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Chapter 5. DISINFECTION

LESSON 2

OBJECTIVES

Chapter 5. DISINFECTION

Following completion of Chapter 5, you should be able to:

1. Describe the factors that influence disinfection.
2. Explain the process of disinfection using chlorine, hypochlorite, chlorine dioxide, and chloramines.
3. Describe the breakpoint chlorination process.
4. Identify the various points of chlorine application.
5. Disinfect new and existing wells.
6. Disinfect mains and storage tanks.
7. Calculate chlorine dosage.
8. Determine hypochlorinator and chlorinator settings.
9. Operate and maintain hypochlorinators.
10. Operate and maintain chlorinators.
11. Troubleshoot chlorination systems.
12. Conduct a chlorine safety program.

WORDS

Chapter 5. DISINFECTION

AMPEROMETRIC (am-purr-o-MET-rick) AMPEROMETRIC

A method of measurement that records electric current flowing or generated, rather than recording voltage. Amperometric titration is a means of measuring concentrations of certain substances in water.

AMPEROMETRIC (am-purr-o-MET-rick) TITRATION AMPEROMETRIC TITRATION

A means of measuring concentrations of certain substances in water (such as strong oxidizers) based on the electric current that flows during a chemical reaction. Also see TITRATE.

BREAKPOINT CHLORINATION BREAKPOINT CHLORINATION

Addition of chlorine to water or wastewater until the chlorine demand has been satisfied. At this point, further additions of chlorine will result in a free chlorine residual that is directly proportional to the amount of chlorine added beyond the breakpoint.

BUFFER CAPACITY BUFFER CAPACITY

A measure of the capacity of a solution or liquid to neutralize acids or bases. This is a measure of the capacity of water or wastewater for offering a resistance to changes in pH.

CHEMTREC (KEM-trek) CHEMTREC

Chemical Transportation Emergency Center. A public service of the American Chemistry Council dedicated to assisting emergency responders deal with incidents involving hazardous materials. Their toll-free 24-hour emergency phone number is (800) 424-9300.

CARCINOGEN (kar-SIN-o-jen) CARCINOGEN

Any substance that tends to produce cancer in an organism.

CHLORAMINES (KLOR-uh-means) CHLORAMINES

Compounds formed by the reaction of hypochlorous acid (or aqueous chlorine) with ammonia.

CHLORINATION (klor-uh-NAY-shun) CHLORINATION

The application of chlorine to water, generally for the purpose of disinfection, but frequently for accomplishing other biological or chemical results (aiding coagulation and controlling tastes and odors).

CHLORINE DEMAND CHLORINE DEMAND

Chlorine demand is the difference between the amount of chlorine added to water or wastewater and the amount of residual chlorine remaining after a given contact time. Chlorine demand may change with dosage, time, temperature, pH, and nature and amount of the impurities in the water.

$$\text{Chlorine Demand, mg}/L = \text{Chlorine Applied, mg}/L - \text{Chlorine Residual, mg}/L$$

CHLORINE REQUIREMENT CHLORINE REQUIREMENT

The amount of chlorine that is needed for a particular purpose. Some reasons for adding chlorine are reducing the MPN (Most Probable Number) of coliform bacteria, obtaining a particular chlorine residual, or oxidizing some substance in the water. In each case, a definite dosage of chlorine will be necessary. This dosage is the chlorine requirement.

CHLORINE RESIDUAL CHLORINE RESIDUAL

The concentration of chlorine present in water after the chlorine demand has been satisfied. The concentration is expressed in terms of the total chlorine residual, which includes both the free and combined or chemically bound chlorine residuals. Also called RESIDUAL CHLORINE.

CHLOROPHENOLIC (KLOR-o-fee-NO-lick) CHLOROPHENOLIC

Chlorophenolic compounds are phenolic compounds (carbolic acid) combined with chlorine.

CHLORORGANIC (klor-or-GAN-ick) CHLORORGANIC

Organic compounds combined with chlorine. These compounds generally originate from, or are associated with, living or dead organic materials, such as algae in water.

COLIFORM (KOAL-i-form) COLIFORM

A group of bacteria found in the intestines of warm-blooded animals (including humans) and also in plants, soil, air, and water. The presence of coliform bacteria is an indication that the water is polluted and may contain pathogenic (disease-causing) organisms. Fecal coliforms are those coliforms found in the feces of various warm-blooded animals, whereas the term "coliform" also includes other environmental sources.

COLORIMETRIC MEASUREMENT COLORIMETRIC MEASUREMENT

A means of measuring unknown chemical concentrations in water by measuring a sample's color intensity. The specific color of the sample, developed by addition of chemical reagents, is measured with a photoelectric colorimeter or is compared with color standards using, or corresponding with, known concentrations of the chemical.

COMBINED AVAILABLE CHLORINE COMBINED AVAILABLE CHLORINE

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. The combined chlorine compounds are more stable than free chlorine forms, but they are somewhat slower in disinfection action.

COMBINED AVAILABLE CHLORINE RESIDUAL COMBINED AVAILABLE CHLORINE RESIDUAL

The concentration of residual chlorine that is combined with ammonia, organic nitrogen, or both in water as a chloramine (or other chloro derivative) and yet is still available to oxidize organic matter and help kill bacteria.

COMBINED CHLORINE COMBINED CHLORINE

The sum of the chlorine species composed of free chlorine and ammonia, including monochloramine, dichloramine, and trichloramine (nitrogen trichloride). Dichloramine is the strongest disinfectant of these chlorine species, but it has less oxidative capacity than free chlorine.

COMBINED RESIDUAL CHLORINATION COMBINED RESIDUAL CHLORINATION

The application of chlorine to water or wastewater to produce a combined available chlorine residual. The residual may consist of chlorine compounds formed by the reaction of chlorine with natural or added ammonia (NH_3) or with certain organic nitrogen compounds.

DPD METHOD DPD METHOD

A method of measuring the chlorine residual in water. The residual may be determined by either titrating or comparing a developed color with color standards. DPD stands for N,N-diethyl-p-phenylenediamine.

DIATOMS (DYE-uh-toms) DIATOMS

Unicellular (single cell), microscopic algae with a rigid, box-like internal structure consisting mainly of silica.

DISINFECTION (dis-in-FECT-shun) DISINFECTION

The process designed to kill or inactivate most microorganisms in water or wastewater, including essentially all pathogenic (disease-causing) bacteria. There are several ways to disinfect, with chlorination being the most frequently used in water and wastewater treatment plants. Compare with STERILIZATION.

EDUCTOR (e-DUCK-ter) EDUCTOR

A hydraulic device used to create a negative pressure (suction) by forcing a liquid through a restriction, such as a Venturi. An eductor or aspirator (the hydraulic device) may be used in the laboratory in place of a vacuum pump. As an injector, it is used to produce vacuum for chlorinators. Sometimes used instead of a suction pump.

EJECTOR EJECTOR

A device used to disperse a chemical solution into water being treated.

ENTERIC ENTERIC

Of intestinal origin, especially applied to wastes or bacteria.

ENZYMES (EN-zimes) ENZYMES

Organic substances (produced by living organisms) that cause or speed up chemical reactions. Organic catalysts and/or biochemical catalysts.

FREE AVAILABLE CHLORINE RESIDUAL FREE AVAILABLE CHLORINE RESIDUAL

That portion of the total available chlorine residual composed of dissolved chlorine gas (Cl_2), hypochlorous acid ($HOCl$), and/or hypochlorite ion (OCl^-) remaining in water after chlorination. This does not include chlorine that has combined with ammonia, nitrogen, or other compounds.

HTH HTH

High Test Hypochlorite. Calcium hypochlorite or $Ca(OCl)_2$.

HETEROTROPHIC (HET-er-o-TROF-ick) HETEROTROPHIC

Describes organisms that use organic matter for energy and growth. Animals, fungi, and most bacteria are heterotrophs.

HYDROLYSIS (hi-DROLL-uh-sis) HYDROLYSIS

(1) A chemical reaction in which a compound is converted into another compound by taking up water.

(2) Usually a chemical degradation of organic matter.

HYPOCHLORINATION (HI-poe-klor-uh-NAY-shun) HYPOCHLORINATION

The application of hypochlorite compounds to water or wastewater for the purpose of disinfection.

HYPOCHLORITE (HI-poe-KLOR-ite) HYPOCHLORITE

Chemical compounds containing available chlorine; used for disinfection. They are available as liquids (bleach) or solids (powder, granules, and pellets) in barrels, drums, and cans. Salts of hypochlorous acid.

IDLH IDLH

Immediately Dangerous to Life or Health. The atmospheric concentration of any toxic, corrosive, or asphyxiant substance that poses an immediate threat to life or would cause irreversible or delayed adverse health effects or would interfere with an individual's ability to escape from a dangerous atmosphere.

MPN MPN

MPN is the Most Probable Number of coliform-group organisms per unit volume of sample water. Expressed as a density or population of organisms per 100 m*L* of sample water.

NITRIFICATION (NYE-truh-fuh-KAY-shun) NITRIFICATION

An aerobic process in which bacteria oxidize the ammonia and organic nitrogen in water into nitrite and then nitrate.

NITROGENOUS (nye-TRAH-jen-us) NITROGENOUS

A term used to describe chemical compounds (usually organic) containing nitrogen in combined forms. Proteins and nitrate are nitrogenous compounds.

ORTHOTOLIDINE (or-tho-TOL-uh-dine) ORTHOTOLIDINE

Orthotolidine is a colorimetric indicator of chlorine residual. If chlorine is present, a yellow-colored compound is produced. This reagent is no longer approved for chemical analysis to determine chlorine residual.

