Drinking Water Operator Certification Training

Module 5:
Disinfection

This course includes content developed by the Pennsylvania Department of Environmental Protection (Pa. DEP) in cooperation with the following contractors, subcontractors, or grantees:

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Unit 1 – Overview of Disinfection

Learning Objectives

- Explain the general purpose and regulatory requirements of the disinfection process.
- List bacteria, viruses and intestinal parasites that contaminate drinking water.
- List factors that influence disinfection and explain how they influence it.
- List five types of chemical disinfectants and explain the advantages and disadvantages of each.
- Explain how irradiation is used as a disinfection process.
- List eight pertinent drinking water regulations and explain the reason for each regulation and the impact of each.

General

Protect Public Health

Disinfection is the process designed to remove, kill or inactivate most microorganisms, including pathogenic bacteria, in a raw water supply.

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

Regulatory Requirements

Groundwater

⊙ A sanitary survey of all potential well sites is required to assure that the aquifer is protected against potential sources of contamination. This should include surface sources and subsurface sources, evaluation of the local geology, current land use and proximity to flood plains.

- A party desiring to obtain water from a well to be drilled is required to conduct a sanitary survey. The survey is performed thru desk top research, commonly using the internet, to define contaminated areas, locations of underground storage tanks and other potential sources of contamination. Subsequent field reviews and interviews are performed to further observe and identify potential pollutants of the source or well. Searches such as these are best performed by personnel trained in conducting these surveys.

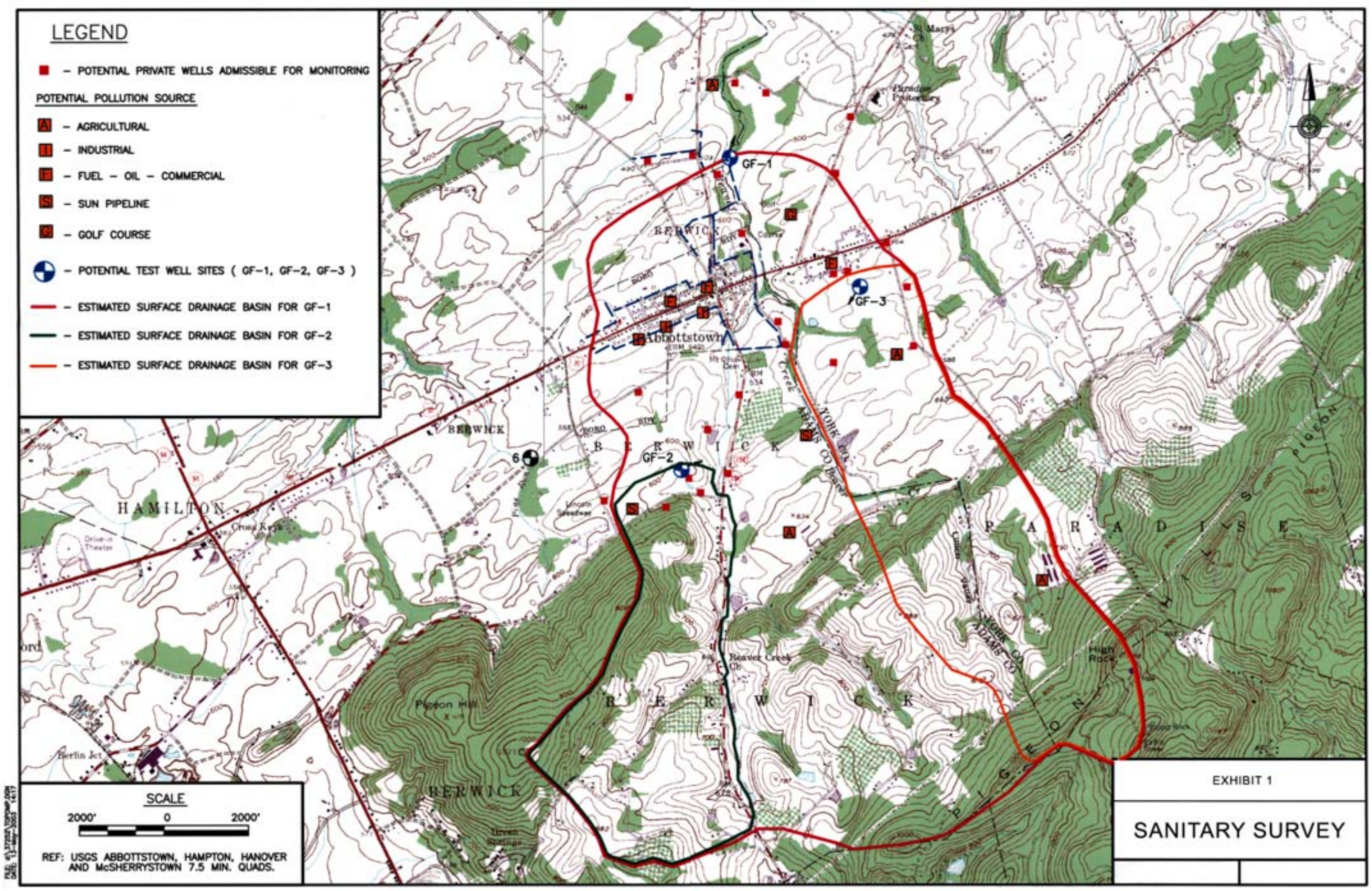


Figure 1.1 A Typical Presentation for a Sanitary Survey[1]

⊙ A wellhead protection program should be implemented to assure that adverse development does not take place in the proximity of the well, which can lead to future contamination. This is to be accomplished via ownership of surrounding property, or easements obtained from surrounding property owners. Figure 1.2 shows a well with the property delineated that falls under the wellhead protection plan.

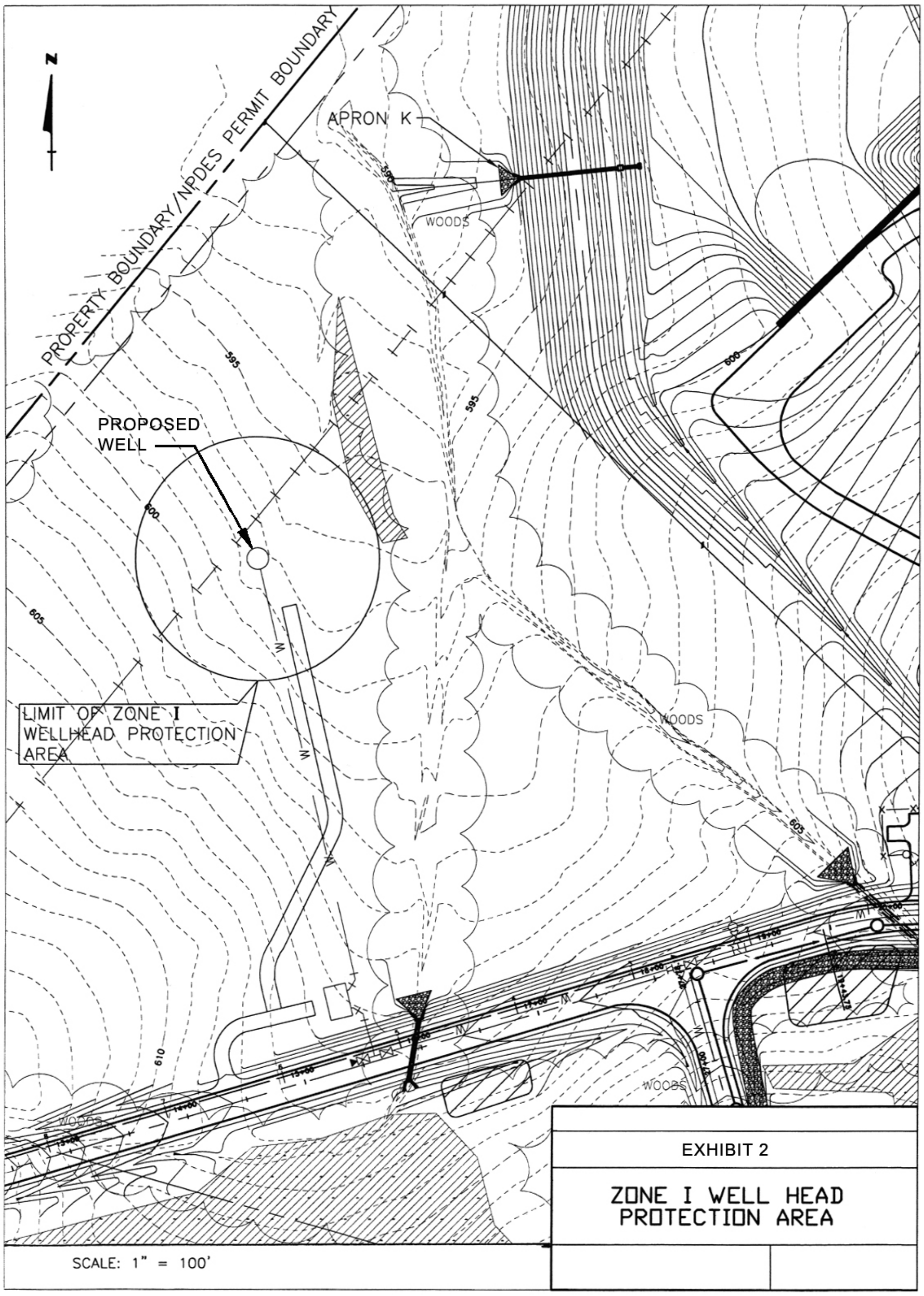


Figure1.2 Wellhead Protection Area[2]

⊙ Chemical treatment for well supplies as a minimum requires provision for disinfection.

⊙ For wells that are considered not to be under the influence of surface waters or requiring other forms of treatment, disinfection using chlorine or one of its compounds, followed by 20 minutes of detention time, is required.

⊙ Detention time is achieved by using a system that minimizes short-circuiting. For example, a baffled tank forces the water to flow through a circuitous route. The following figure shows a section through a tank of this type.

- Short circuiting occurs when the flow path of water thru a vessel takes a route that is shorter and takes less time than desired. To avoid short circuiting, baffles are introduced into the flow path to force the flow to take a longer route through a vessel. This will assure that the time of flow through the vessel is lengthened and in contact with the disinfectant longer to maximize treatment.

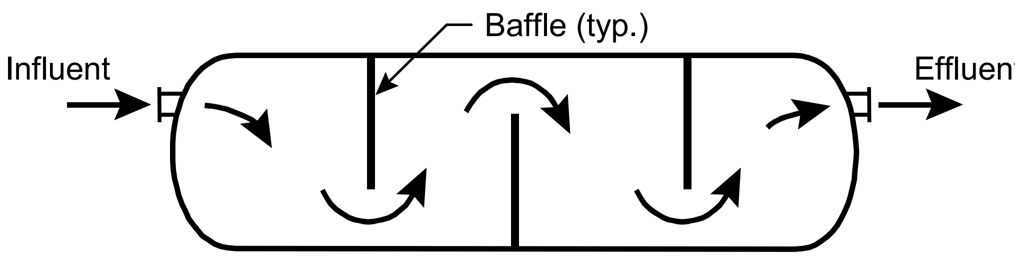


Figure 1.3 A Baffled Tank

Surface Water

Various forms of treatment may be required to clarify and disinfect surface waters.

