Contaminant (health hazard)
- Pollutant (non-health hazard)
- Elevation - at least 12” above downstream piping

Atmospheric Vacuum Breaker (AVB)

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

- During a backsiphonage condition the float drops by gravity due to the loss of incoming pressure which automatically opens the air inlet, introducing air into the system to break any siphon that has formed.

Installation of AVB

- AVB is not designed to protect against backpressure and cannot have any source of backpressure (including head pressure) downstream of the device.
- Needs to be installed **6 inches** above the highest point downstream.

Atmospheric Vacuum Breaker

- Acceptable installation not subject to backpressure.

Chemicals

Aspirator

To Irrigation

Not acceptable in TN – all irrigation systems must be protected by an RP.

Atmospheric Vacuum Breaker

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

Atmospheric Vacuum Breaker

**Backflow Protection Against:**
- Backsiphonage Only
- Contaminant (health hazard)
- Pollutant (non-health hazard)
- Elevation - at least 6”
- Non-Continuous Use

<table>
<thead>
<tr>
<th>Health Hazard</th>
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<th>Direct</th>
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<tr>
<td></td>
<td>Continuous Use</td>
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<td>Non – Health Hazard</td>
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<td>DC</td>
<td>DC</td>
</tr>
<tr>
<td></td>
<td>PVB</td>
<td>PVB</td>
</tr>
</tbody>
</table>

Cross Connection Control
Testing of Assemblies

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

Cross Connection Control

The ultimate goal of cross connection control is to protect the public drinking water supply
**Vocabulary**

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

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

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

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

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

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

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

**Bypass** - Any arrangement of pipes, plumbing or hoses designed to divert the flow around an installed device through which the flow normally passes.
**Chemical** - A substance obtained by a chemical process or used for producing a chemical reaction.

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

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

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

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

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

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

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

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

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

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

**Indirect Connection** - Any arrangement of pipes, fixtures or devices that indirectly connects a potable water supply to a nonpotable source; for example, submerged inlet to a tank.
Isolation (policy) - To confine a potential source of contamination to the nonpotable system being served; for example, to install a backflow prevention device on a laboratory faucet.

Liability - Obligated by law.

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

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

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

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

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

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

Pollution - Contamination, generally with man-made waste.

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

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

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

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

Refusal of Service (Shutdown Policy) - A formal policy adopted by a governing board to enable a utility to refuse or discontinue service where a known hazard exists and corrective measures are not undertaken.
Regulating Agency - Any local, state or federal authority given the power to issue rules or regulations having the force of law for the purpose of providing uniformity in details and procedures.

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

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

Superior Pressure – See backpressure.

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

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

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

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

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

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

1. Air Gap
2. Atmospheric Vacuum Breaker
3. Auxiliary Supply
4. Backflow
5. Back Pressure
6. Backsiphonage
7. Check Valve
8. Cross Connection
9. Feed Water
10. Hose Bibb
11. Overflow Rim
12. Pressure Vacuum Breaker
13. Reduced Pressure Zone
14. RPBP

A. A valve designed to open in the direction of normal flow and close with the reversal of flow.
B. A hydraulic condition, caused by a difference in pressures, in which non-potable water or other fluids flow into a potable water system.
C. Reduced pressure backflow preventer.
D. In plumbing, the unobstructed vertical distance through the free atmosphere between the lowest opening from any pipe or outlet supplying water to a tank, plumbing fixture or other container, and the overflow rim of that container.
E. A backflow condition in which the pressure in the distribution system is less than atmospheric pressure.
F. A faucet to which a hose may be attached.
G. A mechanical device consisting of two independently operating, spring-loaded check valves with a reduced pressure zone between the check valves.
H. Any water source or system, other than potable water supply, that may be available in the building or premises.
I. Water that is added to a commercial or industrial system and subsequently used by the system, such as water that is fed to a boiler to produce steam.
J. A device designed to prevent backsiphonage, consisting of one or two independently operating spring-loaded check valves and an independently operating spring-loaded air-inlet valve.
K. A backflow condition in which a pump, elevated tank, boiler or other means results in a pressure greater than the supply pressure.
L. Any arrangement of pipes, fittings, fixtures or devices that connects a nonpotable water system.
M. The top edge of an open receptacle over which water will flow.
N. A mechanical device consisting of a float check valve and an air-inlet port designed to prevent backsiphonage.
Answers:
1. D
2. N
3. H
4. B
5. K
6. E
7. A
8. L
9. I
10. F
11. M
12. J
13. G
14. C
Section 7