OXIDATION OXIDATION

Oxidation is the addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound; in the environment and in wastewater treatment processes, organic matter is oxidized to more stable substances. The opposite of REDUCTION.

OXIDIZING AGENT OXIDIZING AGENT

Any substance, such as oxygen (O_2) or chlorine (Cl_2), that will readily add (take on) electrons. When oxygen or chlorine is added to water or wastewater, organic substances are oxidized. These oxidized organic substances are more stable and less likely to give off odors or to contain disease-causing bacteria. The opposite is a REDUCING AGENT.

PALATABLE (PAL-uh-tuh-bull) PALATABLE

Water at a desirable temperature that is free from objectionable tastes, odors, colors, and turbidity. Pleasing to the senses.

PATHOGENIC (path-o-JEN-ick) ORGANISMS PATHOGENIC ORGANISMS

Organisms, including bacteria, viruses, or cysts, capable of causing diseases (giardiasis, cryptosporidiosis, typhoid, cholera, dysentery) in a host (such as a person). There are many types of organisms that do not cause disease. These organisms are called nonpathogenic.

PHENOLIC (fee-NO-lick) COMPOUNDS PHENOLIC COMPOUNDS

Organic compounds that are derivatives of benzene. Also called phenols (FEE-nolls).

POTABLE (POE-tuh-bull) WATER POTABLE WATER

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

PRECURSOR, THM (PRE-curse-or) PRECURSOR, THM

Natural, organic compounds found in all surface and groundwaters, which may react with halogens (such as chlorine) to form trihalomethanes (THMs); they must be present in order for THMs to form.

REAGENT (re-A-gent) REAGENT

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

REDUCING AGENT REDUCING AGENT

Any substance, such as base metal (iron) or the sulfide ion (S^{2-}), that will readily donate (give up) electrons. The opposite is an OXIDIZING AGENT.

REDUCTION (re-DUCK-shun) REDUCTION

Reduction is the addition of hydrogen, removal of oxygen, or the addition of electrons to an element or compound. Under anaerobic conditions (no dissolved oxygen present), sulfur compounds are reduced to odor-producing hydrogen sulfide (H_2S) and other compounds. In the treatment of metal finishing wastewaters, hexavalent chromium (Cr^{6+}) is reduced to the trivalent form (Cr^{3+}). The opposite of OXIDATION.

RELIQUEFACTION (re-lick-we-FACK-shun) RELIQUEFACTION

The return of a gas to the liquid state; for example, a condensation of chlorine gas to return it to its liquid form by cooling.

RESIDUAL CHLORINE RESIDUAL CHLORINE

The concentration of chlorine present in water after the chlorine demand has been satisfied. The concentration is expressed in terms of the total chlorine residual, which includes both the free and combined or chemically bound chlorine residuals. Also called CHLORINE RESIDUAL.

ROTAMETER (ROTE-uh-ME-ter) ROTAMETER

A device used to measure the flow rate of gases and liquids. The gas or liquid being measured flows vertically up a tapered, calibrated tube. Inside the tube is a small ball or bullet-shaped float (it may rotate) that rises or falls depending on the flow rate. The flow rate may be read on a scale behind or on the tube by looking at the middle of the ball or at the widest part or top of the float.

SAPROPHYTES (SAP-row-fights) SAPROPHYTES

Organisms living on dead or decaying organic matter. They help natural decomposition of organic matter in water or wastewater.

STERILIZATION (STAIR-uh-luh-ZAY-shun) STERILIZATION

The removal or destruction of all microorganisms, including pathogens and other bacteria, vegetative forms, and spores. Compare with DISINFECTION.

TITRATE (TIE-trate) TITRATE

To titrate a sample, 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). Titration is the process of adding the chemical reagent in small increments (0.1–1.0 milliliter) until completion of the reaction, as signaled by the end point.

TOTAL CHLORINE TOTAL CHLORINE

The total concentration of chlorine in water, including the combined chlorine (such as inorganic and organic chloramines) and the free available chlorine.

TOTAL CHLORINE RESIDUAL TOTAL CHLORINE RESIDUAL

The total amount of chlorine residual (including both free chlorine and chemically bound chlorine) present in a water sample after a given contact time.

TRIHALOMETHANES (THMs) (tri-HAL-o-METH-hanes) TRIHALOMETHANES (THMs)

Derivatives of methane, CH_4, in which three halogen atoms (chlorine or bromine) are substituted for three of the hydrogen atoms. Often formed during chlorination by reactions with natural organic materials in the water. The resulting compounds (THMs) are suspected of causing cancer.

TURBIDITY (ter-BID-it-tee) TURBIDITY

The cloudy appearance of water caused by the presence of suspended and colloidal matter. In the waterworks field, a turbidity measurement is used to indicate the clarity of water. Technically, turbidity is an optical property of the water based on the amount of light reflected by suspended particles. Turbidity cannot be directly equated to suspended solids because white particles reflect more light than dark-colored particles and many small particles will reflect more light than an equivalent large particle.

CHAPTER 5. DISINFECTION

(Lesson 1 of 2 Lessons)

5.0 PURPOSE OF DISINFECTION

5.00 Making Water Safe for Consumption

Our single most important natural resource is water. Without water we could not exist. Unfortunately, safe water is becoming very difficult to find. In the past, safe water could be found in remote areas, but with population growth and related pollution of waters, there are very few natural waters left that are safe to drink without treatment of some kind.

Water is the universal solvent and, therefore, carries all types of dissolved materials. Water also carries biological life forms that can cause diseases. These waterborne pathogenic organisms can cause the types of diseases listed in Table 5.1. Most of these organisms and the diseases they transmit are no longer a problem in the United States due to proper water protection, treatment, and monitoring. However, many developing regions of the world still experience serious outbreaks of various waterborne diseases.

TABLE 5.1 DISEASES TRANSMITTED BY PATHOGENIC ORGANISMS IN WATER

Bacteria-Caused:
Anthrax
Bacillary Dysentery
Cholera
Gastroenteritis
Leptospirosis
Paratyphoid
Salmonellosis
Shigellosis
Typhoid Fever

Internal Parasite-Caused:
Amoebic Dysentery
Ascariasis
Cryptosporidiosis
Giardiasis
Virus-Caused:
Gastroenteritis
Heart anomalies
Infectious Hepatitis
Meningitis
Poliomyelitis

One of the cleansing processes in the treatment of safe water is called disinfection. Disinfection is the selective destruction or inactivation of pathogenic organisms. Do not confuse disinfection with sterilization. Sterilization is the complete destruction of all organisms. Sterilization is not necessary in water treatment and is also quite expensive. (Also note that disinfection does not remove toxic chemicals that could make the water unsafe to drink.)

5.01 Safe Drinking Water Act (SDWA)

5.010 Historical Regulations

In the United States, the US Environmental Protection Agency is responsible for setting drinking water standards and for ensuring their enforcement. This agency sets federal regulations that all state and local agencies must enforce. The 1976 Primary Drinking Water Regulations contain specific maximum allowable levels of substances known to be hazardous to human health. In addition to describing maximum contaminant levels (MCLs), the 1976 Primary Drinking Water Regulations also give detailed instructions on what to do when you exceed the maximum contaminant level for a particular substance. In Table 5.2 you will find an example of the Primary Drinking Water Regulations for *COLIFORM*[1] bacteria, which are supposed to be killed by disinfection. Table 5.3 lists the coliform samples required per population served.

The Safe Drinking Water Act (SDWA), originally enacted in 1974, was amended in 1980, 1986, and 1996 to expand and strengthen the protection of drinking water. The 1986 amendments, for example, authorized penalties for tampering with drinking water supplies and mandated complete elimination of lead from drinking water. The 1996 SDWA amendments required EPA to develop several new rules and regulations, including the Disinfectants/Disinfection By-Products (D/DBP) Rule, Enhanced Surface Water Treatment Rule (ESWTR), Ground Water Disinfection Rule (GWDR), Lead and Copper Rule revisions, and regulations for arsenic, radon, and sulfate.

In 1998, the Interim Enhanced Surface Water Treatment Rule (IESWTR) and the Disinfectants/Disinfection By-Products (D/DBP) Rule were signed into law, and further modifications of these two rules were developed later. The goal of the IESWTR is to reduce the occurrence of *Cryptosporidium* and other disease-causing organisms. The new D/DBP Rule was developed to protect the public from harmful concentrations of disinfectants and from trihalomethanes, which could form when disinfection by-products combine with organic matter in drinking water.

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[1] *Coliform* (KOAL-i-form). A group of bacteria found in the intestines of warm-blooded animals (including humans) and also in plants, soil, air, and water. The presence of coliform bacteria is an indication that the water is polluted and may contain pathogenic (disease-causing) organisms. Fecal coliforms are those coliforms found in the feces of various warm-blooded animals, whereas the term "coliform" also includes other environmental sources.

TABLE 5.2 MICROBIOLOGICAL STANDARDS[a]

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 (see Table 5.3).	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 upstream connection, and one from downstream. All coliform positives must be tested for presence of *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 (99.9%) removal or inactivation		If residual is less than 0.2 mg/*L*, then sampling must be every 4 hours until residual is restored.

[a] See *WATER TREATMENT PLANT OPERATION,* Volume II, Chapter 22, "Drinking Water Regulations," and the poster provided with this manual for more details.