⊙ Physical treatment of a raw water surface supply can remove pathogenic organisms. Some of these forms of treatment include filtration, ultraviolet rays (UV), heat and ultrasonic waves.

⊙ Chemical treatment includes coagulation followed by sedimentation, and treatment with oxidants such as chlorine and some of its compounds. Other chemicals such as iodine, bromine, sodium hydroxide and lime, as well as ozone are effective to varying degrees, but each has its drawbacks and is not commonly used as the primary disinfectant leaving a water treatment facility.

Various forms of microbiological contaminants may be found in raw water supplies. These include bacteria, viruses and intestinal parasites.

Bacteria

Common bacterial contaminants include the following:

- *Salmonella*, which causes Salmonellosis.
- *Shigella*, which causes Bacillary Dysentery.
- *Bacillus typhosus*, which causes Typhoid.
- *Salmonella paratyphi*, which causes Paratyphoid.
- *Vibrio cholerae*, which causes Cholera.
- *Escherichia coliform*

Viruses

Enteroviruses

Enteroviruses are a large family of viruses responsible for many infections in children such as viral meningitis, encephalitis and myelitis, among other illnesses. These viruses live in the intestinal tract, but can cause a wide variety of illnesses. Though more common in children, adults are also susceptible to these illnesses.

- There are more than 70 different strains, which include the group A and group B coxsackieviruses, the echoviruses, the polioviruses, hepatitis A virus and several strains that just go by the name enterovirus.
- These viruses can live for days at room temperature. Refrigerating and freezing do not inactivate them. They are, however, easy to kill with heat and with disinfectants.

Andenoviruses

Adenoviruses are very common viruses that can cause infections in children, such as tonsillitis, conjunctivitis, the common cold and other illnesses. Again, though more common in children, adults are also susceptible to these illnesses. There are over fifty subtypes of adenovirus.

- Adenoviruses most commonly cause upper respiratory tract infections, including the common cold, sore throats, tonsillitis, ear infections and conjunctivitis.
- Another common adenoviral infection is pharyngoconjunctival fever (sore throat, red eyes and a fever).
- Less commonly, adenoviruses cause croup, pertussis syndrome or bronchitis.
- Adenoviruses are a common cause of gastroenteritis. They can also cause urinary tract infections (UTI), including hemorrhagic cystitis, a UTI with blood in the urine.
- In rare cases, adenoviruses cause pneumonia, meningitis or encephalitis.

Reoviruses

Reoviruses are responsible for many common human diseases such as colds, flu, diarrhea, chicken pox, measles and mumps.

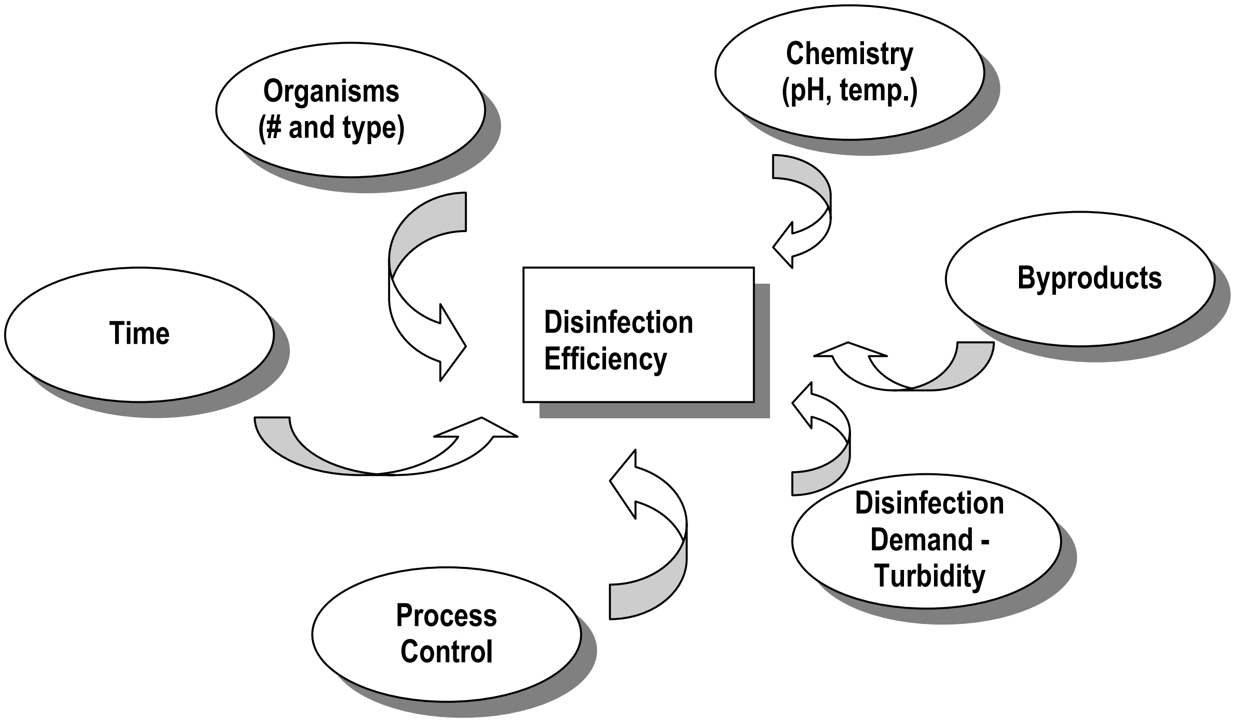
- Some viral diseases, such as rabies, hemorrhagic fevers, encephalitis, polio, yellow fever and acquired immunodeficiency syndrome (AIDS), can result in death.
- German measles and cytomegalovirus can cause serious abnormalities or death in unborn infants.

Intestinal Parasites

Common intestinal parasites include the following:

- *Entamoeba histolytica* (Amoebic Dysentery).
- *Giardial lamblia* (Giardiasis).
- *Ascaris lumbricoides* (Giant Roundworm).
- *Cryptosporidium* (Cryptosporidiosis).

Several factors will influence the disinfection of water supplies. These include the type and number of organism, the water chemistry, the disinfection byproducts, the disinfection demand, process control and time.



Organisms

The numbers and types of organisms could determine the type of disinfectant needed and the amount or dosage of that product.

In general, actual testing for these organisms is beyond the capability of the average lab. Testing is also time consuming and costly.

So, we use an indicator organism to determine the bacterial quality of the water.

Coliform bacteria make good indicator organisms because:

- They are always present when pathogens are present.
- The testing method for detection is easy and reliable.
- When they are absent, we can assume that pathogens are also absent.

Temperature

Disinfection of water with free chlorine will be more efficient at temperatures greater than 60°F than at temperatures less than 60°F.

- ⊙ Due to dissipation of chlorine into the atmosphere at warmer temperatures, it is important to monitor its residual throughout the disinfection process.

pH

Disinfection of water with free chlorine will be more efficient at values lower than 7.0 than at values greater than 7.0.

Disinfection Byproducts

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

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

Disinfection Demand

Demand is defined as anything in the source water that will react with the disinfectant and make it unavailable for disinfection. This includes turbidity, inorganics and organic material.

Process Control

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

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

Time

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

Chemical Disinfection

Gas Chlorine

Gas chlorine is the pure elemental form of the chemical chlorine when delivered to a water treatment plant site. Although it is in liquid form in the pressurized vessel, It is converted to the gas form by evaporation in the delivery container or through evaporators in the facility. Gas chlorine is the most common form of chlorine used in water treatment plants.

Advantages

- Gas chlorine is an effective disinfectant.
- It lowers the pH of water, making it more effective as a disinfectant.
- Gas chlorine is economical, stable, easy to use, and easy to apply.
- It is easy to monitor to determine whether there is a residual disinfectant in the distribution system.

Disadvantages

- Gas chlorine is an aggressive chemical that can corrode many materials it comes into contact with.
- It can react with organics in either the raw water or finished water to form trihalomethane and haloacetic acids, which are known carcinogenics.
- It requires special training to assure safe handling of the chemical and related equipment.
- If a facility stores over 2,500 pounds of gas chlorine, a risk management plan must be prepared.

Hypochlorite

Hypochlorite generally is a compound of chlorine and either sodium or calcium.

Advantages

- Hypochlorite is an effective disinfectant.
- It is safer to handle than gas chlorine.
- Hypochlorite is easy to use and apply and does not require special training for handling.
- It is easy to monitor to determine whether there is a residual disinfectant in the distribution system.

Disadvantages

- Hypochlorite solution is prone to degrade over time as chlorine vaporizes from solution, reducing its chlorine content, making it less effective and requiring a higher feed rate of the weaker product.
- It may increase the pH of water and is less effective than gas chlorine.
- It is an aggressive chemical that can corrode many materials it comes in contact with.
- Hypochlorite can react with organics in either the raw water or finished water to form trihalomethane and haloacetic acids, which are known carcinogenics.
- It can "off gas" in the feed system, resulting in operational problems.
- Hypochlorite can form chlorate, which may have adverse health impacts

Chlorine Dioxide

Chlorine dioxide is a powerful disinfectant. It is relatively unstable and must be generated on site via the reaction of chlorine with sodium chlorite. Quantities of the chemical can be stored, but only for short durations. The chemical does not react with organic compounds and therefore is a good substitute for gas chlorine when a preoxidant is required and there is a high potential to form trihalomethanes.

Advantages

- Chlorine dioxide is an effective disinfectant that has pathogen removal values comparable to that of gas chlorine but at lower doses.
- It is still effective at higher pH values.
- Chlorine dioxide will not react with organics in either the raw water or finished water to form trihalomethanes or haloacetic acids.

Disadvantages

- Chlorine dioxide is an unstable chemical requiring on site generation.
- It requires the reaction of gas chlorine and sodium chlorite.
- In addition to the disadvantages associated with gas chlorine, sodium chlorite is a very aggressive chemical with strong bleaching capabilities and can spontaneously ignite when in the dry form and if it comes in contact with organic materials.
- The production of chlorine dioxide can generate chlorate and chlorite which may have adverse health impacts. It is therefore not used as the final disinfectant leaving a water treatment plant.

Chloramines

Although quite stable, chloramines are substantially less powerful as a disinfectant than the other forms of chlorine. They are therefore not used as the primary disinfectant in treatment plants, but rather as maintenance treatment following primary disinfection.

Advantages

- ⊙ Although chloramines are a relatively weak disinfectant, they will maintain chlorine residual in the distribution system longer than free chlorine which is more prone to react with materials in the piping system.
- ⊙ They will reduce the potential for trihalomethane and haloacetic formation in the distribution system.