Safety
SAFETY

ACCIDENT
• An accident is caused by either an unsafe act or an unsafe environment

GENERAL DUTY CLAUSE
Federal - 29 CFR 1903.1

• EMPLOYERS MUST:
  • Furnish a place of employment free of recognized hazards that are causing or are likely to cause death or serious physical harm to employees
  • Comply with occupational safety and health standards promulgated under the Williams-Steiger Occupational Safety and Health Act of 1970.

CONFINED SPACES

CONFINED SPACE CONDITIONS
• Defined as any space where BOTH of the following conditions exist at the same time:
  • existing ventilation is insufficient to remove dangerous air contamination and/or oxygen deficiency which may exist or develop
  • ready access/egress for the removal of a suddenly disabled employee (operator) is difficult due to the location and/or size of opening(s)
• Large enough and so configured that an employee can bodily enter and perform assigned work
• Limited or restricted means of entry or exit
• Not designed for continuous employee occupancy

CONFINED SPACE EXAMPLES
• Vaults
• Silos
• Inside filters
• Basins
• Storage tanks
• Pits
• Hoppers
Safety harness with lifeline, tripod, and winch
- Electrochemical sensors
- Ventilation blower with hose
- PPE
- Ladder
- Rope
- Breathing apparatus

Spaces that require permits
- Contains or has potential to contain hazardous atmosphere
- Contains material with potential to engulf and entrant
- Entrant could be trapped or asphyxiated

ATMOSPHERIC HAZARDS
- Need to have atmosphere monitored!!!
- Explosive or flammable air
- Toxic air
- Depletion or elimination of breathable oxygen

Hydrogen sulfide - H₂S
- Detected by the smell of rotten eggs
- Loss of ability to detect short exposures
- Not noticeable at high concentrations
- Exposures to 0.07% to 0.1% will cause acute poisoning and paralyze the respiratory center of the body
- At the above levels, death and/or rapid loss of consciousness occur

Methane gas - CH₄
- Product of waste decomposition
- Leaks in natural gas pipelines can saturate the soil
- Explosive at a concentration of 5%
- Spaces may contain concentrations above the Lower Explosive Limits (LEL) and still have oxygen above the 19.5% allowable
- Gasoline storage tanks, gas stations, petroleum product pipelines, accidental spills by traffic accidents
CARBON MONOXIDE - CO
- Decreases amount of oxygen present
- ALWAYS VENTILATE
- 0.15% (1500 ppm) = DEATH
- Will cause headaches at 0.02% in a two hour period
- Maximum amount of 0.04% in 60 minute period
- Colorless, odorless, tasteless, flammable and poisonous

OXYGEN - O₂
- ALWAYS ventilate - normal air contains ~ 21%
- Oxygen deficient atmosphere if less than 19.5%
- Oxygen enriched at greater than 23.5%
  - Speeds combustion
- Leave area if oxygen concentrations approach 22%
- At 8%, you will be dead in 6 minutes
- At 6%, coma in 40 seconds and then you die

OXYGEN - O₂
- When O₂ levels drop below 16%, a person experiences
  - Rapid fatigue
  - Inability to think clearly
  - Poor coordination
  - Difficulty breathing
  - Ringing in the ears
  - Also, a false sense of well-being may develop

ATMOSPHERIC ALARM UNITS
- Should continuously sample the atmosphere of the area
- Test atmospheres before entering
- Test for oxygen first
- Combustible gases second

ATMOSPHERIC ALARM UNITS
- Alarms set to read flammable gasses exceeding 10% of the lower explosive limit
  - H₂S exceeds 10 ppm and/or O₂ percentage drops below 19.5%
- Calibrate unit before using
- Most desirable units simultaneously sample, analyze, and alarm all 3 atmospheric conditions
REQUIRED TRAINING
- Employer shall train all employees on hazards, procedures, and skills to perform their jobs safely
- Employees trained before first assigned duty
- Employer shall certify training of employees
- Maintain individual training records of employees