5.011 Newer Surface Water Treatment Rules

On January 14, 2002, the EPA promulgated the Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR). The purpose of this rule is to improve public health protection through the control of microbial contaminants, particularly *Cryptosporidium* and to prevent significant increases in microbial risk that might otherwise occur when systems implement the Stage 1 Disinfectants and Disinfection By-Products Rule.

On December 15, 2005, the EPA promulgated the Long Term 2 Enhanced Surface Water Treatment Rule (LT2), which increases the monitoring and treatment requirements for water systems that are prone to outbreaks such as *Cryptosporidium.* A purpose of this rule is to reduce the risk of disease-causing microorganisms from entering drinking water systems. This rule also contains provisions to reduce risks from uncovered finished water reservoirs and to ensure that systems maintain microbial protection when they take steps to decrease the formation of disinfection by-products that results from chemical water treatment.

The major provisions of these rules include the control of *Cryptosporidium* and combined filter effluent (CFE) turbidity performance standards. Turbidity monitoring requirements are also included in these rules.

5.012 Newer Disinfectants and Disinfection By-Products (D/DBP) Rules

On December 15, 2005, EPA promulgated the Stage 2 Disinfection By-Products (Stage 2 D/DBP) Rule, which establishes standards for controlling the harmful by-products of drinking water disinfection measures. A purpose of this rule is to limit the amount of potentially harmful disinfection by-products that end up in drinking water systems. The rule strengthens public health protection for consumers by tightening compliance monitoring requirements for two groups of DBPs: total trihalomethanes (TTHMs) and haloacetic acids (HAA5). The rule targets systems with the greatest risk. It will reduce potential health risks related to DBP exposure and provide more equitable public health protection.

5.013 New Ground Water Rule (GWR)

On October 11, 2006, the final Ground Water Rule (GWR) (formerly called the Ground Water Disinfection Rule (GWDR)) was signed by the USEPA Administrator to protect the public from pathogen contamination in water systems that use groundwater. Pathogens are microorganisms, such as bacteria *(E. Coli),* viruses, and protozoa, such as *Cryptosporidium* and *Giardia lamblia.* Essentially, the GWR aims to identify operating deficiencies in water systems and requires them to do more frequent monitoring.

TABLE 5.3 TOTAL COLIFORM SAMPLING REQUIREMENTS ACCORDING TO POPULATION SERVED

Population Served	Minimum Number of Routine Samples Per Month[a]	Population Served	Minimum Number of Routine Samples Per Month[a]
25 to 1,000[b]	1[c]	59,001 to 70,000	70
1,001 to 2,500	2	70,001 to 83,000	80
2,501 to 3,300	3	83,001 to 96,000	90
3,301 to 4,100	4	96,001 to 130,000	100
4,101 to 4,900	5	130,001 to 220,000	120
4,901 to 5,800	6	220,001 to 320,000	150
5,801 to 6,700	7	320,001 to 450,000	180
6,701 to 7,600	8	450,001 to 600,000	210
7,601 to 8,500	9	600,001 to 780,000	240
8,501 to 12,900	10	780,001 to 970,000	270
12,901 to 17,200	15	970,001 to 1,230,000	300
17,201 to 21,500	20	1,230,001 to 1,520,000	330
21,501 to 25,000	25	1,520,001 to 1,850,000	360
25,001 to 33,000	30	1,850,001 to 2,270,000	390
33,001 to 41,000	40	2,270,001 to 3,020,000	420
41,001 to 50,000	50	3,020,001 to 3,960,000	450
50,001 to 59,000	60	3,960,001 or more	480

[a] A noncommunity water system using groundwater and serving 1,000 persons or fewer may monitor at a lesser frequency specified by the state until a sanitary survey is conducted and the state reviews the results. Thereafter, noncommunity water systems using groundwater and serving 1,000 persons or fewer must monitor in each calendar quarter during which the system provides water to the public, unless the state determines that some other frequency is more appropriate and notifies the system (in writing). In all cases, noncommunity water systems using groundwater and serving 1,000 persons or fewer must monitor at least once/year.

A noncommunity water system using surface water, or groundwater under the direct influence of surface water, regardless of the number of persons served, must monitor at the same frequency as a like-sized community public system. A noncommunity water system using groundwater and serving more than 1,000 persons during any month must monitor at the same frequency as a like-sized community water system, except that the state may reduce the monitoring frequency for any month the system serves 1,000 persons or fewer.

[b] Includes public water systems that have at least 15 service connections, but serve fewer than 25 persons.

[c] For a community water system serving 25 to 1,000 persons, the state may reduce this sampling frequency if a sanitary survey conducted in the last five years indicates that the water system is supplied solely by a protected groundwater source and is free of sanitary defects. However, in no case may the state reduce the sampling frequency to less than once/quarter.

The GWR applies to all systems using groundwater and it takes a targeted, risk-based approach. There are no mandatory disinfection requirements, but the rule does build on existing state programs and provides flexibility in defining significant deficiencies.

A significant deficiency refers to a problem that could have immediate potential to affect public health. Some possible examples include:

- Maximum contaminant level violations
- Not enough chlorine contact time
- Insufficient water for normal demand
- Not enough disinfectant residual to meet the minimum requirement
- No licensed operator for the water system

Under the GWR, primacy agencies must complete a sanitary survey of treatment plants that identifies any problems that could cause contamination. A hydrogeology sensitivity assessment must also be completed to determine the groundwater's vulnerability to contamination. For those water systems that use groundwater and that do not disinfect, the rule requires continuous monitoring for susceptible systems. For systems that disinfect, a

4-log (99.9 percent) inactivation of viruses should be demonstrated.

5.02 Newer and Proposed Regulations

To help operators and managers quickly learn the basics of newer and proposed drinking water regulations, the USEPA has developed a "Compilation of Quick Reference Guides." These guides provide information such as: (1) an overview of the rules, (2) public health-related benefits, (3) critical deadlines and requirements, (4) compliance determinations, and (5) monitoring requirements.

If you would like to know how new and proposed rules and regulations apply specifically to your water supply system, contact your local drinking water regulator or visit the USEPA website at www.epa.gov/safewater/standards.html. Also, a phone call to EPA's Safe Drinking Water Hotline at (800) 426-4791 can be very helpful.

Operators are urged to develop close working relationships with their state regulatory agencies to keep themselves informed of the expected future changes in regulations.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 349.

5.0A What are pathogenic organisms?

5.0B What is disinfection?

5.0C Drinking water standards are established by what agency of the United States government?

5.0D MCL stands for what words?

5.1 FACTORS INFLUENCING DISINFECTION

5.10 pH

The pH of water being treated can alter the efficiency of disinfectants. Chlorine, for example, disinfects water much faster at a pH around 7.0 than at a pH over 8.0.

5.11 Temperature

Temperature conditions also influence the effectiveness of the disinfectant. The higher the temperature of the water, the more efficiently it can be treated. Water near 70 to 85°F (21 to 29°C) is easier to disinfect than water at 40 to 60°F (4 to 16°C). Longer contact times are required to disinfect water at lower temperatures. To speed up the process, operators often simply use larger amounts of chemicals. Where water is exposed to the atmosphere, the warmer the water temperature, the greater the dissipation rate of chlorine into the atmosphere.

5.12 Turbidity

Under normal operating conditions, the turbidity level of water being treated is very low by the time the water reaches the disinfection process. Excessive turbidity will greatly reduce the efficiency of the disinfecting chemical or process. Studies in water treatment plants have shown that when water is filtered to a turbidity of one unit or less, most of the bacteria have been removed.

The suspended matter itself may also change the chemical nature of the water when the disinfectant is added. Some types of suspended solids can create a continuing demand for the chemical, thus changing the effective germicidal (germ killing) properties of the disinfectant.

5.120 Organic Matter

Organics found in the water can consume great amounts of disinfectants while forming unwanted compounds. *TRIHALOMETHANES*[2] are an example of undesirable compounds formed by reactions between chlorine and certain organics. Disinfecting chemicals often react with organics and *REDUCING AGENTS*[3] (Section 5.13). Then, if any of the chemical remains available after this initial reaction, it can act as an effective disinfectant. The reactions with organics and reducing agents, however, will have significantly reduced the amount of chemical available for disinfection.

5.121 Inorganic Matter

Inorganic compounds such as ammonia (NH_3) in the water being treated can create special problems. In the presence of ammonia, some oxidizing chemicals form side compounds causing a partial loss of disinfecting power. Silt can also create a chemical demand. It is clear, then, that the chemical properties of the water being treated can seriously interfere with the effectiveness of disinfecting chemicals.

5.13 Reducing Agents

Chlorine combines with a wide variety of materials, especially reducing agents. Most of the reactions are very rapid, while others are much slower. These side reactions complicate the use of chlorine for disinfection. The demand for chlorine by reducing agents must be satisfied before chlorine becomes available to accomplish disinfection. Examples of inorganic reducing agents present in water that will react with chlorine include hydrogen sulfide (H_2S), ferrous ion (Fe^{2+}), manganous ion (Mn^{2+}), ammonia (NH_3), and the nitrite ion (NO_2^-). Organic reducing agents in water also will react with chlorine and form chlorinated organic materials of potential health significance.

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[2] *Trihalomethanes (THMs)* (tri-HAL-o-METH-hanes). Derivatives of methane, CH_4, in which three halogen atoms (chlorine or bromine) are substituted for three of the hydrogen atoms. Often formed during chlorination by reactions with natural organic materials in the water. The resulting compounds (THMs) are suspected of causing cancer.

[3] *Reducing Agent.* Any substance, such as base metal (iron) or the sulfide ion (S^{2-}), that will readily donate (give up) electrons. The opposite is an OXIDIZING AGENT.