Disadvantages

- ⊙ Chloramines are not as effective as free chlorine at killing or inactivating pathogens.
- ⊙ They must be monitored to assure that the ammonia to chlorine feed ratio is properly maintained at the feed point to ensure the generation of only the monochloramine variety of chloramines. Inadequate feed rates can generate the dichloramine or trichloramine variety, which can create taste and odor in the finished water.

Ozone

Ozone gas is an extremely powerful oxidant. It is very unstable and used immediately after manufacture. Although very effective as a disinfectant, its instability precludes its use as the final disinfectant entering the distribution system.

Advantages

- ⊙ Ozone is the most effective disinfectant available of those commonly used in water treatment.
- ⊙ It is more effective in treating for *Cryptosporidium* than other chemical disinfectants.
- ⊙ Ozone will not generate trihalomethanes or haloacetic acid.

Disadvantages

- An ozone system is expensive to install and operate.
- Operating staff must become familiar with a relatively complex chemical feed system.
- Ozone is highly toxic and highly corrosive.
- It will not carry ozone residual into the distribution system, which means a second chlorine-based feed system is needed.

Irradiation

Ultra-violet Light

Ultra-violet is a band of non-visible light located between the purple end of the visible band, and x-rays. The waves are shorter than that of the visible spectrum, of higher frequency than the visible spectrum and higher energy than the visible spectrum. Light specifically in the wave lengths at and around 254 nanometers has been found to be readily absorbed by the cells of microorganisms causing damage to the genetic material. This damage, though not killing the microorganism, prevents it from reproducing itself. Eventually the cell dies without replicating itself.

Advantages

- The use of ultra-violet light is an effective disinfectant process that can reliably inactivate Cryptosporidium oocysts.
- It is more effective than ozone in treating for *Cryptosporidium.*
- It is easier and less costly to operate than an ozone system.
- It will not form trihalomethanes or haloacetic acids.

Disadvantages

- This type of system is expensive to install and operate.
- The system requires routine maintenance to assure efficient operation.
- It requires the use of a chlorine-based chemical system to assure that a disinfectant chemical residual is carried into the distribution system.
- Standards have not been developed for the use of ultra-violet light as a disinfectant for water treatment.

Chlorination

Europe – Historical Practices

- Hypochlorination was first practiced in England in the 1880s.[3]

- Gas chlorine was first used in England, too, but not until 1917. [4]

United States – Historical Practices

- Hypochlorination was first practiced in 1908 with the installation of a facility in Jersey City, New Jersey. This was followed by installations in Elmira, Poughkeepsie and Albany, New York.[5]

- Gas chlorine was first used in Niagara Falls, New York in 1912.[6]

Surface Water Treatment Rule

- The Surface Water Treatment Rule was published in June of 1989.
- This rule required all surface waters or ground waters under the influence of surface waters to provide filtration and/or disinfection of the source to meet 3 log removal or inactivation of *Giardia Lamblia* cysts and 4 log removal or inactivation of enteric viruses.

Information Collection Rule

- The Information Collection Rule was published in May of 1996.
- It required large public water suppliers to undertake monitoring of microbial and disinfection byproducts in their water systems.
- Some systems also conducted studies on the use of granular activated carbon and membrane processes in treating for these contaminants. The information was used to learn more about the occurrence of microbial contamination and disinfection by-products, the health risks posed, appropriate analytical methods and effective forms of treatment.

Interim Enhanced Surface Water Treatment Rule

- The Interim Enhanced Surface Water Treatment Rule was published in December of 1998.
- This rule primarily addresses the reduction of risk from *Cryptosporidium* by limiting the turbidity levels of filter effluents.

Stage 1 (US EPA) Disinfectants and Disinfection Byproducts (D-DBP) rule

- The Stage 1 Disinfectants and Disinfection Byproduct Rule, was published in December 1998.
- This rule set maximum contaminant level goals and maximum contaminant levels for trihalomethanes, five haleocetic acids, bromate and chlorite. These are byproducts of treatment of water with chlorine and are known carcinogenics.
- The rule also set maximum disinfectant residual level goals and maximum disinfectant residual levels.
- The rule also required the removal of trihalomethane precursors from the water supply to minimize reactions with chlorine and the potential formation of trihalomethane.

Long Term 1-Enhanced Surface Water Treatment Rule

- The Long Term 1-Enhanced Surface Water Treatment Rule was published in February of 2002.
- The rule requires all systems serving fewer than 10,000 people to achieve at least 99% removal or inactivation of *Cryptosporidium*.

Long Term 2-Enhanced Surface Water Treatment Rule

- The Long Term 2-Enhanced Surface Water Treatment Rule is scheduled to be published in the summer of 2003.
- This rule is anticipated to propose treatment techniques to improve control of microbial pathogens, specifically including C*ryptosporidium*. The purpose of the techniques is to consider the risks of treatment for C*ryptospodrium* versus the potential for generation of disinfection byproducts.

Stage 2-Disinfectants and Disinfection Byproduct Rule

- Its purpose is to assess information and research that was not fully considered in the Stage 1 process or that has only been available since 1998, as it relates to microbial standards to protect public health.

Ground Water

- The Ground Water Rule was proposed in May of 2000.
- When enacted, the rule provides guidelines for identifying ground water sources at risk for contamination and guidelines for taking corrective action.

Total Coliform Rule

- The Total Coliform Rule became effective in December of 1990.
- The rule sets monitoring and compliance requirements for coliform bacteria.

Exercise

1. List the common bacteria, viruses and intestinal parasites that contaminate drinking water.

2. List five types of chemical disinfectants.

3. Match the regulation from the following list with its appropriate description in the column on the right.

Information Collection Rule
Long Term 1-Enhanced Surface Water Treatment Rule
Ground Water
Stage 2-Disinfectant Byproduct Rule
Long Term 2-Enhanced Surface Water Treatment Rule
Interim Enhanced Surface Water Treatment Rule
Disinfection/Disinfection Byproduct Rule, Phase I
Total Coliform Rule
Surface Water Treatment Rule

Regulation	Purpose of Regulation
	This rule provides guidelines for identifying ground water sources at risk for contamination and guidelines for taking corrective action.
	This rule primarily addresses the reduction of risk from *Cryptosporidium* by limiting the turbidity levels of filter effluents.
	This rule requires all systems serving fewer than 10,000 people to achieve at least 99% removal or inactivation of *Cryptosporidium*.
	This rule sets the monitoring and compliance requirements for coliform bacteria.
	It required large public water suppliers to undertake monitoring of microbial and disinfection byproducts in their water systems.
	This rule set maximum contaminant level goals and maximum contaminant levels for trihalomethanes, five haleocetic acids, bromate and chlorite.
	This rule required all surface waters or ground waters under the influence of surface waters to provide filtration and/or disinfection of the source to meet 3 log removal or inactivation of *Giardia Lamblia* cysts and 4 log removal or inactivation of enteric viruses.
	This rule is anticipated to propose treatment techniques to improve control of microbial pathogens, specifically including C*ryptosporidium*. The techniques are to consider the risks of treatment for *Cryptospodrium* versus the potential for generation of disinfection byproducts.
	The purpose of this rule is to assess information and research that was not fully considered in the Stage 1 process or that has only been available since 1998, as it relates to microbial standards to protect public health.

Key Points

- Disinfection protects public health by rendering harmless or removing pathogenic microorganisms.
- Because of the importance to public health, the disinfection process has numerous regulatory requirements.
- Coliform is used as an indicator organism.
- The effectiveness of the disinfection process is influenced by many factors.
- Different disinfecting agents are available and their use depends on factors at each treatment system.

[1] Borough of Abbottstown, Adams County, Pennsylvania.

[2] Adams County Facilities Center, Straban Township, Adams County, Pennsylvania.

[3] Gerald F. Connell, *The Chlorination/Chloramination Handbook*, (American Water Works Association, 1996), p. 3.

[4] Connell, p. 4.

[5] *Manual of Instruction for Water Treatment Plant Operators*, prepared by New York State Department of Health, Office of Environmental Health Manpower, Division of Pure Water, Office of Public Health Education, p. 153.

[6] Connell, p. 4.

Unit 2 – The Disinfection Process

Learning Objectives

- Explain the importance of organic and inorganic oxidant demand.
- Define residual and explain why it is necessary to measure and monitor it.
- Identify and explain the points of application of the disinfection process.
- Identify chemical feed equipment used in the disinfection process.
- Identify ultra-violet equipment used in the disinfection process.
- Identify laboratory equipment used in monitoring the disinfection process.

Demand

The demand by inorganic and organic materials is referred to as the **chlorine demand**. It is the difference between the amount of chlorine applied to the water and the amount of free residual chlorine after a given contact time.

Free Chlorine residual is the amount of uncombined (free) chlorine remaining in the water after reactions with inorganic and organic material.

- This residual, plus the combined chlorine from other reactions that have slight disinfection capability, is the total residual available for maintaining the sanitary quality of the water.

Inorganic Demand

⊙ Inorganic reducing materials commonly found in raw water that take precedence in reacting with chlorine include ferrous iron and manganese.

Organic Demand

⊙ Organic compounds will react on a secondary level with available chlorine in the raw water and form chlororganic compounds.

- Some of these have slight disinfection capability; however, some have also been found to be carcinogenic and are the reason chlorination for disinfection is not provided for raw water at many water treatment plants.
- Some of these carcinogenics include Trihalomethanes such as chloroform, bromodichloromethane, dibromochloromethane and bromoform and haloacetic acids such as trichloroacetic acid and dichloroacetic acid.

Residual

Measurement
Measurement of chlorine residual may be accomplished through several methods, including iodometric, DPD colorimetric, amperometric titration and oxidation-reduction potential. The most common is the DPD Colorimetric method.

Iodometric

- This method uses a standard sodium thiosulfate solution to titrate the iodine liberated by the chlorine from potassium iodide. Starch, which is used as an indicator, gives a blue color with iodine.
- To ensure the measurement of chloramines, the titration is performed in an acidic solution.
- The method measures total residual chlorine.

DPD Colorimetric

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

Amperometric Titration

- This method uses a bi-metallic cell immersed in a solution containing the chlorine to be measured. The chlorine (an oxidizing agent) causes a current to flow, which is measured by a micro-ammeter.

- The titration is performed by adding a reducing agent (which reacts with the chlorine) to the solution and measuring the reduction in the current. The end point is reached when no further reduction in the current can be measured.

- A plate showing the sample flow through an automatic residual analyzer is shown below.