RECORD KEEPING
- Identification and evaluation of all hazardous areas in workplace
- Entrance permits filed
- Training certification
- Written confined space program

GENERAL REQUIREMENTS
- Identify, evaluate, and monitor hazards in permit-required confined spaces
- Post signs “Permit Required”
- Prevent unauthorized entries
- Re-evaluate areas
- Inform contractors
- Have a written program available for employees
- Have proper PPE
- Annual training (OSHA requirement)

CONFINED SPACE REQUIREMENTS
- All electrodes removed and machines disconnected from power sources
- Gas supply shut off
- Gas cylinders outside of work area
- All employees entering must undergo confined space training
- Ventilation used to keep toxic fumes, gasses, and dusts below max levels

ELECTRICAL SAFETY
OSHA says:
- Any electrical installations shall be done by a professionally trained electrician
- Any employee who is in a work area where there is a danger of electric shock shall be trained
- Employees working on electrical machinery shall be trained in lockout/tagout procedures
**Transformer**

- Allows energy to be transferred in an AC system for one circuit to another
- 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

**Fire Protection**

**Equipment**

- Fire extinguishers shall be located where they are readily accessible
- Shall be fully charged and operable at all times
- All fire fighting equipment is to be inspected at least annually

**Types of Fire Extinguishers**

- **Class A**
  - Used on combustible materials such as wood, paper or trash
  - Can be water based

- **Class B**
  - Used in areas where there is a presence of a flammable or combustible liquid
  - Shall not be water based
  - Example is dry chemical extinguisher
  - An existing system can be used but not refilled

- **Class C**
  - Use for areas electrical
  - Best is carbon dioxide extinguisher
  - Using water to extinguish a class C fire risks electrical shock

- **Class D**
  - Used in areas with combustible metal hazards
  - Dry powder type
  - Use no other type for this fire
FIRE EXTINGUISHERS
Types of Fire Extinguishers

<table>
<thead>
<tr>
<th>Class</th>
<th>Material</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Wood, paper</td>
<td>Water</td>
</tr>
<tr>
<td>B</td>
<td>Flammable liquids (oil, grease, paint)</td>
<td>Carbon dioxide, foam, dry chemical, Halon</td>
</tr>
<tr>
<td>C</td>
<td>Live electricity</td>
<td>Carbon dioxide, dry chemical, Halon</td>
</tr>
<tr>
<td>D</td>
<td>Metals</td>
<td>Carbon dioxide</td>
</tr>
</tbody>
</table>

• Combination ABC are most common
• Have the types of extinguishers available depending upon analyses performed in each area.

To operate a fire extinguisher, remember the word PASS

- Pull the pin. Hold the extinguisher with the nozzle pointing away from you.
- Aim low. Point the extinguisher at the base of the fire.
- Squeeze the lever slowly and evenly.
- Sweep the nozzle from side-to-side.

Gloves
Coveralls/overalls
Face shield/goggles
Respirator/SCBA
Boots
Ear plugs/muffs

“Right to Know”
- In 1983, OSHA instituted Hazard Communication Standard 1910-1200, a rule that gives employees the right to know the hazards of chemicals to which they may be exposed in the workplace.

CHEMICAL SAFETY
**NFPA**
- National Fire Protection Association
- Chemical hazard label
  - Color coded
  - Numerical system
  - Health
  - Flammability
  - Reactivity
  - Special precautions
- Labels are required on all chemicals in the lab

**CHEMICAL HAZARD LABEL**
- Degrees of Hazard
  - Each of the colored areas has a number in it regarding the degree of hazard
    - 4 \(\rightarrow\) extreme
    - 3 \(\rightarrow\) serious
    - 2 \(\rightarrow\) moderate
    - 1 \(\rightarrow\) slight
    - 0 \(\rightarrow\) minimal