5.14 Microorganisms

5.140 Number and Types of Microorganisms

The concentration of microorganisms is important because the higher the number of microorganisms, the greater the demand for a disinfecting chemical. The resistance of microorganisms to specific disinfectants varies greatly. Non-spore-forming bacteria are generally less resistant than spore-forming bacteria. Cysts and viruses can be very resistant to certain types of disinfectants.

5.141 Removal Processes

Pathogenic organisms can be removed from water, killed, or inactivated by various physical and chemical water treatment processes. These processes are:

1. *COAGULATION.* Chemical coagulation followed by sedimentation and filtration will remove 90 to 95 percent of the pathogenic organisms, depending on which chemicals are used. Alum usage can increase virus removals up to 99 percent.
2. *SEDIMENTATION.* Properly designed sedimentation processes can effectively remove 20 to 70 percent of the pathogenic microorganisms. This removal is accomplished by allowing the pathogenic organisms (as well as non-pathogenic organisms) to settle out by gravity, assisted by chemical floc.
3. *FILTRATION.* Filtering water through granular filters is an effective means of removing pathogenic and other organisms from water. The removal rates vary from 20 to 99+ percent depending on the coarseness of the filter media and the type and effectiveness of pretreatment.
4. *DISINFECTION.* Disinfection chemicals such as chlorine are added to water to kill or inactivate pathogenic microorganisms.

In Chapter 4, you have studied the first three processes and were introduced to the disinfection methods used in small plants. This chapter provides an in-depth look at the principles and methods of disinfection.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 349.

5.1A How does pH influence the effectiveness of disinfection with chlorine?

5.1B How does the temperature of the water influence disinfection?

5.1C What two factors influence the effectiveness of disinfection on microorganisms?

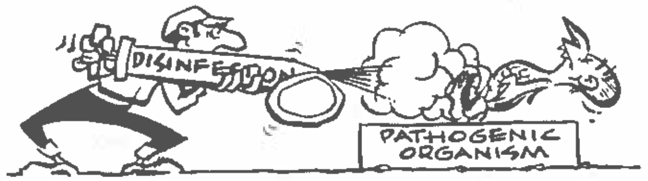
5.2 PROCESS OF DISINFECTION

5.20 Purpose of Process

The purpose of disinfection is to destroy harmful organisms. This can be accomplished either physically or chemically. Physical methods may: (1) physically remove the organisms from the water, or (2) introduce motion that will disrupt the cells' biological activity and kill or inactivate them.

Chemical methods alter the cell chemistry causing the microorganism to die. The most widely used disinfectant chemical is chlorine. Chlorine is easily obtained, relatively cheap, and most importantly, leaves a *RESIDUAL CHLORINE*[4] that can be measured. Other disinfectants are also used. There has been increased interest in disinfectants other than chlorine because of the *CARCINOGENIC*[5] compounds that chlorine may form (trihalomethanes or THMs).

This chapter will focus primarily on the use of chlorine as a disinfectant. However, let us take a brief look first at other disinfection methods and chemicals. Some of these are being more widely applied today because of the potential adverse side effects of chlorination.



5.21 Agents of Disinfection

5.210 Physical Means of Disinfection

A. *ULTRAVIOLET RAYS* can be used to destroy pathogenic microorganisms. To be effective, the rays must come in contact with each microorganism. The ultraviolet energy disrupts various organic components of the cell causing a biological change that is fatal to the microorganisms.

This system has not had widespread acceptance because of the lack of measurable residual and the cost of operation. Currently, use of ultraviolet rays is limited to small or local systems and industrial applications. Ocean-going ships have used these systems for their water supply.

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[4] *Residual Chlorine.* The concentration of chlorine present in water after the chlorine demand has been satisfied. The concentration is expressed in terms of the total chlorine residual, which includes both the free and combined or chemically bound chlorine residuals. Also called CHLORINE RESIDUAL.

[5] *Carcinogen* (kar-SIN-o-jen). Any substance that tends to produce cancer in an organism.

Advances in UV technology and concern about disinfection by-products (DBPs) produced by other disinfectants have prompted a renewed interest in UV disinfection. See *WATER TREATMENT PLANT OPERATION,* Volume I, Chapter 7, Section 7.9, "Disinfection Using Ultraviolet (UV) Systems," for a more detailed description of this process.

B. *HEAT* has been used for centuries to disinfect water. Boiling water for about 5 minutes will destroy essentially all microorganisms. This method is very energy intensive and thus very expensive. The only practical application is in the event of a disaster when individual local users are required to boil their water.

C. *ULTRASONIC WAVES* have been used to disinfect water on a very limited scale. Sonic waves destroy the microorganism by vibration. This procedure is not yet practical and is very expensive.

5.211 Chemical Disinfectants (Other Than Chlorine)

A. *IODINE* has been used as a disinfectant in water since 1920, but its use has been limited to emergency treatment of water supplies. Although it has long been recognized as a good disinfectant, iodine's high cost and potential physiological effects (pregnant women can suffer serious side effects) have prevented widespread acceptance. The recommended dosage is two drops of iodine (tincture of iodine, which is 7 percent available iodine) in a liter of water.

B. *BROMINE* has been used only on a very limited scale for water treatment because of its handling difficulties. Bromine causes skin burns on contact. Because bromine is a very reactive chemical, residuals are hard to obtain. This also limits its use. Bromine can be purchased at swimming pool supply stores.

C. *BASES* such as sodium hydroxide and lime can be effective disinfectants but the high pH leaves a bitter taste in the finished water. Bases can also cause skin burns when left too long in contact with the skin. Bases effectively kill all microorganisms (they sterilize rather than just disinfect water). Although this method has not been used on a large scale, bases have been used to sterilize water pipes.

D. *OZONE* has been used in the water industry since the early 1900s, particularly in France. In the United States, it has been used primarily for taste and odor control. The limited use in the United States has been due to its high costs, lack of residual, difficulty in storing, and maintenance requirements.

Although ozone is effective in disinfecting water, its use is limited by its solubility. The temperature and pressure of water being treated regulate the amount of ozone that can be dissolved in the water. These factors tend to limit the disinfectant strength that can be made available to treat the water.

Many scientists claim that ozone destroys all microorganisms. Unfortunately, significant residual ozone does not guarantee that a water is safe to drink. Organic solids may protect organisms from the disinfecting action of ozone and increase the amount of ozone needed for disinfection. In addition, ozone residuals cannot be maintained in metallic conduits for any period of time because of ozone's reactive nature. The inability of ozone to provide a residual in the distribution system is a major drawback to its use. However, information about the formation of trihalomethanes by chlorine compounds has resulted in renewed interest in ozone as an alternative means of disinfection. See *WATER TREATMENT PLANT OPERATION,* Volume I, Chapter 7, Section 7.10, "Disinfection Using Ozone Systems," for a description of disinfection using ozone.

5.212 Mixed-Oxidants (MIOX) System

Mixed-oxidants disinfection systems are providing good protection from *Cryptosporidium* and *Giardia.* Field studies using mixed oxidants have achieved 99.99 percent reduction of *Giardia* after 30 minutes, and eliminated *E. coli* and cholera after 30 minutes. For more information on this process and how it works, see *WATER TREATMENT PLANT OPERATION,* Volume I, Chapter 7, Section 7.11, "Mixed-Oxidants (MIOX) System."

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 349.

5.2A List the physical agents that have been used for disinfection (chlorine is not a physical agent).

5.2B List the chemical agents other than chlorine that have been used for disinfection.

5.2C What is a major limitation to the use of ozone?

5.22 Chlorine (Cl_2)

5.220 Properties of Chlorine

Chlorine is a greenish-yellow gas with a penetrating and distinctive odor. The gas is two-and-a-half times heavier than air. Chlorine has a very high coefficient of expansion. If there is a temperature increase of 50°F (28°C) (from 35°F to 85°F or 2°C to 30°C), the volume will increase by 84 to 89 percent. This expansion could easily rupture a cylinder or a line full of liquid chlorine. For this reason, no chlorine containers should be filled to more than 85 percent of their capacity. One liter of liquid chlorine can evaporate and produce 450 liters of chlorine gas.

Chlorine by itself is nonflammable and nonexplosive, but it will support combustion. When the temperature rises, so does the vapor pressure of chlorine. This means that when the temperature increases, the pressure of the chlorine gas inside a chlorine container will increase. This property of chlorine must be considered when:

1. Feeding chlorine gas from a container
2. Dealing with a leaking chlorine cylinder

5.221 Chlorine Disinfection Action

The exact mechanism of chlorine disinfection action is not fully known. One theory holds that chlorine exerts a direct action against the bacterial cell, thus destroying it. Another theory is that the toxic character of chlorine inactivates the *ENZYMES*[6] that enable living microorganisms to use their food supply. As a result, the organisms die of starvation. From the point of view of water treatment, the exact mechanism of chlorine disinfection is less important than its demonstrated effects as a disinfectant.

When chlorine is added to water, several chemical reactions take place. Some involve the molecules of the water itself, and some involve organic and inorganic substances suspended in the water. We will discuss these chemical reactions in more detail in the next few sections of this chapter. First, however, there are some terms associated with chlorine disinfection that you should understand.

When chlorine is added to water containing organic and inorganic materials, it will combine with these materials and form chlorine compounds. If you continue to add chlorine, you will eventually reach a point where the reaction with organic and inorganic materials stops. At this point, you have satisfied what is known as the "chlorine demand."