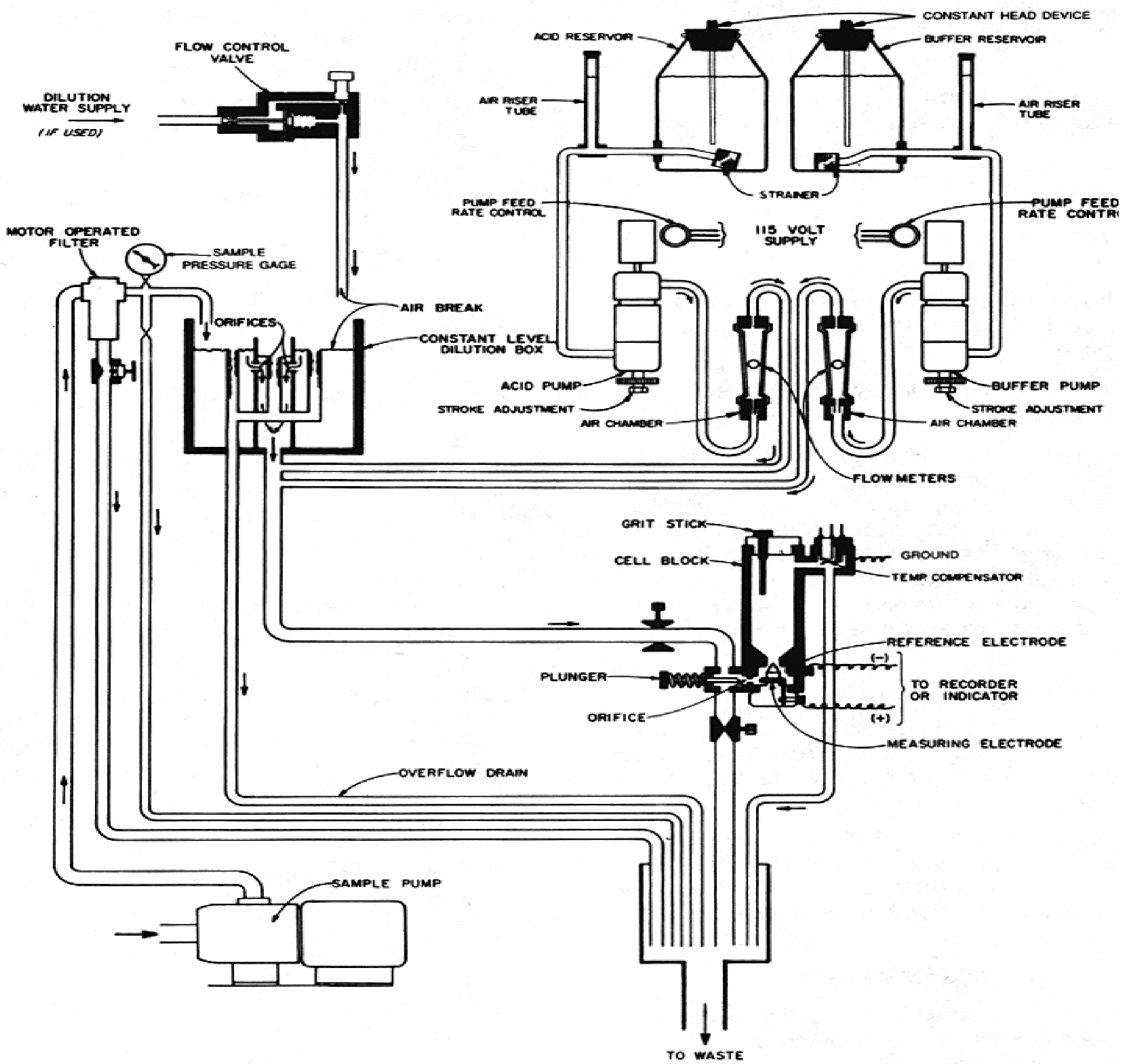


Figure 2.1 Chlorine Residual Analyzer[1]

Oxidation-Reduction Potential Meter (ORP)

- The ORP instrument monitors water for its oxidation potential. The measurement of the oxidation potential is related to the chlorine residual in the water since chlorine is an oxidant.

Monitoring

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

Table 2.1 Microbial Standards[2]

Contaminant	Maximum Contaminant Level (MCL)	Monitoring Requirement – Surface Only or Combination	Check Sampling, Reporting and Public Notice
TOTAL COLIFORM	<40 samples/month, no more than 1 positive ≥40 samples/month, no more than 5% positive.	Compliance is based on the presence or absence of total coliforms. All coliform positives must be tested for presence of fecal coliform or *E.coli*. The total number of samples is based on the population served.	Repeat samples are required for each coliform-positive sample. All samples must be collected the same day. At least one sample from same tap as original, another from an up-stream connection, and one from downstream. All coliform positives must be tested for presence of fecal coliform or *E.coli*. If repeat sample is fecal coliform positive or if the original fecal coliform or *E.coli* positive is followed by a total coliform positive, the state must be notified on the same business day.
GIARDIA LAMBLIA	3-Log (99.9%) removal or inactivation.	Based on calculated residual disinfectant CT values.	Failure to meet total percent inactivation on more than two days in a month is a violation. State must be notified within one business day when disinfectant residual is less than 0.2 mg/L.
VIRUSES	4-Log (99.99%) removal or inactivation		If residual is less than 0.2 mg/L, then sampling must be every 4 hours until residual is restored.

Ground Water

Spring House Intakes

- Spring house intakes are to be protected from physical forms of contamination such as surface waters, animals and airborne contaminants.

- Those that can remain contaminant free, and do not require treatment for other constituents, need only be disinfected.

- Disinfection consists of an application of chlorine prior to 20 minutes of detention time through a well-baffled facility. The residual of chlorine leaving the detention facility must be 0.2 mg/L or more prior to entering the distribution system.

Well Pump Discharge

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

- As with springs, the treatment consists of an application of chlorine, followed by 20 minutes of detention time through a well-baffled facility. The residual of chlorine leaving the detention facility must be 0.2 mg/L or more prior to entering the distribution system.

Surface Water

Pretreatment

Raw Water

- In the past, raw water was treated with an oxidant, generally chlorine, for both disinfection of the raw water and oxidation of its constituents.

- Due to the high levels of turbidity and other oxidant demands in the raw water supply, the disinfection process is not very efficient.

- Potential formation of trihalomethanes and haleocetic acids in some of the raw water supplies has limited chlorination or oxidation of the raw water supply to chemicals such as chlorine dioxide, potassium permanganate and in some more recent cases, ozone.

Mixed Water

- As with raw water, mixed water still may have agglomerated materials, and disinfection in this portion of a water treatment plant process is still not very efficient. However, with the removal of suspended solids, as flocculated particles settle, the reaction of the disinfectant becomes more efficient.

Filter Influent

- Filter influent in a water treatment plant having sedimentation as part of the process generally consists of settled water having turbidity levels of two or less.
  - At these levels of turbidity, the disinfection process becomes more efficient, having fewer particles for pathogens to be shielded by, and few, if any, other dissolved solids to react with.
  - The disinfectant is also considered an aid in the filtration process due to its ability to improve particle removal and filter run time. Filter run time is the time that a filter has been in continuous service since its last backwash.

Post Treatment

Filter Effluent

- Filter effluent is essentially water that is considered of potable quality requiring proper disinfection prior to usage.

- In general, for compliance with EPA/DEP requirements for contact time (CT), the disinfection process begins at this point with the dosage of a disinfectant.

Clearwell Influent

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

Clearwell Effluent

- Clearwell effluent is monitored for chlorine residual.

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

Plant Effluent

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

Chemical Feed Equipment

Gas Regulators

- Gas regulators are provided in chlorine gas feed lines to maintain pressure in the supply line.

- The current practice is to design supply facilities that actually provide the gas into the supply line under negative pressure directly from a connection to the chlorine storage facility. In the event of a loss of vacuum on the downstream side of the regulator, the device closes. This assures that failure of equipment downstream of the regulator resulting in loss of vacuum will not result in a release of chlorine gas since the gas flow will stop.

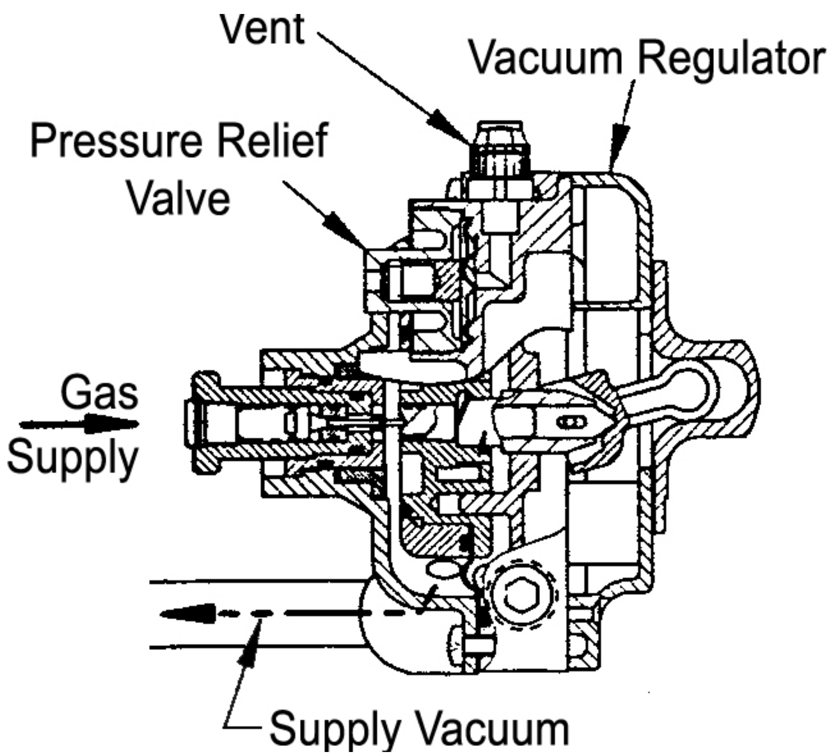


Figure 2.2 A Typical Gas Regulator[3]

Chlorinator

- The chlorinator meters the flow of gas.
- The chlorinator can be fitted with auxiliary equipment to allow for the automated control of chlorine to either match flow variations in a system, or maintain a set residual.