**Osha Pictograms**

**WORKPLACE LABELING**
- Can HMIS or NFPA system be used?
  - While, the hazard category does not appear on the label, consider
    - GHS
      - Hazard Category
        - 1: highest
        - 2: high
        - 3: medium
        - 4: low
    - NFPA categories were intended for emergency response, not workplace hazards; only considers acute effects, does not consider chronic effects
**TERMS**
- Lower Explosive Level (LEL)
  - minimum concentration of flammable gas or vapor in air that supports combustion
- Upper Explosive Level (UEL)
  - maximum concentration of flammable gas or vapor in air that will support combustion
- Teratogen
  - causes structural abnormality following fetal exposure during pregnancy
- Mutagen
  - capable of altering a cell's genetic makeup

**CHLORINE GAS - Cl₂**
- 2.5 times as dense as air
- Liquid expands easily into gas at room temperature 460 times
- Pungent, noxious odor
- Greenish-yellow color
- Toxic by inhalation, ingestion and through skin contact
- May irritate or burn skin

**CHLORINE SAFETY**
Safety Precautions for Chlorine Gas
- Compressed air
  - 30 minute capacity
- Annually inspected
- Trained/fit tested
- PPE
  - Rubber gloves
  - Apron
  - Goggles
  - Safety shower, eyewash

**CHLORINE & HYPOCHLORITE SAFETY**

**CHLORINE SAFETY**
Where Chlorine Gas Is Used:
- Separate room for chlorine, with window to view inside
- Ventilation provided for one complete air change per minute
- Air outlet located near the floor
- Air inlet near the ceiling
- Temperature controlled room, 60°F
- Switches for lights and fans located outside of room, crash-bar on door inside of chlorine room
- Vents from feeders and storage shall discharge to the outside atmosphere, above grade
CHLORINE SAFETY
Where Chlorine Gas Is Used (cont’d):
• Must have a chlorine gas detection device connected to an alarm that can be heard throughout the treatment plant
• All gaseous feed chlorine installations shall be equipped with appropriate leak repair kits
• A fusible plug, designed to melt at 158° to 165°F (70-74°C), is located in the valve on a 150-lb cylinder and on the head of a ton container
  • It is designed to relieve pressure in the cylinder or container when exposed to high heat
• Leak detection - an ammonia solution produces white “smoke” in the presence of chlorine
  • A sensor type leak detector is the best means of detecting small leaks, less than 1ppm

CHLORINE GAS CONTAINERS
• 3 types of Containers
  • 150 lb cylinder - Emergency repair kit A
  • Ton cylinder - Emergency repair kit B
  • Railroad cars - Emergency repair kit C

CHLORINE SAFETY
Calcium Hypochlorite (HTH)
• Dry, white or yellow granular material
• Strong oxidizer
• Reacts with organics and can start fires
• Gives off lots of heat when mixed with water
• Will give off chlorine gas when it reacts
• Always add HTH to water when mixing
  • NEVER add water to HTH!!

CHLORINE SAFETY
Calcium Hypochlorite (HTH)
• Granular HTH is safer to work with than tablet or liquid form
• HTH should be stored in a cool dry place away from acids, reducing agents, paints, oils, and grease
• Use a carbon dioxide extinguisher to put out fires started by HTH

CHLORINE SAFETY
Calcium Hypochlorite (HTH) – PPE
• Eye protection, protective clothing
• Rubber gloves
  • It will react with leather
• Rubber boots
  • It will react with leather
• SCBA

CHLORINE SAFETY
Calcium Hypochlorite (HTH) – PPE
• Eye protection, protective clothing
• Rubber gloves
  • It will react with leather
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• SCBA
Section 8

Laboratory
Water Quality

Degradation
- Treated water is disinfected, not sterilized
- Disinfection kills or inactivates harmful organisms (pathogens)
- Organisms can grow in distribution system if conditions are right
- To prevent growth of organisms
  - Keep chlorine residuals up
  - Keep excess nutrients out
  - Prevent stagnation
  - Prevent cross-connections

Analysis
- The first step in water quality analysis is collecting samples which accurately represent the water
  - Representative sample
    - sample which contains basically the same constituents as the body of water from which it was taken
  - Improper sampling is one of the most common causes of error in water quality
  - All chemical analysis must be kept for 10 years

Sampling
Types of Samples
- Grab sample
  - Single volume of water
  - Representative of water quality at exact time and place of sampling
  - Coliform bacteria, residual chlorine, temperature, pH, dissolved gases
- Composite samples
  - Representative of average water quality of location over a period of time
  - Series of grab samples mixed together
  - Determines average concentration
  - Not suitable for all tests