The chemical reactions between chlorine and these organic and inorganic substances produce chlorine compounds. Some of these compounds have disinfecting properties; others do not. In a similar fashion, chlorine reacts with the water itself and produces some substances with disinfecting properties. The total of all the compounds with disinfecting properties plus any remaining free (uncombined) chlorine is known as the "chlorine residual." The presence of this measurable chlorine residual is what indicates to the operator that all possible chemical reactions have taken place and that there is still sufficient "available residual chlorine" to kill the microorganisms present in the water supply.

Now, if you add together the amount of chlorine needed to satisfy the chlorine demand and the amount of chlorine residual needed for disinfection, you will have the "chlorine dose." This is the amount of chlorine you will have to add to the water to disinfect it.

Chlorine Dose, mg/*L* = Chlorine Demand, mg/*L* + Chlorine Residual, mg/*L*

where

Chlorine Demand, mg/*L* = Chlorine Dose, mg/*L* – Chlorine Residual, mg/*L*

and

Chlorine Residual, mg/*L* = Combined Chlorine Forms, mg/*L* + Free Chlorine, mg/*L*

5.222 Reaction with Water

Free chlorine combines with water to form hypochlorous and hydrochloric acids:

Chlorine + Water ⇌ Hypochlorous Acid + Hydrochloric Acid

$$Cl_2 + H_2O \rightleftharpoons HOCl + HCl$$

Depending on the pH, hypochlorous acid may be present in the water as the hydrogen ion and hypochlorite ion (Figure 5.1).

Hypochlorous Acid ⇌ Hydrogen Ion + Hypochlorite Ion

$$HOCl \rightleftharpoons H^+ + OCl^-$$

In solutions that are dilute (low concentration of chlorine) and have a pH above 4, the formation of HOCl (hypochlorous acid) is most complete and leaves little free chlorine (Cl_2). The hypochlorous acid is a weak acid and hence is poorly dissociated (broken up into ions) at pH levels below 6. Thus, any free chlorine added to water will immediately form either HOCl or OCl^-; the species formed is controlled by the pH value of the water. The same is true for adding hypochlorite (OCl^-) to water; the pH controls whether it will form HOCl or remain as OCl^-. This is extremely important because HOCl and OCl^- differ in disinfection ability. HOCl has a much greater disinfection potential than OCl^-. Normally, in water with a pH of 7.5, approximately 50 percent of the chlorine present will be in the form of HOCl and 50 percent in the form of OCl^-. The higher the pH level, the greater the percent of OCl^-.

5.223 Reaction with Impurities in Water

Most waters that have been processed still contain some impurities. In this section, we will discuss some of the more common impurities that react with chlorine and we will examine the effects of these reactions on the disinfection ability of chlorine.

A. Hydrogen sulfide (H_2S) and ammonia (NH_3) are two inorganic substances that may be found in water when it reaches the disinfection stage of treatment. Their presence can complicate the use of chlorine for disinfection purposes. This is because hydrogen sulfide and ammonia are what is known as "reducing agents." That is, they give up electrons easily. Chlorine reacts rapidly with these particular reducing agents producing some undesirable results.

Hydrogen sulfide produces an odor that smells like rotten eggs. It reacts with chlorine to form sulfuric acid and elemental sulfur (depending on temperature, pH, and hydrogen sulfide concentration). Elemental sulfur is objectionable because it can cause odor problems and will precipitate as finely divided white particles that are sometimes colloidal in nature.

The chemical reactions between hydrogen sulfide and chlorine are as follows:

Hydrogen Sulfide + Chlorine + Oxygen Ion → Elemental Sulfur + Water + Chloride Ions

$$H_2S + Cl_2 + O^{2-} \rightarrow S\downarrow + H_2O + 2\,Cl^-$$

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[6] *Enzymes* (EN-zimes). Organic substances (produced by living organisms) that cause or speed up chemical reactions. Organic catalysts and/or biochemical catalysts.

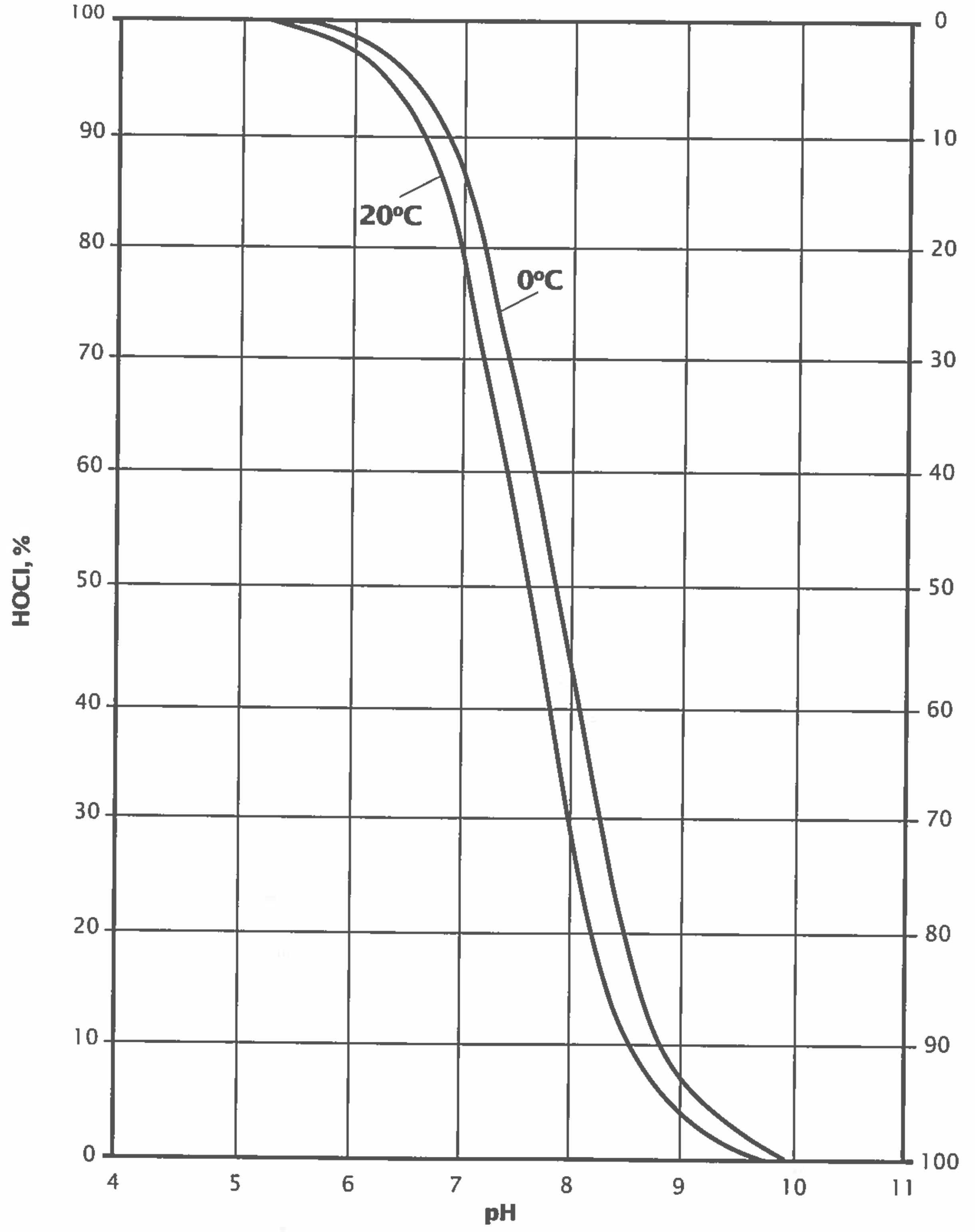

Fig. 5.1 Relationship between hypochlorous acid (HOCl), hypochlorite ion (OCl⁻), and pH

The chlorine required to oxidize hydrogen sulfide to sulfur and water is 2.08 mg/*L* chlorine to 1 mg/*L* hydrogen sulfide. The complete oxidation of hydrogen sulfide to the sulfate form is as follows:

$$\text{Hydrogen Sulfide} + \text{Chlorine} + \text{Water} \rightarrow \text{Sulfuric Acid} + \text{Hydrochloric Acid}$$

$$H_2S + 4\,Cl_2 + 4\,H_2O \rightarrow H_2SO_4 + 8\,HCl$$

Thus, 8.32 mg/*L* of chlorine are required to oxidize one mg/*L* of hydrogen sulfide to the sulfate form. Note that in both reactions, the chlorine is converted to the chloride ion (Cl^- or HCl), which has no disinfecting power and does not produce a chlorine residual. In waterworks practice, we always chlorinate to produce a chlorine residual; therefore, the second reaction (complete oxidation of hydrogen sulfide) occurs before we have any chlorine residual in the water we are treating.

When chlorine is added to water containing ammonia (NH_3), it reacts rapidly with the ammonia and forms *CHLORAMINES.*[7] This means that less chlorine is available to act as a disinfectant. As the concentration of ammonia increases, the disinfectant power of the chlorine drops off at a rapid rate.

B. When organic materials are present in water being disinfected with chlorine, the chemical reactions that take place may produce suspected carcinogenic compounds (for example, trihalomethanes). The formation of these compounds can be prevented by limiting the amount of prechlorination and by removing the organic materials prior to chlorination of the water.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 349.

5.2D How is the chlorine dosage determined?

5.2E How is the chlorine demand determined?

5.2F List two inorganic reducing chemicals with which chlorine reacts rapidly.