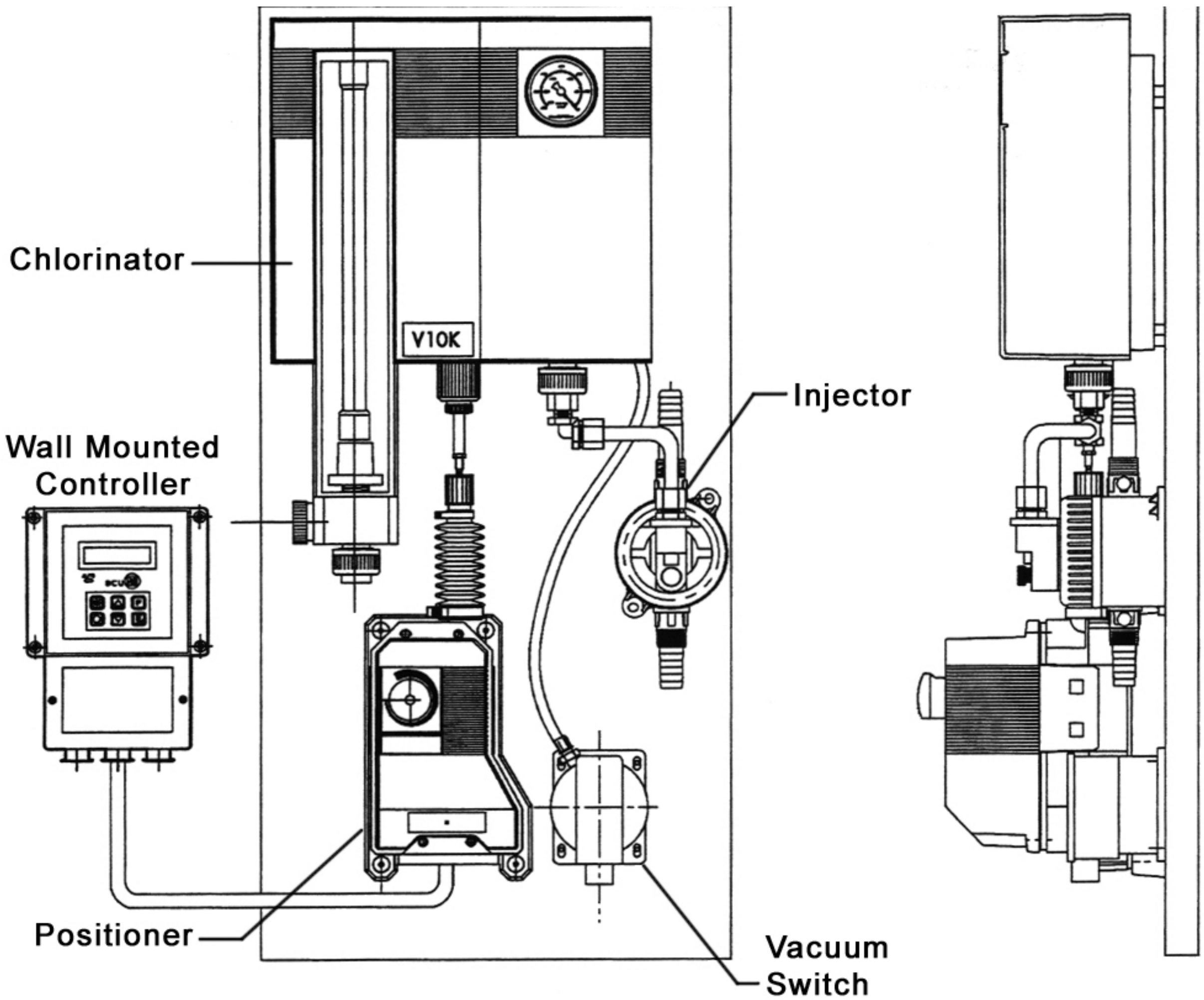


Figure 2.3 A Typical Gas Chlorinator[4]

Eductor

- The eductor is a device used in a chlorine gas feed system to create the negative pressure to allow the gas regulator valve to open, and pass flow through the chlorinator to the eductor.

- The negative pressure is created by the flow of water through a venturi, which creates negative pressure in the throat of the venturi. The gas flow enters the throat of the venturi and mixes with the water and forms a chlorine/gas solution that is introduced to the point of feed via an injector.

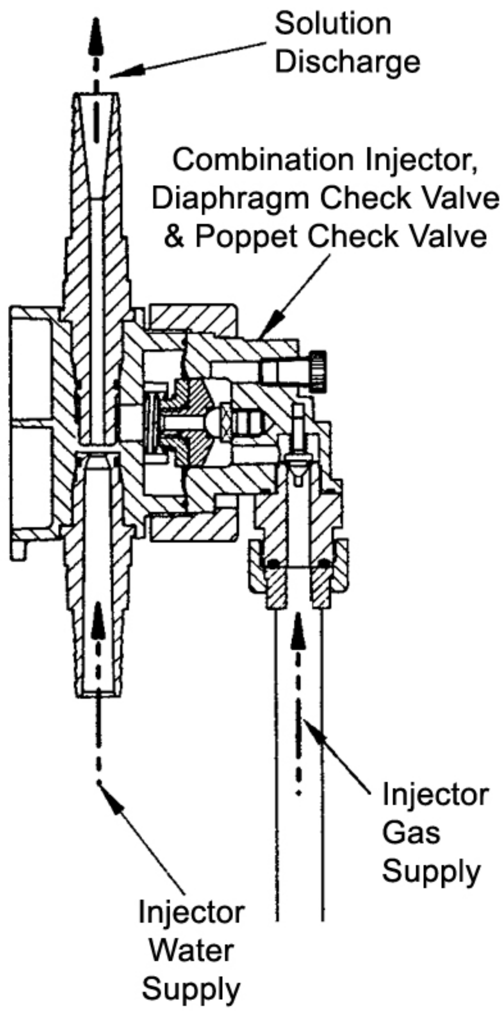


Figure 2.4 A Typical Eductor[5]

Feed Pumps

⦿ Feed pumps are used to apply various disinfectants to the water. Typical pumps for this type of service include:

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

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

On-Site Generators

⦿ On-Site generators are used in several cases to produce the disinfectant. In some cases this is required due to the instability of the chemical and the inability to store it for a significant time period. Examples of these chemicals include chlorine dioxide, ozone and sodium hypochlorite.

⦿ In some cases, on-site generation of chemicals reduces the risks associated with bulk storage of the chemical. An example of this is sodium hypochlorite, which when purchased in bulk, has a concentration of 12 to 15%. This chemical is a powerful oxidant and requires special storage and handling. When produced on-site, however, it is manufactured from salt and stored at a concentration of 0.8% in a less hazardous form.

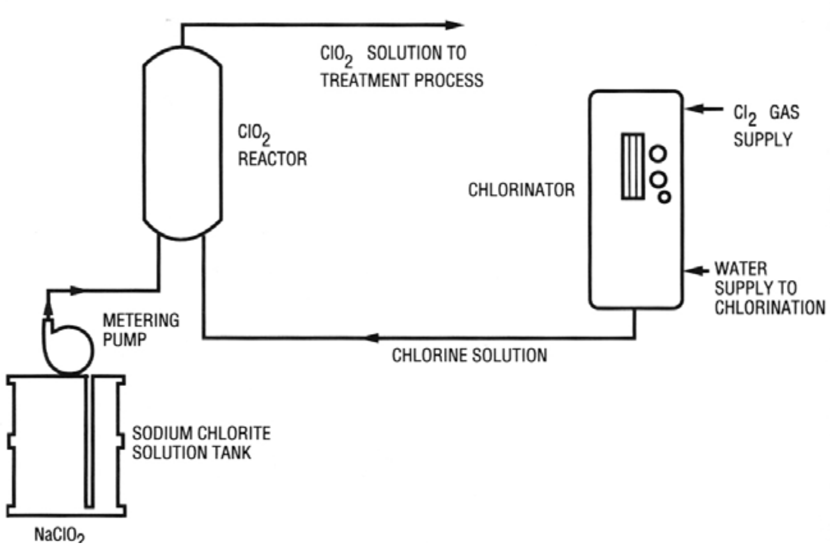


Figure 2.5 A Chlorine Dioxide Generator[6]

Figure 2.6 An Ozone GenerationSystem[7]

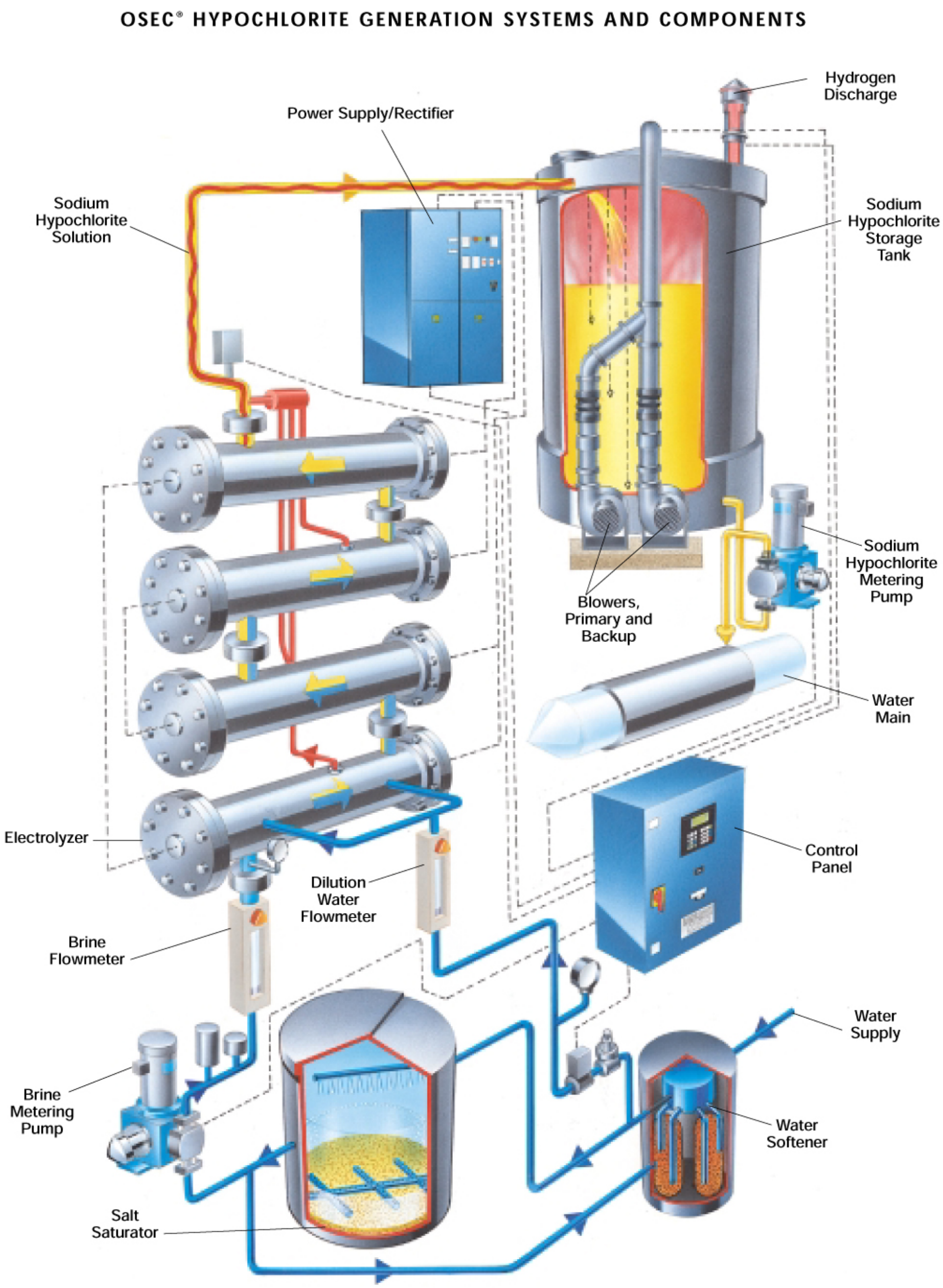


Figure 2.7 A Sodium Hypochlorite Generator[8]

Ammoniators

- Ammoniators are used to feed anhydrous ammonia to chlorinated water to produce chloramines.
- The equipment used in this process is very similar to that used in applying chlorine gas, as noted above. The primary differences relate to some of the materials of construction of the two systems.