Sample Volume and Storage
- Volume depends on test requirements
- Use proper sampling container
- Follow recommended holding times and preservation methods
  - If bottle already has preservative or dechlorinator in it, don't over fill or rinse out
- If you have questions regarding volume, container or holding times, check Standard Methods or contact the lab if you have an outside lab do you analysis
**Sampling**

Sample Labeling
- Specific location (address)
- Date and time sampled
- Chlorine residual
- pH and temperature
- Sample type
- Name or initials of person taking sample

**Sampling**

Selecting Sampling Points
- Raw-water supply
- Treatment plant
- Distribution system

**Sampling**

Raw-water Sampling Points
- Install valve or sample cock on raw-water transmission lines or well discharge pipe

**Sampling**

Treatment Plant Sampling Points
- Sampling from various points helps determine efficiency of processes
- Sample at every point where a change in water quality is expected
- Finished water sample point usually at point of discharge from clearwell

**Sampling**

Distribution Sampling Points
- Distribution sampling is the best indicator of system water quality
- Water quality changes in the distribution system:
  - Corrosion
  - Increase in color, turbidity, taste and odor
  - Microbiological growth
  - Slime
  - Cross-connections

**Sampling**

Distribution Samples
- Determine water quality at customers' taps
- Most common tests are chlorine residual and coliform bacteria
- Number of samples depends on population served or water source
Sampling
Monthly Distribution System Bacteriological Samples
- Samples should never be taken from a hydrant or hose
- Only collect samples from approved faucets
- Don’t collect samples from swivel faucets
- Only use cold water tap
- Front yard faucets on homes with short service lines

Collection of Samples
- Only approved containers should be used
  - 125 mL volume
  - Pre-sterilized bottles recommended
  - Other bottles sterilized at 121°C for 15 min
  - Should contain sodium thiosulfate

Collection of Samples
- Disinfect faucet with sodium hypochlorite
- Flush service line
- Adjust flow so that no splashing will occur

Collection of Samples
- Do not flame faucet with torch
  - Use alcohol or bleach solution to clean
- Turn on faucet to steady flow and flush service line (2-5 min) – getting water from the main line
- Fill bottle to proper level
- Label bottle with pertinent information
- Refrigerate to proper temperature, 4°C
- Test as soon as possible – within 30 hours

Collection of Samples
- Remove aerator or screen
- Collect sample from cold water tap
- Sample from homes with short service lines
  - same side of street as water main

Collection of Samples
- Do not touch inside of lid of sample bottle
- Do not set lid down or put it in your pocket
- Do not rinse bottle or allow it to overflow
Microbiological Indicator Organism
- Always present in contaminated water
- Always absent when no contamination
- Survives longer in water than other pathogens
- Is easily identified
- Water treatment indicator organism

Total Coliforms

EPA Approved Methods
- Multiple-Tube Fermentation
- Presence-Absence Test
- MMO-MUG
- Membrane Filter Method
- Enzyme (chromogenic/fluorogenic) Substrate Tests

Bacteriological Samples
- The MCL for coliform bacteria is based on presence or absence
- Finished and distributed water should be Zero (absent)

Bacteriological Testing
- Results must keep results for 5 years
- Must collect chlorine residual wherever a bac’t sample is collected
- Sample must be tested within 30 hours of sample collection (holding time)
- Sample must be incubated at 35 ±/−5°C for 24 hours
- Any sample that test positive for total coliform must be tested for E. coli

State Regulations
- 0400-45-1-.06(4) Microbiological
  - (a): If you collect 40 samples/month, no more than 5% can be positive to be in compliance
  - (a)2: If you collect less than 40 samples/month, no more than 1 sample can be positive to be in compliance
  - (c) If any routine or repeat sample test (+) for total coliform, it must be analyzed for fecal or E. coli

State Regulations
- 0400-45-1-.07(2) Repeat Monitoring
  - (a) If a routine sample is total coliform positive, the system must collect a set of repeat samples within 24 hours of being notified of the positive result. A system which collects one routine sample per month or fewer must collect no fewer than four repeat samples for each total coliform-positive sample found. The Department may extend the 24-hour limit on a case-by-case basis if the system has a problem in collecting the repeat samples within 24 hours that is beyond its control. In the case of an extension, the Department must specify how much time the system has to collect the repeat samples.
State Regulations