5.23 Hypochlorite (OCl^-)

5.230 Reactions with Water

The use of hypochlorite to treat potable water achieves the same result as chlorine gas. Hypochlorite may be applied in the form of calcium hypochlorite ($Ca(OCl)_2$) or sodium hypochlorite (NaOCl). The form of calcium hypochlorite most frequently used to disinfect water is known as High Test Hypochlorite (HTH). The chemical reactions of hypochlorite in water are similar to those of chlorine gas.

CALCIUM HYPOCHLORITE

$$\text{Calcium Hypochlorite} + \text{Water} \rightarrow \text{Hypochlorous Acid} + \text{Calcium Hydroxide}$$

$$Ca(OCl)_2 + 2\,H_2O \rightarrow 2\,HOCl + Ca(OH)_2$$

SODIUM HYPOCHLORITE

$$\text{Sodium Hypochlorite} + \text{Water} \rightarrow \text{Hypochlorous Acid} + \text{Sodium Hydroxide}$$

$$NaOCl + H_2O \rightarrow HOCl + NaOH$$

Calcium hypochlorite (HTH) is used by a number of small water supply systems. A problem occurs in these systems when sodium fluoride is injected at the same point as the hypochlorite. A severe crust forms when the calcium and fluoride ions combine.

5.231 Differences Between Chlorine Gas and Hypochlorite Compound Reactions

The only difference between the reactions of the hypochlorite compounds and chlorine gas is the side reactions of the end products. The reaction of chlorine gas tends to lower the pH (increases the hydrogen ion (H^+) concentration) by the formation of hydrochloric acid, which favors the formation of hypochlorous acid (HOCl). The hypochlorite tends to raise the pH with the formation of hydroxyl ions (OH^-) from the calcium or sodium hydroxide. At a high pH of around 8.5 or higher, the hypochlorous acid (HOCl) is almost completely dissociated to the ineffective hypochlorite ion (OCl^-) (Figure 5.1). This reaction also depends on the *BUFFER CAPACITY*[8] (amount of bicarbonate, HCO_3^-, present) of the water.

$$\text{Hypochlorous Acid} \rightleftharpoons \text{Hydrogen Ion} + \text{Hypochlorite Ion}$$

$$HOCl \rightleftharpoons H^+ + OCl^-$$

5.232 On-Site Chlorine Generation

Small water systems are generating chlorine on site for their water treatment processes. On-site generation (OSG) of process chlorine is attractive due to the lower safety hazards and costs involved. On-site generated chlorine systems produce 0.8-percent sodium hypochlorite. This limited solution strength (about $\frac{1}{15}$ the strength of commercial bleach and $\frac{1}{7}$ that of household bleach) is below the lower limit deemed a "hazardous liquid," with obvious economic and safety advantages.

Operators' only duties with on-site generation systems are to observe the control panel daily for proper operating guidelines and to dump bags of salt every few weeks. Because the assemblies (which are quite small) include an ion exchange water softener, mineral deposits forming with the electrolytic cell are minimal, with an acid cleaning being necessary only every few months. Cell voltage is controlled at a low value to maximize electrode life, which is about three years. Process brine strength

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[7] *Chloramines* (KLOR-uh-means). Compounds formed by the reaction of hypochlorous acid (or aqueous chlorine) with ammonia.

[8] *Buffer Capacity.* A measure of the capacity of a solution or liquid to neutralize acids or bases. This is a measure of the capacity of water or wastewater for offering a resistance to changes in pH.

and cell current determine chlorine production at the anode, with hydrogen gas continually vented from the cathode. The units include provisions for storing the chlorine solution in order to deliver chlorine for several days in the event of a power failure or other problems causing equipment failure.

5.24 Chlorine Dioxide (ClO_2)

5.240 Reaction in Water

Chlorine dioxide may be used as a disinfectant. Chlorine dioxide does not form carcinogenic compounds that may be formed by other chlorine compounds. Also, it is not affected by ammonia, and is a very effective disinfectant at higher pH levels. In addition, chlorine dioxide reacts with sulfide compounds, thus helping to remove them and eliminate their characteristic odors. Phenolic tastes and odors can be controlled by using chlorine dioxide.

Chlorine dioxide reacts with water to form chlorate and chlorite ions in the following manner:

Chlorine Dioxide + Water → Chlorate Ion + Chlorite Ion + Hydrogen Ions

$$2\,ClO_2 + H_2O \rightarrow ClO_3^- + ClO_2^- + 2\,H^+$$

5.241 Reactions with Impurities in Water

A. *INORGANIC COMPOUNDS*

Chlorine dioxide is an effective *OXIDIZING AGENT*[9] with iron and manganese and does not leave objectionable tastes or odors in the finished water. Because of its oxidizing ability, chlorine dioxide usage must be monitored and the dosage will have to be increased when treating waters with iron and manganese.

B. *ORGANIC COMPOUNDS*

Chlorine dioxide does not react with organics in water. Therefore, there is little danger of the formation of potentially dangerous trihalomethanes.

QUESTIONS

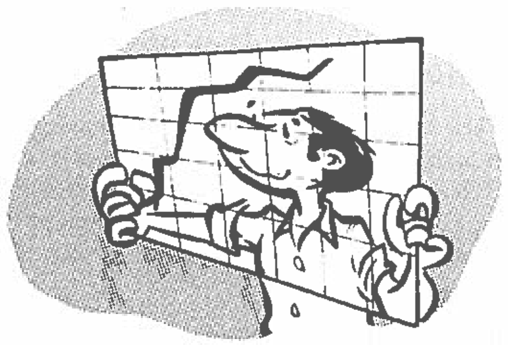
Write your answers in a notebook and then compare your answers with those on page 350.

5.2G How do chlorine gas and hypochlorite influence pH?

5.2H How does pH influence the relationship between HOCl and OCl^-?

5.25 Breakpoint Chlorination[10]

In determining how much chlorine you will need for disinfection, remember you will be attempting to produce a certain chlorine residual in the form of *FREE AVAILABLE RESIDUAL CHLORINE.*[11] Chlorine in this form has the highest disinfecting ability. "Breakpoint chlorination" is the name of this process of adding chlorine to water until the chlorine demand has been satisfied. Further additions of chlorine will result in a free available chlorine residual that is directly proportional to the amount of chlorine added beyond the breakpoint. Public water supplies are normally chlorinated past the breakpoint.



Take a moment here to look at the breakpoint chlorination curve in Figure 5.2. Assume the water being chlorinated contains some manganese, iron, nitrite, organic matter, and ammonia. Now add a small amount of chlorine. The chlorine reacts with (oxidizes) the manganese, iron, and nitrite. That is all that happens—no disinfection and no chlorine residual (Figure 5.2, points 1 to 2). Add a little more chlorine, enough to react with the organics and ammonia; *CHLORORGANICS*[12] and *CHLORAMINES*[13] will form. The chloramines produce a combined chlorine residual—a chlorine residual combined with other substances so it has lost some of its disinfecting strength. Combined residuals have rather poor disinfecting power and may cause tastes and odors (points 2 to 3).

With just a little more chlorine, the chloramines and some of the chlororganics are destroyed (points 3 to 4). Adding just one last amount of chlorine we get "free available chlorine residual" (beyond point 4)—free in the sense that it has not reacted with anything and available in that it can and will react if need be.

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[9] *Oxidizing Agent.* Any substance, such as oxygen (O_2) or chlorine (Cl_2), that will readily add (take on) electrons. When oxygen or chlorine is added to water or wastewater, organic substances are oxidized. These oxidized organic substances are more stable and less likely to give off odors or to contain disease-causing bacteria. The opposite is a REDUCING AGENT.

[10] *Breakpoint Chlorination.* Addition of chlorine to water or wastewater until the chlorine demand has been satisfied. At this point, further additions of chlorine will result in a free chlorine residual that is directly proportional to the amount of chlorine added beyond the breakpoint.

[11] *Free Available Chlorine Residual.* That portion of the total available chlorine residual composed of dissolved chlorine gas (Cl_2), hypochlorous acid (HOCl), and/or hypochlorite ion (OCl^-) remaining in water after chlorination. This does not include chlorine that has combined with ammonia, nitrogen, or other compounds.

[12] *Chlororganic* (klor-or-GAN-ick). Organic compounds combined with chlorine. These compounds generally originate from, or are associated with, living or dead organic materials, such as algae in water.

[13] *Chloramines* (KLOR-uh-means). Compounds formed by the reaction of hypochlorous acid (or aqueous chlorine) with ammonia.