Ultra-violet Light

Ultra-Violet Light at a wavelength of 254 nanometers has been found to be a very effective disinfectant and is especially suitable for inactivation of *Cryptosporidium*. Various lamp geometries, as well as lamp ratings, are available for this purpose. Some available lamps include low pressure/ low intensity, low pressure/high intensity and medium pressure/high intensity.

Low Pressure/Low Intensity

- This system utilizes a series of low pressure low intensity lamps operating at about 27 watts each to provide the necessary dosage for disinfection.
- The lamps are mono chromatic and produce over 95% of their light in the effective 254 nanometer range.
- Operating at low temperatures results in bulb life of about 8750 hours.
- When operating in clean water, the low temperature of operation will generally not result in any scale buildup and cleaning is not required.
- To change dosage levels, or intensity, banks of lights must be turned on or off. Cycling of lamps will result in lower life cycles due to the heating and cooling of the element.

Low Pressure/High Intensity

- This system utilizes a series of low pressure high intensity lamps operating at 140 watts each to provide the necessary dosage for disinfection.
- Due to the higher intensity, fewer bulbs are required than the low pressure, low intensity system.
- The lamps are also mono chromatic and produce over 95% of their light in the effective 254 nanometer range.
- The lamps operate at low temp with a life expectancy of 12000 hours.
- When operating in clean water, the low temperature of operation will generally not result in any scale buildup and cleaning is not required.
- To change dosage levels, or intensity, lamps can be modulated.

Medium Pressure/High Intensity

- This system uses a series of medium pressure lamps operating at 400 watts to provide the necessary dosage for disinfection.
- The lamps are multi chromatic operating over wide spectrum, with only 40% of the band in a range of 240 to 260 nanometers for effective disinfection.
- Due to its high intensity fewer lamps are required.
- The lamps have an estimated life of 5000 hours.
- To change dosage levels, or intensity, lamps can be modulated.

Laboratory

Chlorine residual analyzers are available in several configurations. These can test for free chlorine residual, combined chlorine residual and chloramines. Examples include colorimeters and amperometric titrators.

Colorimeters

- This process is portable and generally useful in field testing. It may also be used in laboratory testing.

- There are various kits available for this test, but in general, they all compare a sample color to a standard. This process requires the introduction of reagents into the sample. The sample will then change color to a shade that can be compared to a standard. The standard color that best matches the sample is the residual being tested.

Amperometric Titrators

- This system is generally used in the laboratory and in on-stream field analyzers.

- Current flow, monitored between two dissimilar electrodes, is directly proportional to chlorine residual. To monitor for free chlorine, a buffering agent is added to maintain a constant pH of approximately 4. An iodide salt may be added to monitor for total chlorine residual which includes the combined portion.[9]

Key Points

- The organic and inorganic demand of the water consumes (uses) the disinfectant before it can kill pathogenic microorganisms or create a residual.
- A chlorine residual is needed to maintain disinfection properties in distribution systems.
- The disinfection process and the creation of disinfection byproducts are closely related to the disinfectant application points.
- Monitoring disinfectant levels is extremely important in protection the health of the public.

[1] John Brady, William Garber and James F. Stahl, "Disinfection and Chlorination", in *Operation of Wastewater Treatment Plants*, Vol II, (Sacramento California: California State University, Sacramento Foundation, 2001), p. 363.

[2] Tom Ikesaki, "Disinfection", in *Water Treatment Plant Operation: A Field Study Training Program*, Vol I, (Sacramento California: California State University, Sacramento Foundation, 1999), p. 269.

[3] US Filter/Wallace & Tiernan.

[4] US Filter/Wallace & Tiernan

[5] US Filter/Wallace & Tiernan

[6] US Filter/Wallace & Tiernan

[7] Ozonia North America.

[8] US Filter/Wallace & Tiernan

[9] (Information from pg 120 of The Chlorination/Chloramination Handbook)

Unit 3 – Contact Time Computations

Learning Objectives

- Define contact time.
- List five factors that impact contact time and explain how they impact it.
- Perform disinfection contact time computations.

Definition

Contact Time, or C

CT = Concentration X Contact Time = mg/L x minutes

Factors Influencing Contact Time

In addition to chlorine residual, there are a number of factors that influence the efficiency of the disinfection process:

- The type of disinfectant will have an impact on the efficiency of the disinfection process and the contact time required to achieve the required degree of disinfection. For example, ozone is approximately 1000 times more effective than chloramines and would require less contact time
- The point of injection into the flow stream and the thorough mixing is essential to assure full treatment.

- Lower pH will result in more efficient use of chlorine as a disinfectant.

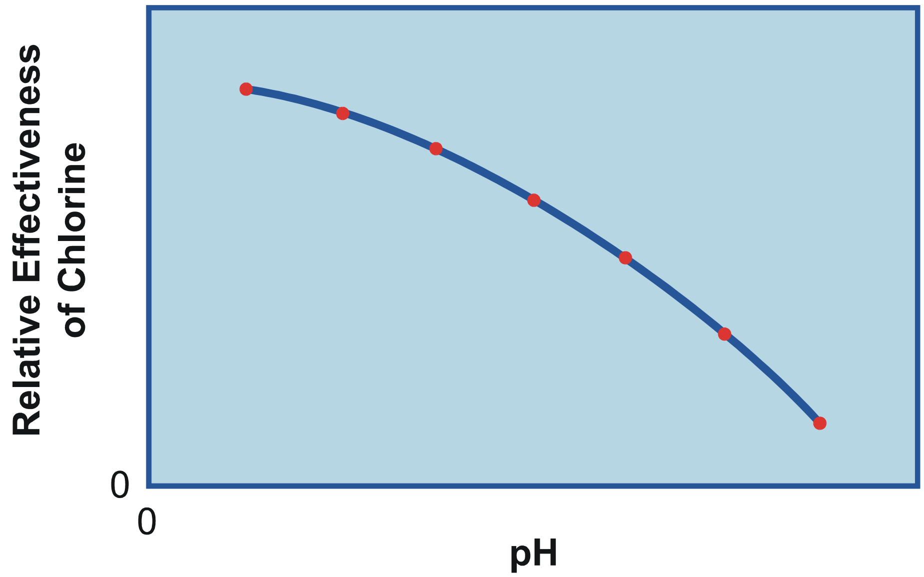


Figure 3.1 The Relationship Between pH and Disinfection When Using Chlorine.

- A higher temperature will result in more efficient disinfection.

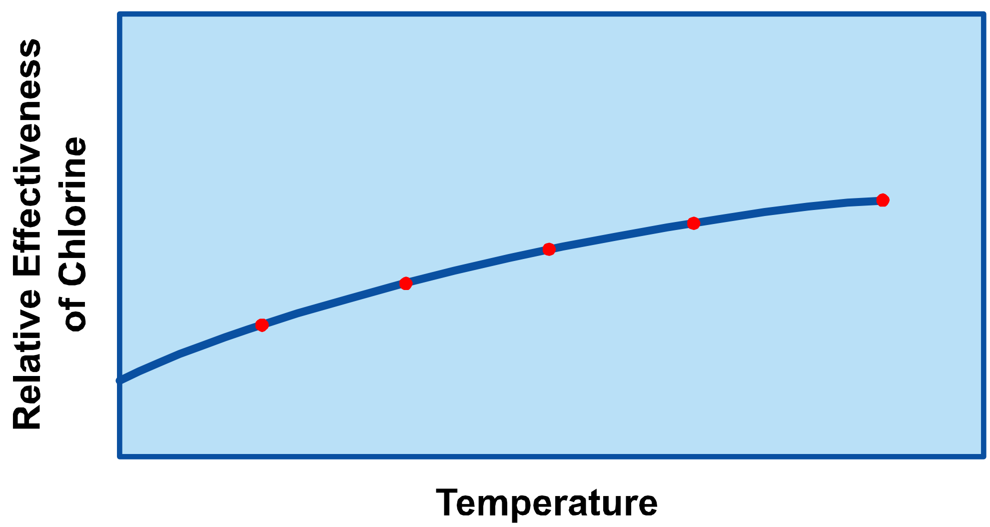


Figure 3.2 The Relationship Between Temperature and Disinfection When Using Chlorine.

⊙ A higher dosage of disinfectant will result in more rapid disinfection.

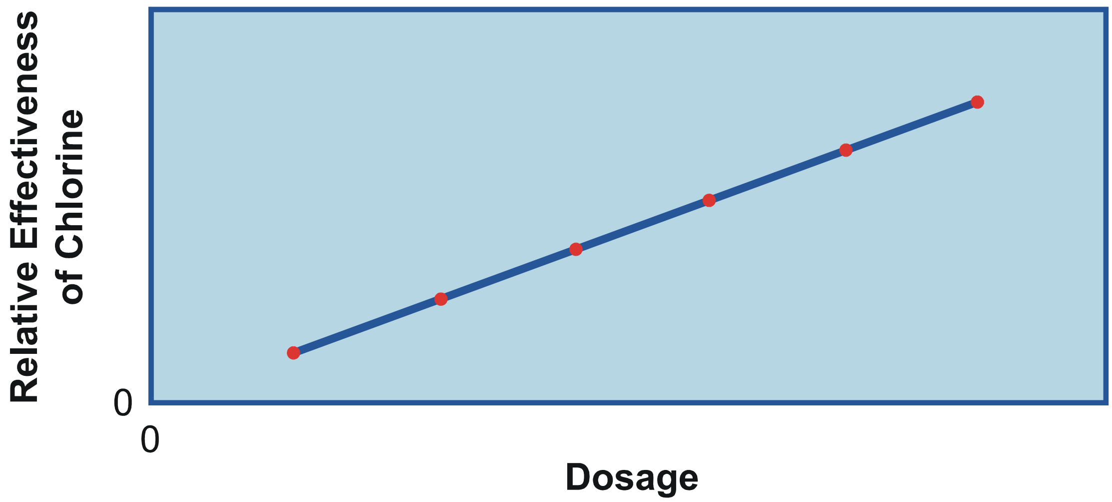
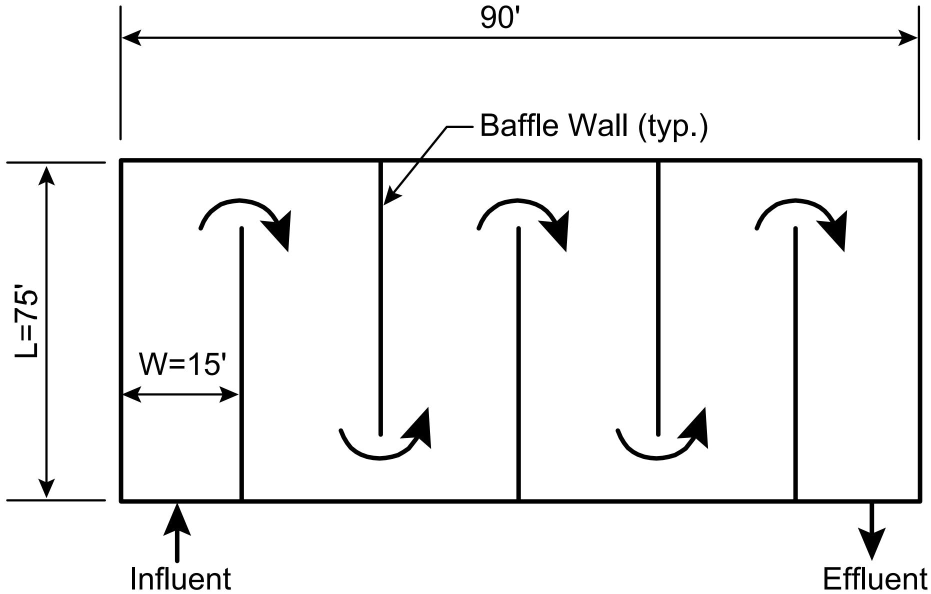


Figure 3.3 The Relationship Between Disinfection and Dosage.