- **0.400-45(1-07)(a) Repeat Monitoring**
  - (b) The system must collect one at original site, at least one repeat within five service connections upstream and at least one repeat within five service connections downstream
  - (c) The system must collect all repeat samples on the same day and within 24 hours of being notified of a positive result, except that the Department may allow a system with a single service connection to collect the required set of repeat samples over a four consecutive day period or to collect a larger volume repeat sample(s) in one or more sample containers of any size, as long as the total volume collected is at least 400 ml (300 ml for systems which collect more than one routine sample per month.)

Testing

Membrane Filter Technique

- 100 mL sample is filtered through a membrane filter under a vacuum
- Filter placed on sterile Petri-dish containing M-Endo broth (food source for bacteria) for Total Coliforms
- Petri-dish labeled, turned upside down, placed in incubator at 35° +/− 0.5°C for 24 hours
- A coliform bacteria colony will grow at each point on filter where a viable bacterium was left during filtering
- The colonies will appear red with a green-gold metallic sheen

Chlorine Residual

- Free chlorine residual must be tested and recorded when bacteriological samples are collected
- Two most common tests:
  - Amperometric titration
  - less interferences as color and/or turbidity
  - DPD (N,N-diethyl-p-phenylenediamine)
- Analysis should be performed ASAP
- Exposure to sunlight or agitation of the sample will cause a reduction in the chlorine residual

Chlorine Free Residual

- DPD colorimetric method most commonly used
  - Match color sample to a standard
  - **Swirl sample for 20 seconds** to mix
  - Within one minute of adding reagent, place it into colorimeter
  - Different than Total Residual
  - Must maintain a free residual of 0.2 mg/L throughout entire distribution system
  - Chlorine residual must not be less than 0.2 mg/L in more that 5% of samples each month for any two consecutive months

pH

- Power of hydrogen
  - Measurement of the hydrogen concentration
  - Each decrease in pH unit equals 10x increase in acid
  - Indicates the intensity of its acidity or basicity
  - Scale runs from 0 to 14, with 7 being neutral
  - pH probe measures millivolts, then converts into pH units
  - Temperature affects millivolts generated, therefore you need a temperature probe as well for corrections

pH

- Calibrate daily with fresh buffers
  - Use at least two buffers
  - Gel filled probes are not recommended for water industry
  - Water is too clean for probe to make an accurate measurement
  - Store probe in slightly acidic solution
  - Replace probes yearly
Fluoride

- Added to drinking water for the reduction of dental caries (cavities)
- Interferences
- Primary MCL = 4.0 mg/L
- Secondary MCL = 2.0 mg/L
- State of Tennessee recommends 0.7 mg/L
- Fluoridation of drinking water in the state of Tennessee is not required

Turbidity

- Physical cloudiness of water
  - Due to suspended silt, finely divided organic and inorganic matter, and algae
  - Nephelometric method measures scattered light
  - unit - NTU
  - SDWA stipulates monitoring requirements

Turbidity

- Measure samples ASAP
- Keep sample tubes clean and scratch free
- Gently mix samples prior to reading
- Calibrate meter at least quarterly
- Records must be kept until next sanitary survey

Fluoride

- Methods
  - SPADNS
    - interferences are more common with this test
  - alum or aluminum complexes can interfere
- Electrode
  - TISAB removes most of the aluminum interferences
  - Total Ionic Strength Adjustment Buffer
  - Contains CDTA – used to tie up interferences
  - store probe in a standard, the higher the better
  - probes can last 3-5 years
  - can clean with toothpaste

Turbidity

- Measure samples ASAP
- Keep sample tubes clean and scratch free
- Gently mix samples prior to reading
- Calibrate meter at least quarterly
- Records must be kept until next sanitary survey
Alkalinity
- Capacity of water to neutralize acids
- Due to presence of hydroxides, carbonates, and bicarbonates
- Many water treatment chemicals (alum, chlorine, lime) alter water quality
- Titration using H₂SO₄ to pH endpoint or color change of indicator