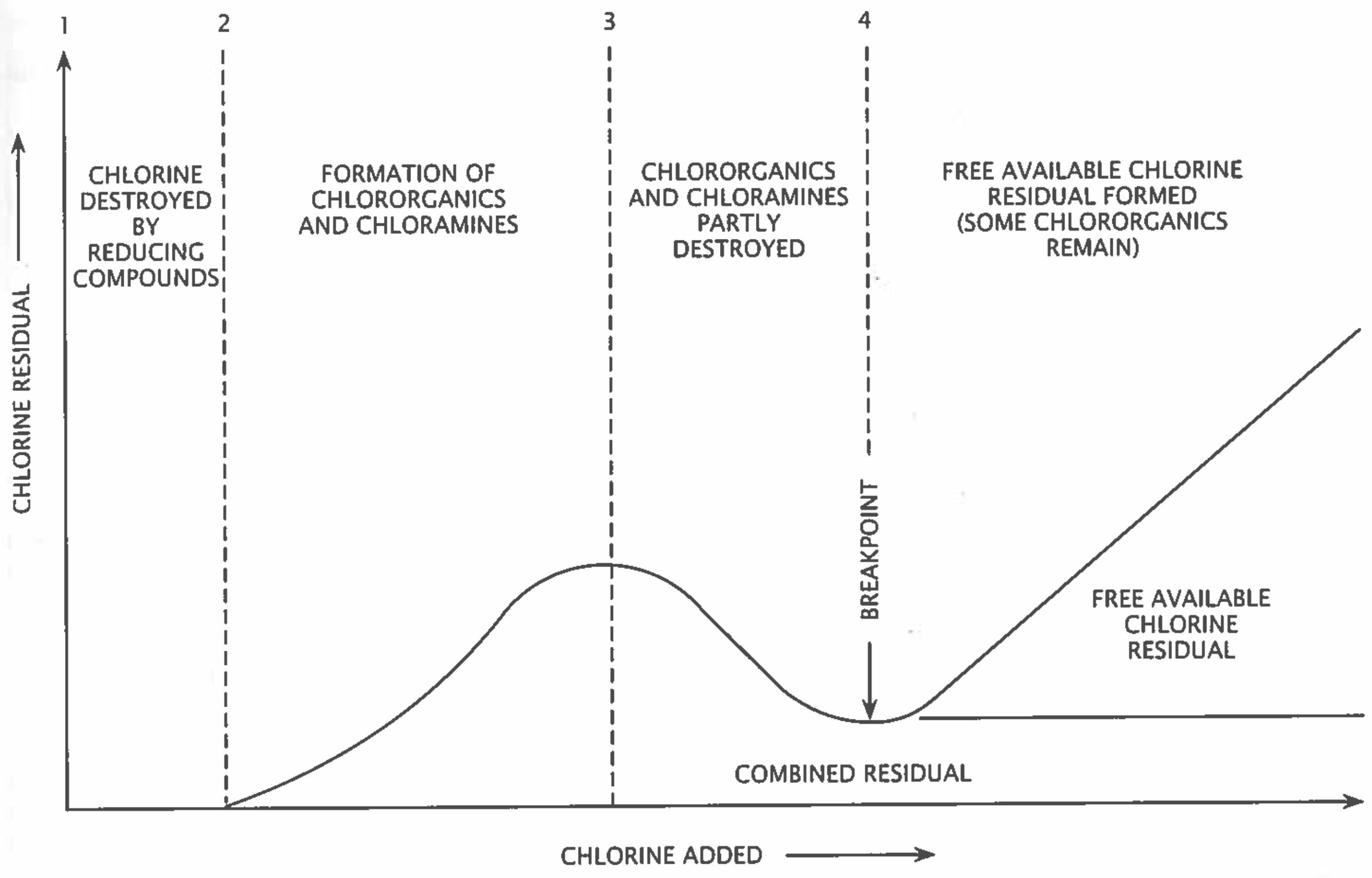

Fig. 5.2 Breakpoint chlorination curve

Free available residual chlorine is the best residual for disinfection. It disinfects faster and without the swimming-pool odor of combined residual chlorine. Free available residual chlorine begins to form at the breakpoint; the process is called "breakpoint chlorination." In water treatment plants today it is common practice to go past the breakpoint. This means that the treated water will have a low chlorine residual, but the residual will be a very effective disinfectant because it is in the form of free available chlorine residual.

CAUTION: Ammonia must be present to produce the breakpoint chlorination curve from the addition of chlorine. Sources of ammonia in raw water include fertilizer in agricultural runoff and discharges from wastewater treatment plants. High-quality raw water without any ammonia will not produce a breakpoint curve. Therefore, if there is no ammonia present in the water, and chlorinated water smells and tastes like chlorine, and a chlorine residual is present, do not add more chlorine.

In plants where trihalomethanes (THMs) are not a problem, sufficient chlorine is added to the raw water (prechlorination) to go past the breakpoint. The chlorine residual will aid coagulation, control algal problems in basins, reduce odor problems in treated water, and provide sufficient chlorine contact time to effectively kill or inactivate pathogenic organisms. Therefore, the treated water will have a very low chlorine residual, but the residual will be a very effective disinfectant.

Let us look more closely at some of the chemical reactions that take place during chlorination. When chlorine is added to waters containing ammonia (NH_3), the ammonia reacts with hypochlorous acid (HOCl) to form monochloramine, dichloramine, and trichloramine. The formation of these chloramines depends on the pH of the solution and the initial chlorine-ammonia ratio.

Ammonia + Hypochlorous Acid → Chloramine + Water

$NH_3 + HOCl \rightarrow NH_2Cl + H_2O$ Monochloramine

$NH_2Cl + HOCl \rightarrow NHCl_2 + H_2O$ Dichloramine

$NHCl_2 + HOCl \rightarrow NCl_3 + H_2O$ Trichloramine[14]

As the chlorine to ammonia-nitrogen ratio increases, the ammonia molecule becomes progressively more chlorinated. At

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[14] More commonly called nitrogen trichloride.

Cl_2:NH_3-N weight ratios higher than 7.6:1, all available ammonia is theoretically oxidized to nitrogen gas and chlorine residuals are greatly reduced. The actual Cl_2:NH_3-N ratio for breakpoint for a given source water will usually be greater than 7.6:1 (typically 10:1 for most water), depending on the levels of other substances present in the water (such as nitrite and organic nitrogen). Once this point is reached, additional chlorine dosages yield an equal and proportional increase in free available chlorine.

At the pH levels that are usually found in water (pH 6.5 to 7.5), monochloramine and dichloramine exist together. At pH levels below 5.5, dichloramine exists by itself. Below pH 4.0, trichloramine is the only compound found. The mono- and dichloramine forms have definite disinfection powers and are of interest in the measurement of chlorine residuals. Dichloramine has a more effective disinfecting power than monochloramine. However, dichloramine is not recommended as a disinfectant because of taste and odor problems. Chlorine reacts with *PHENOLIC COMPOUNDS*[15] and salicylic acid (both are leached into water from leaves and blossoms) to form *CHLOROPHENOL*,[16] which has an intense medicinal odor. This reaction goes much slower in the presence of monochloramine.

5.26 Critical Factors

Both chlorine residual and contact time are essential for effective killing or inactivation of pathogenic microorganisms. Complete initial mixing is very important. Changes in pH affect the disinfection ability of chlorine and you must reexamine the best combination of contact time and chlorine residual when the pH fluctuates. The critical factors influencing disinfection are summarized as follows:

1. Effectiveness of upstream treatment processes. The lower the turbidity (suspended solids, organic content, reducing agents) of the water, the better the disinfection.
2. Injection point and method of mixing to get disinfectant in contact with water being disinfected. Depends on whether using prechlorination or postchlorination.
3. Temperature. The higher the temperature, the more rapid the rate of disinfection.
4. Dosage and type of chemical. Usually, the higher the dosage, the faster the disinfection rate. The form (chloramines or free chlorine residual) and type of chemical also influence the disinfection rate.
5. pH. The lower the pH, the better the disinfection.
6. Contact time. With good initial mixing, the longer the contact time, the better the disinfection.
7. Chlorine residual.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 350.

5.2I What is breakpoint chlorination?

5.2J What does chlorine produce when it reacts with organic matter?

5.2K List the critical factors that influence disinfection.

5.27 Chlorine Residual Testing

Many small system operators attempt to maintain a chlorine residual throughout the distribution system. Chlorine is very effective in biological control and especially in elimination of coliform bacteria that might reach water in the distribution system through cross connections or leakage into the system. A chlorine residual also helps to control any microorganisms that could produce slimes, tastes, or odors in the water in the distribution system.

Adequate control of coliform aftergrowth is usually obtained only when chlorine residuals are carried to the farthest points of the distribution system. To ensure that this is taking place, make daily chlorine residual tests. A chlorine residual of about 0.2 mg/*L* measured at the extreme ends of the distribution system is usually a good indication that a free chlorine residual is present in all other parts of the system. This small residual can destroy a small amount of contamination, so a lack of chlorine residual could indicate the presence of heavy contamination. If routine checks at a given point show measurable residuals, any sudden absence of a residual at that point should alert the operator to the possibility that a potential problem has arisen that needs prompt investigation. Immediate action that can be taken includes retesting for chlorine residual, then checking chlorination equipment, and finally searching for a source of contamination that could cause an increase in the chlorine demand.

5.28 Chlorine Residual Curve

The chlorine residual curve procedure is a quick and easy way for an operator to estimate the proper chlorine dose, especially when surface water conditions are changing rapidly such as during a storm.

Fill a clean five-gallon bucket from a sample tap located at least two 90-degree elbows (or where chlorine is completely mixed with the water in the pipe) after the chlorine has been injected into the pipe. Immediately measure the chlorine residual and record this value on the "time zero" line of your record sheet (Figure 5.3). This is the initial chlorine residual. At 15-minute intervals, vigorously stir the bucket using an up and down motion. (A large plastic spoon works well for this purpose.) Collect a sample from one or two inches below the water surface and measure the chlorine residual. Record this chlorine residual value on the record sheet. For at least one hour, collect a sample every 15 minutes, measure the chlorine residual, and record the results to indicate the chlorine demand of the treated water. Plot these recorded values on a chart or graph paper as shown on Figure 5.3. Connect the plotted points to create a chlorine residual curve. If the chlorine residual after one hour is not correct (about 0.2 mg/*L*), increase or decrease the initial chlorine dose so the final chlorine residual will be approximately at the desired ultimate chlorine residual in the water distribution system. Repeat this procedure until the desired target initial chlorine residual will achieve the desired chlorine residual throughout the distribution system.