- The chlorine contact basin design is of critical importance to maximize the effective detention time through the basin, and minimize short-circuiting. Baffling within the basins help minimize short-circuiting and aids in mixing. Note that the length to width ratio of 25:1 or greater should result in effective storage or baffling efficiencies of 70% or greater.



L:W = ≥ 25

for 70% Baffling Efficiency

$$\frac{6x75}{15} = 30 \geq 25$$

Figure 3.4 Chlorine Contact Basin.

Disinfection Contact Time Computation

- Required contact time can be determined by looking up the requirements in published EPA documents.

- Table 3.1 is a typical table that shows the required CT for water having a temperature of 10^{o}C and using free chlorine as the disinfectant. Similar tables are available for waters having temperatures from 0.5^{o}C thru 25^{o}C. Additional tables are also available for the use of ozone, chlorine dioxide and chloramines as the disinfectant.

TABLE 3.1
CT VALUES FOR INACTIVATION
OF GIARDIA CYSTS BY FREE CHLORINE
AT 10 C (1)

CHLORINE CONCENTRATION (mg/L)	pH<=6 Log Inactivations						pH=6.5 Log Inactivations						pH=7.0 Log Inactivations						pH=7.5 Log Inactivations					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<0.4	12	24	37	49	61	73	15	29	44	59	73	88	17	35	52	69	87	104	21	42	63	83	104	125
0.6	13	25	38	50	63	75	15	30	45	60	75	90	18	36	54	71	89	107	21	43	64	85	107	128
0.8	13	26	39	52	65	78	15	31	46	61	77	92	18	37	55	73	92	110	22	44	66	87	109	131
1	13	26	40	53	66	79	16	31	47	63	78	94	19	37	56	75	93	112	22	45	67	89	112	134
1.2	13	27	40	53	67	80	16	32	48	63	79	95	19	38	57	76	95	114	23	46	69	91	114	137
1.4	14	27	41	55	68	82	16	33	49	65	82	98	19	39	58	77	97	116	23	47	70	93	117	140
1.6	14	28	42	55	69	83	17	33	50	66	83	99	20	40	60	79	99	119	24	48	72	96	120	144
1.8	14	29	43	57	72	86	17	34	51	67	84	101	20	41	61	81	102	122	25	49	74	98	123	147
2	15	29	44	58	73	87	17	35	52	69	87	104	21	41	62	83	103	124	25	50	75	100	125	150
2.2	15	30	45	59	74	89	18	35	53	70	88	105	21	42	64	85	106	127	26	51	77	102	128	153
2.4	15	30	45	60	75	90	18	36	54	71	89	107	22	43	65	86	108	129	26	52	79	105	131	157
2.6	15	31	46	61	77	92	18	37	55	73	92	110	22	44	66	87	109	131	27	53	80	107	133	160
2.8	16	31	47	62	78	93	19	37	56	74	93	111	22	45	67	89	112	134	27	54	82	109	136	163
3	16	32	48	63	79	95	19	38	57	75	94	113	23	46	69	91	114	137	28	55	83	111	138	166

CHLORINE CONCENTRATION (mg/L)	pH=8.0 Log Inactivations						pH=8.5 Log Inactivations						pH<=9.0 Log Inactivations					
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	25	50	75	99	124	149	30	59	89	118	148	177	35	70	105	139	174	209
0.6	26	51	77	102	128	153	31	61	92	122	153	183	36	73	109	145	182	218
0.8	26	53	79	105	132	158	32	63	95	126	158	189	38	75	113	151	188	226
1	27	54	81	108	135	162	33	65	98	130	163	195	39	78	117	156	195	234
1.2	28	55	83	111	138	166	33	67	100	133	167	200	40	80	120	160	200	240
1.4	28	57	85	113	142	170	34	69	103	137	172	206	41	82	124	165	206	247
1.6	29	58	87	116	145	174	35	70	106	141	176	211	42	84	127	169	211	253
1.8	30	60	90	119	149	179	36	72	108	143	179	215	43	86	130	173	216	259
2	30	61	91	121	152	182	37	74	111	147	184	221	44	88	133	177	221	265
2.2	31	62	93	124	155	186	38	75	113	150	188	225	45	90	136	181	226	271
2.4	32	63	95	127	158	190	38	77	115	153	192	230	46	92	138	184	230	276
2.6	32	65	97	129	162	194	39	78	117	156	195	234	47	94	141	187	234	281
2.8	33	66	99	131	164	197	40	80	120	159	199	239	48	96	144	191	239	287
3	34	67	101	134	168	201	41	81	122	162	203	243	49	97	146	195	243	292

Notes: (1) $CT_{99.9}$ = CT for 3-log inactivation

Disinfection CT Computation

The following is a computation for CT for a clearwell:

Capacity of 500,000 gallons available for disinfectant storage.
Baffling Efficiency of 70%.
Clearwell Flow Thru Rate of 10 MGD or 6,944 gallons/minute.
Chlorine Residual at point of discharge 1.0 mg/L.

The first thing we have to determine is T or Time for the water to flow through the clearwell.

$$T = \frac{\text{Capacity (Gallons) x Baffling Efficiency (\%)}}{\text{Flow (gpm)}}$$

$$T = \frac{\text{500,000 gallons x 0.70}}{\text{6,944 gallons/minute}} = \text{50.40 minutes}$$

Now we'll determine the CT value. Remember CT = C (concentration) x T (time)
CT =1.0 mg/L x 50.40 minutes

CT= 50.4 mg/L-minutes

If the water quality were described as; temperature of 10^{o}C, pH of 7.5, with a chlorine residual of 1.0 mg/L, does the computation indicates that the CT provided (50.4 mg/L- minutes), meets or exceeds the required CT for 1.0 log removal?

According to Table 3.1 the CT value is 45 mg/l-min, so yes this is sufficient.

What size clearwell is required to provide 3.0 log removal of Giardia if the flow rate through the water treatment plant is 3 million gallons per day, the pH is 7.0, the temperature of the water is 10^{o} C and the chlorine residual is 2.0 mg/L? Assume that the clearwell baffling efficiency is 70%.

Unit 4 – Maintenance Issues

Learning Objectives

- Identify the residual maintenance issues that must be considered when protecting treated water.
- List and explain distribution system issues that must be considered when protecting treated water.
- Describe the disinfection procedure for each of the following:
  - Pipelines
  - Storage tanks
  - Water treatment plants
  - Wells
  - Distribution systems
- Explain the dechlorination process.

Residual Maintenance

Residual maintenance is important in assuring the disinfection process is effective in a water supply system. Generally, maintenance of residual levels of 0.2 mg/L at the end of a distribution system is a good indication that the system is disinfected. Lack of residual is an indicator that contamination may have taken place.

Distribution System Issues

Pipes

- Pipes within a transmission distribution system may have a demand for chlorine residual reducing the value that is measured at the far ends of the system. This demand may relate to reactions with exposed metal in iron pipe, or growths in the distribution system. Close monitoring of the distribution system will detect whether this is a problem. If so, additional chlorine application points may have to be provided at judicious locations within the system.

Tanks

- Tanks with water that does not circulate, or that have a low turnover rate may have a tendency to lose chlorine residual over time. This may be especially noticeable during warmer weather when heat will help to dissipate the chlorine from the water. To help in alleviating degradation of chlorine within a storage tank, inlets and outlets should be designed to minimize short-circuiting as flow passes through the tank. Close monitoring of flows leaving the tank will detect whether this is a problem.

Additional Chlorination – Rechlorination

- Additional chlorine may be necessary when residuals fall below 0.2 mg/L.

Distribution System

- Adding chlorine may be accomplished by judicious selection of a location within the distribution system such as a pump station, flow control station, pressure control station or point of entry into a system. Each one of these locations is a point of flow concentration where rechlorination can be readily accomplished.

Storage Tank

- Rechlorination may be accomplished by providing a chlorination station at the storage tank. The station could chlorinate water and re-circulate it through the tank to assure that the proper level of residual is maintained.

- Alternatives would be to add chlorine to the entire supply as it either enters or exits the tank.

Pipelines

All new water mains, or mains taken out of service for inspection, repair or other activity, shall be disinfected prior to placing into service.

- As a precaution during construction, repair or opening the main, care shall be taken to prevent materials or water from entering the main, which could contaminate the water supply.
- Prior to disinfection, flush the main and clean out all particulates. If adequate flushing velocities cannot be achieved, cleaning may be accomplished by pigging the main.
- After cleaning the main, a solution of chlorinated water is to be introduced into the main at a minimum concentration of 25 mg/L.
- Retain the solution in the main for a period of 24 hours during which time all valves, hydrants and appurtenances are to be operated to assure their disinfection.
- At the conclusion of 24 hours, a sample is to be extracted and analyzed for chlorine residual. If the residual is above 10 mg/L, proceed to the next step. If not, rechlorinate the main until this requirement is met.
- After meeting the previous requirement, perform final flushing of the main, taking care to dechlorinate the water as required assuring that no environmental damage takes place.
- After final flushing, obtain the necessary bacteriological samples for analysis. If the results are negative, consider the line disinfected and place in service.
- Should the confirmation test prove positive, repeat the above as required.

Storage Tanks

All new storage tanks, repainted tanks, or tanks taken out of service for any other activity, shall be disinfected prior to placing into service.

- Prior to disinfection, the tank shall be cleaned of all scaffolding, planks, tools, rags and other deleterious materials.
- The tank shall then be thoroughly cleaned by methods including sweeping, scrubbing, high-pressure water jet or other effective means.
- All water, dirt and foreign material shall then be removed from the tank.