Hardness
- Mainly due to calcium and magnesium ions in solution
- Can cause scale when water evaporates or when heated in water heaters and pipes
- Test involves titration with 0.02 N EDTA standard from a red to a blue endpoint
- Precautions
  - Metal ions may interfere, so an inhibitor may be needed
  - Measured as CaCO₃ in mg/L

Iron and Manganese
- Can precipitate out in distribution system
- Elevated levels in water can cause staining of plumbing fixtures and laundry
- sMCL for iron is 0.3 mg/L
- sMCL for manganese is 0.05 mg/L

Lead and Copper Rule
- Established by EPA in 1991
- All community and non-community water systems must monitor for lead and copper at customers’ taps
- If aggressive water is dissolving these metals, system must take action to reduce corrosivity
  - Samples must be taken at high risk locations
  - Homes with lead service lines
  - Water must sit in lines for at least 6 hours
  - First draw
  - One liter of sample collected from cold water tap in kitchen or bathroom
  - Test results must be maintained for 12 years

Lead and Copper Rule
- Action levels
  - Lead - 0.015 mg/L
  - Copper - 1.3 mg/L
- If action level is exceeded in more than 10% of samples, steps must be taken to control corrosion
  - Corrosion control program
  - Source water treatment
  - Public Education
  - and/or Lead service line replacement

Phosphates
- Orthophosphates work well for lead and copper protection
- Polyphosphates work as sequestering agents – tie up iron and manganese to prevent color and taste complaints
  - Tie up calcium carbonate as a catalyst
  - Calcium (from alkalinity) is required as a catalyst
  - If low alkalinity, need a blend of polyphosphate and orthophosphate
  - Orthophosphate coats pipe; polyphosphate sequesters
**THM**
- Trihalomethane
- Chloroform
- Dibromochloromethane
- Bromodichloromethane
- Tribromomethane

- MCL = 0.080 mg/L

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**HAA5**
- Haloacetic acids
  - Monochloroacetic acid
  - Dichloroacetic acid
  - Trichloroacetic acid
  - Monobromoacetic acid
  - Dibromoacetic acid

- MCL = 0.060 mg/L

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**Cryptosporidium (Crypto)**
- Protozoan parasite
- Common in surface water
- Resistant to traditional disinfectants
- Can pass through filters
- Causes cryptosporidiosis
- Filtration and alternative disinfectants can remove and/or inactivate

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**Lab Safety**
- Read SDS for all chemicals used in lab
- Store chemicals properly
- Know where safety equipment is stored
- Never pour water into acid
- CPR and First Aid Training (TOSHA requirement)
- Clean chemical spills immediately
- Follow published lab procedures (Standard Methods)
- Read and become familiar with Safety SOP

---

**Lab Safety**
- Safety Data Sheets (SDS)
  - Keep on file for all chemicals purchased
  - According to the Americans with Disabilities Act of 1990, MSDS’s should be kept for a minimum of 30 years
  - Includes all information shown on chemical label and more

- Must be readily available for employee review at all times you are in the work place
  - The can’t be locked in an office or filing cabinet to which you don’t have access to
  - If they are on a computer, everyone must know how to access them
  - If you request to see an SDS for a product you use at work and your employer can’t show it to you, after one working day you have the right refuse to work with that product until you are shown the correct SDS
Lab Safety – Chemical Label

FLAMMABLE
1. Extremely flammable
2. Ignites when moderately heated
3. Must be protected from burns
4. Visible color

HEALTH
5. Lowest toxicity
6. Inhale vapor
7. Skin exposure
8. Ingestion

REACTION
9. May be explosive
10. Ignites on contact with water
11. May react with water
12. Inert

W
3
4
3
Total Coliform Action Flow Chart

Original Total Coliform Positive

≥ 2 Routine Samples/Month

3 Repeat Samples

≤ 1 Routine Samples/Month

4 Repeat Samples

Routine Sampling NEXT MONTH: 5

Repeat Sample Coliform Results

Total Coliform Absent

Stop

Original Sample FECAL NEGATIVE

>1 positive sample for PWSs taking < 40 samples/month

>5% positive samples for PWSs taking ≥ 40 samples/month

No

Contact Lab for 3 or 4 More Repeat Samples

Original Sample FECAL NEGATIVE

Yes

If State Requires Another Set of Samples

Acute MCL violation

Start Notification Process

Fecal or E. coli Present

Total Coliform Present (only)