- Typically, one of three methods is then utilized to disinfect the tank. Additional methods of disinfection may be found in the American Water Works Association (AWWA) Standard C652.
  - The first method involves filling the tank with a chlorine solution so that at the end of the retention time, the residual in the facility is no less than 10 mg/L of free chlorine. The retention time is dependent upon the type of chlorine applied to the water and could vary from 6 to 24 hours.
  - The second method involves partial filling of the tank, approximately 5% by volume, with a concentrated chlorine solution so that the residual in the tank is about 50 mg/L. After allowing the solution to be held in the tank for about 6 hour, the tank is filled with potable water. The concentrated chlorine solution is applied continuously to the water while the tank is being filled. At the end of this period, the concentration should be about 2 mg/L. After allowing a retention time of 24 hours, the tank is sampled for proper disinfection.
  - The third method is the spray method, which is the most commonly used method. In this method, a chlorinated solution having a concentration in excess of 200 mg/L is prepared. The solution is applied to all parts of the tank that may be in contact with potable water up to the overflow elevation. All surfaces remain in contact with this solution of chlorinated water for a period of at least 30 minutes. The tank may then be filled with potable water, at which time the necessary bacteriological samples for analysis are obtained.
- If the results of the bacteriological tests are negative, consider the tank disinfected and place in service.
- Should the confirmation test prove positive, repeat the above as required.

Water Treatment Plants

- ⊙ All new water treatment plants, rehabilitated portions of existing plants, facilities that have been taken out of service for maintenance or in general, facilities that are subject to contamination, shall be disinfected prior to placing into service.
- ⊙ For a new water treatment plant, this requires disinfection of all facilities downstream of the filter influent. Where the pretreatment process includes disinfection, the facilities in the water treatment plant beginning at this point should also be disinfected. Points upstream of this process need not be disinfected but should be thoroughly cleaned.
- ⊙ The disinfection process should be applied to all conveyance facilities including pipes, flumes, basins, tanks and equipment that convey or are in contact with disinfected water.
- ⊙ In general, disinfection of pipe, basins and tanks shall be performed as described above for Pipelines and Storage Tanks; however, special care must be undertaken when disinfecting either.

The following presents one of the common methods of disinfection of filters:

- ⊙ Sand and Anthracite:
  - Thoroughly clean the filter box prior to placing the media.
  - After placing the media slowly fill the box with chlorinated water via the backwash line. Chlorine is to be introduced into the backwash water so that the full box, to its overflow elevation, has a chlorine residual of at least 25 mg/L.
  - Retain this solution in the filter box for a period of at least 12 hours.
  - At the conclusion of 12 hours, samples should be extracted from the top, bottom, and intermediate levels to assure that a residual of 15 mg/L has been maintained throughout the filter.
  - If the residual is above 15 mg/L, proceed to the next step. If not rechlorinate the filter till this requirement is met.
  - Discharge the chlorinated water, taking care that environmental damage does not take place.
  - Refill the filter box with backwash water and obtain the necessary bacteriological samples for analysis. If the results are negative, consider the line disinfected and place in service.
  - Should the confirmation test prove positive, repeat the above as required.
- ⊙ GAC Filters:
  - Due to the affinity of GAC for chlorine, the media cannot be disinfected as noted above. Rather the filter box and GAC supporting media are disinfected as noted above and then the GAC installed.
  - Care must be taken when installing the GAC to assure that it is not contaminated during the installation process.
  - GAC should be stored in a clean environment prior to placing.
  - GAC should be placed and handled with equipment that has been disinfected with a solution of 200-mg/L-chlorine prior to use. This includes workers' rubber boots and gloves.

Wells

All new wells, or wells that have been taken out of service for rehabilitation, shall be disinfected prior to placing into service.

New Well

- Prior to disinfection, the well shall be cleaned of all foreign substances including rope, cement, and other deleterious materials.
- Apply a chlorinated solution at a concentration of at least 100 mg/L in a manner so that it is uniformly distributed throughout the entire depth of the well.
- Where available, the well should be surged to assure good circulation within the aquifer.
- Retain this solution in the well for a period of 24 hours.
- At the conclusion of this period remove the chlorinated water using disinfected tools such as pumps or bailers and obtain the necessary bacteriological samples for analysis. If the results are negative, consider the well disinfected and cap for future use.
- Should the confirmation test prove positive rechlorinate as above, but in a quantity that assures displacement of four times the volume of the well back into the aquifer.

Existing Well

- Apply a chlorinated solution at a concentration of at least 50 mg/L in a manner so that it is uniformly distributed throughout the entire depth of the well.
- Surge the well to assure good distribution into the aquifer.
- Retain this solution in the well for a minimum period of 12 hours.
- Then utilize the existing well pump to circulate the chlorinated water through the pump, pump column and well to assure that the entire system is chlorinated.
- Pump the chlorinated water to waste, taking care to dechlorinate the water as required assuring that no environmental damage takes place.
- Periodically monitor for chlorine residual. When this has reached zero, continue to discharge until at least one volume of well water has been discharged. At the conclusion of this period obtain the necessary bacteriological samples for analysis. If the results are negative, consider the well disinfected.
- Should the confirmation test prove positive, rechlorinate as required.

Distribution Systems

- Where repairs or connections are made to existing pipe, care must be taken not to introduce contaminants into the pipe.
- Hypochlorite solution or tablets shall be applied to water in open trenches to minimize the potential for contamination of the main to be opened.
- The interior of all pipe, fittings and valves used in making repairs or connections shall be swabbed with a one percent solution of hypochlorite.
- After making a repair, or connection, the section of main shall be flushed through the nearest hydrant locations.
- At the conclusion of the flushing sequence, obtain bacteriological samples to determine the procedures effectiveness.
- If the bacteriological testing has a positive result, evaluate alternatives for corrective action and sample daily thereafter until two negative samples are recorded.

Dechlorination

Dechlorination is the physical or chemical removal of chlorine residual from water prior to its discharge to receiving streams. This includes both free and combined residuals.

- The dechlorination process is needed to protect fish and aquatic organisms residing in receiving streams from the toxic effects of chlorine. Some species of fish, such as salmon and trout, can only tolerate trace amounts (O.01mg/l) of chlorine. Regulatory agencies have therefore adopted requirements to limit discharges to values that reflect no measurable chlorine entering a receiving stream.

Detention Ponds

- Ponds may be designed to detain water for an adequate amount of time to allow chlorine to naturally dissipate prior to discharge to a receiving stream.

Aeration

- Bubbling air through the water will provide the necessary turbulence and contact aeration to drive remaining chlorine from the water.

Sunlight

- Exposure to sunlight may cause the chlorine residual to decompose. Thin layers of flow, when exposed to sunlight, react with the light to form hydrochloric acid.

Activated Carbon

- Passing chlorinated water through a bed of activated carbon will result in the carbon absorbing the chlorine.

Chemical Compounds

- Sulfur compounds are commonly used in the dechlorination process due to their rapid reaction, ease of use and relatively inexpensive cost.
- Typical compounds include sulfur dioxide (SO_2), sodium sulfite (Na_2SO_3), sodium bisulfite ($NaHSO_3$), sodium metabisulfite ($Na_2S_2O_5$) and sodium thiosulfate ($Na_2S_2O_3$).
  - Of these, sulfur dioxide is one of the most common forms of dechlorination agent in use. It utilizes equipment that is similar to chlorination facilities and therefore operators understand its operation readily.
- Two of the more common sulfur compounds are sulfur dioxide and sodium sulfite.

Sulfur Dioxide

- Sulfur dioxide is a colorless, toxic gas provided in liquid form. It is stored in cylinders or containers much like chlorine is.
- Sulfur dioxide is not flammable, explosive or corrosive to most metals when dry. When in the presence of moisture, the gas forms sulfuric acid, which is highly corrosive.
- Sulfonators are similar in design and operation as a chlorinator, but are manufactured with special materials suitable for sulfur dioxide.
- Approximately one pound of sulfur dioxide will react and neutralize one pound of chlorine.

  $SO_2 + H_2O \rightarrow HSO_3^- + H^+$

  $HOCl + HSO_3^- \rightarrow Cl^- + SO_4^{-2} + 2H^+$

  $SO_2 + HOCl + H_2O \rightarrow Cl^- + SO_4^{-2} + 3H^+$

  - For combined forms of chlorine, such as chloramines, the reaction is still one to one and as follows:

    $NH_2Cl + H_2SO_3 + H_2O \rightarrow NH_4HSO_4 + HCl$

Sulfur Dioxide Safety

- Sulfur dioxide is a highly toxic chemical that must be handled with care to minimize exposure to personnel. It is more than 2.3 times heavier than air, and any leak in a quiescent room will stay close to the ground where an operator can inhale it.
- Concentrations of 0.04% (400 ppm) in the air may be fatal after only a few breaths. The Immediate Dangerous to Life of Heath (IDLH) concentration is 100 ppm according to National Institute for Occupational Safety and Health. The OSHA regulations limit short-term exposure to no more than 5 parts per million over a 15-minute period.
- Sulfur dioxide is hazardous and when combined with moisture (including body moisture) becomes extremely corrosive.

Dechlorination Control

- Dechlorination control may be manual or automatic.
- Automatic control is generally used since it is important to maintain chlorine residual as low as possible and automatic control assures minimal chlorine residual without the need to wastefully overdose with chemical. Compound loop control is the preferred method of control. Compound loop control utilizes a flow signal and an analytical measurement downstream of a chemical feed point to readjust a chemical feed rate at an upstream feed point so as to keep the downstream measurement within a set range.
- Manual control should only be used when there is a failure of the automatic control system.
- By maintaining a residual of 0.5 mg/l of sulfur dioxide, an operator can be assured that residual chlorine has fully reacted.

Safety

Procedures and Response

- Safety procedures and response to leaks are similar to those for use with chlorine gas. These leaks are related to defective valve connections and improper connections to the gas supply cylinder.

Emergency Safety Equipment

- Equipment is similar to that used for response to chlorine leaks including respiratory and leak repair equipment.

Additional Equipment

- Equipment for the use of sulfur dioxide is the same as for chlorine gas; however, some of the materials used are different. Consideration should be given to using valves manufactured from type 316 stainless steel with Teflon seats. The sulfonator also has orifices, diaphragms and rotameters of specific type and size for use with sulfur dioxide.

- Equipment for use with liquid sodium sulfite is similar to that used for feeding liquid sodium hypochlorite.

Exercise

1. Maintenance of residual levels of 0.2 mg/L at the end of a distribution system is a good indication that the system is disinfected.

   a. True
   b. False

2. Water mains taken out of service for inspection or repair do not need to be disinfected prior to being placed back in service.

   a. True
   b. False

3. All new water treatment plants, rehabilitated portions of existing plants, facilities that have been taken out of service for maintenance or in general, facilities that are subject to contamination, shall be disinfected prior to placing into service.

   a. True
   b. False

4. What is dechlorination?

5. List five methods of dechlorination.

Key Points

- Pipes, storage tanks and distribution systems must be maintained and inspected to insure recontamination does not occur
- On occasion, pipes, tanks, storage tanks, wells, distribution systems may need to go through a maintenance disinfection procedure
- Dechlorination is the process of removing the chlorine residual when desired. Usually to protect the environment.