Repeat Samples

Routine Sampling NEXT MONTH: regular monitoring schedule or at least 5

TDEC - Fleming Training Center

Section 8

Laboratory

133
Small Water Systems
Laboratory Practice Quiz

1. The MCL for total coliform bacteria is based on their ______________ .
   a. Concentration in mg/L
   b. Concentration in colonies per 100 mL
   c. Presence or absence
   d. All of the above
   e. None of the above

2. The sample volume to be used when running a membrane filter test for coliform bacteria is ______________ .
   a. 20 mL
   b. 40 mL
   c. 60 mL
   d. 80 mL
   e. 100 mL

3. Records of bacteriological analyses must be kept at least ______________ .
   a. Until the next sanitary survey
   b. Three years or until the next sanitary survey
   c. Five years
   d. Ten years
   e. Twelve years

4. Analysis of samples for determining bacteriological quality of the water must be started within ______________ hours of collection.
   a. 24
   b. 30
   c. 36
   d. 42
   e. 48

5. A bacteriological bottle contains a white powder which is placed in the bottle in order to ______________ .
   a. Keep the bottle clean
   b. Kill any bacteria present
   c. Remove any chlorine residual
   d. All of the above
   e. None of the above
6. Any sample that contains coliform bacteria is a ________________ sample.
   a. Grab 
   b. Negative 
   c. Positive 
   d. Representative 
   e. Routine 

7. Any sample that does not contain coliform bacteria is a ________________ sample.
   a. Grab 
   b. Negative 
   c. Positive 
   d. Representative 
   e. Routine 

8. For bacteriological sample to be useful, it must contain essentially the same constituents as the body of water from which it was taken. This type of sample is called a ________________ sample.
   a. Grab
   b. Flow-proportional time composite
   c. Representative
   d. Time composite

9. To remove any stagnant water from the customer’s service line, and to make certain that water from the distribution main is being sampled, flush the faucet for ________ minutes.
   a. 1 – 3 
   b. 2 – 5 
   c. 5 – 7 
   d. 7 – 9 
   e. 10 – 15 

10. Bottles for collecting samples for bacteriological analyses should ________________.
    a. Not be rinsed before use 
    b. Be rinsed before use 
    c. Be completely filled 
    d. All of the above 
    e. None of the above 

11. Bottles for collecting samples for bacteriological analyses contain ________________, which destroys any chorine residual in the sample.
    a. Sodium arsenite 
    b. Sodium chloride 
    c. Sodium fluoride 
    d. Sodium hydroxide 
    e. Sodium thiosulfate
12. Samples for bacteriological analysis should not be taken from _________________.
   a. Swivel faucets
   b. Leaking faucets
   c. Faucets with aerators, strainers or hose attachments
   d. All of the above
   e. None of the above

13. A sample which consists of a number of grab samples taken from the same
    sampling point at different times and mixed together before analysis is called a
    ________________ sample.
   a. Composite
   b. Grab
   c. Flow-proportional time composite
   d. Representative
   e. Time composite

15. High fluoride readings can result from all of the following causes except _________.
   a. Polyphosphates can interfere with the SPADNS method, resulting in high
      fluoride readings
   b. Not accounting for natural fluoride in the water
   c. Dilution of water which has been fluoridated with unfluoridated water in storage
      tanks
   d. All of the above
   e. None of the above

16. What is the secondary maximum contaminant level for fluoride?
   a. 0.2 mg/L
   b. 0.4 mg/L
   c. 2.0 mg/L
   d. 4.0 mg/L

17. The maximum permissible level of a contaminant in water as specified in the
    regulations of the Safe Drinking Water Act is the _________________.
   e. Maximum contaminant level
   f. Saturation point
   g. Zeta potential
   h. All of the above
   i. None of the above

18. ________________ is an indicator used when measuring the total alkalinity
    concentration on a water sample.
   j. EDTA
   k. Eriochrome black-T
   l. Brom cresol Green Methyl Red
   m. Phenolphthalein
   n. Sodium thiosulfate
4. B 10. A 16. A
6. C 12. D