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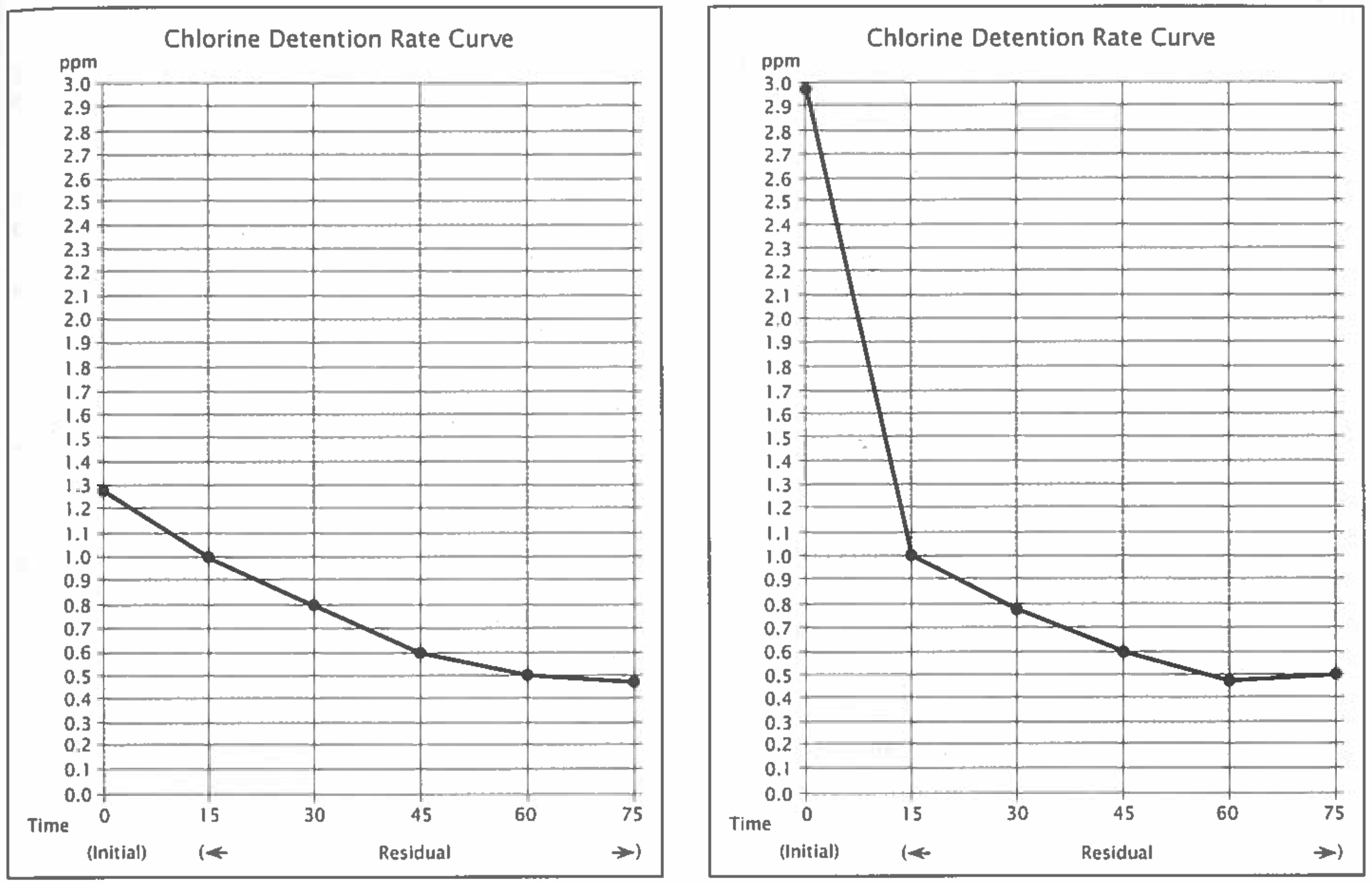
[15] *Phenolic* (fee-NO-lick) *Compounds.* Organic compounds that are derivatives of benzene. Also called phenols (FEE-nolls).

[16] *Chlorophenolic* (KLOR-o-fee-NO-lick). Chlorophenolic compounds are phenolic compounds (carbolic acid) combined with chlorine.



Average surface water
(moderate to low turbidity)

Alaskan river water and water from
tundra ponds and catchment basins
(high organic load)

Fig. 5.3 Chlorine detention rate curves

Precautions that must be taken when performing this test include being sure the five-gallon plastic test bucket is clean and only used for this purpose. A new bucket does not need to be used for every test, but the bucket should be new when the first test is performed. The stirrer should also be clean. Do not use the stirrer for the chlorine solution mixing and holding tank. During the test, the bucket should be kept cool so that the chlorine gas does not escape from the water and give false chlorine residual values.

The chlorine demand for groundwater changes slowly, or not at all; therefore, the initial or target chlorine residual does not have to be checked more frequently than once a month. Always be sure to measure the chlorine residual in the distribution system on a daily basis. This is also a good check that the chlorination equipment is working properly and that the chlorine stock solution is the correct concentration.

The chlorine demand for surface water can change continuously, especially during storms and the snow melt season. Experience has proven that the required initial or target chlorine residual at time zero is directly tied to the turbidity of the finished (treated) water. The higher the finished water turbidity, the higher the initial chlorine residual value will have to be to ensure the desired chlorine residual in the distribution system. Careful documentation of this information in your records will greatly reduce the lag time in chlorine addition changes to maintain the desired residual in the distribution system and the delivery of safe drinking water to your consumers. Experience and a review of your records will indicate that for a given turbidity value, you can estimate the desired initial chlorine residual, which will require a given chlorinator output level for a given water flow rate.

Acknowledgment

The information in Sections 5.27 and 5.28 was developed by Bill Stokes. His suggestions and procedures are greatly appreciated.

5.29 Chloramination

by David Foust

5.290 Use of Chloramines

Chloramines have been used as an alternative disinfectant by water utilities since the 1930s. An operator's decision to use chloramines depends on several factors, including the quality of the raw water, the ability of the treatment plant to meet various regulations, operational practices, and distribution system characteristics. Chloramines have proven effective in accomplishing the following objectives:

1. Reducing the formation of trihalomethanes (THMs) and other disinfection by-products (DBPs)
2. Maintaining a detectable residual throughout the distribution system
3. Penetrating the biofilm (the layer of microorganisms on pipeline walls) and reducing the potential for coliform regrowth
4. Killing or inactivating *HETEROTROPHIC*[17] plate count bacteria
5. Reducing taste and odor problems

5.291 Methods for Producing Chloramines

There are three primary methods by which chloramines are produced: (1) preammoniation followed by chlorination, (2) addition of chlorine and ammonia at the same time (concurrently), and (3) prechlorination/postammoniation.

1. *PREAMMONIATION FOLLOWED BY CHLORINATION*

   In this method, ammonia is applied at the rapid-mix unit process and chlorine is added downstream at the entrance to the flocculation basins. This approach usually produces lower THM levels than the postammoniation method. Preammoniation to form chloramines (monochloramine) does not produce phenolic tastes and odors, but this method may not be as effective as postammoniation for controlling tastes and odors associated with *DIATOMS*[18] and anaerobic bacteria in source waters.

2. *CONCURRENT ADDITION OF CHLORINE AND AMMONIA*

   In this method, chlorine is applied to the plant influent and, at the same time or immediately thereafter, ammonia is introduced at the rapid-mix unit process. Concurrent chloramination produces the lowest THM levels of the three methods.

3. *PRECHLORINATION/POSTAMMONIATION*

   In prechlorination/postammoniation, chlorine is applied at the head of the plant and a free chlorine residual is maintained throughout the plant processes. Ammonia is added at the plant effluent to produce chloramines. Because of the longer free chlorine contact time, this application method will result in the formation of more THMs, but it may be necessary to use this method to meet the disinfection requirements of the Surface Water Treatment Rule (SWTR). A major limitation of using chloramine residuals is that chloramines are less effective as a disinfectant than free chlorine residuals.

5.292 Chlorine to Ammonia-Nitrogen Ratios

After a method of chloramine application has been selected, the best ratio of chlorine to ammonia-nitrogen (by weight) and the desired chloramine residual for each system must be determined. A dosage of three parts of chlorine to one part ammonia (3:1) will form monochloramines. This 3:1 ratio provides an excess of ammonia-nitrogen, which will be available to react with any chlorine added in the distribution system to boost the chloramine residual.

Higher chlorine to ammonia-nitrogen weight ratios such as 4:1 and 5:1 also have been used successfully by many water agencies. However, the higher the chlorine to ammonia-nitrogen ratio, the less excess ammonia will be available for rechlorination. Some agencies have found it necessary to limit the amount of excess available ammonia to prevent incomplete *NITRIFICATION*.[19]

Monochloramines form combined residual chlorine (rising part of curve in Figure 5.4) as the chlorine dose is increased in the presence of ammonia. As the chlorine dose increases, the combined residual increases and excess ammonia decreases. The maximum chlorine to ammonia ratio that can be achieved is 5:1. At a chlorine dose above the 5:1 ratio, the combined residual actually decreases and the total ammonia-nitrogen also begins to decrease as it is oxidized by the additional chlorine. Dichloramines form during this oxidation and may cause tastes and odors. As the chlorine dose is further increased, breakpoint chlorination will eventually occur. Trichloramines are formed past the breakpoint and also may form tastes and odors. As with breakpoint chlorination, further additions of chlorine will result in a chlorine residual that is proportional to the amount of chlorine added beyond the breakpoint.

Calculating the chlorine to ammonia-nitrogen ratio on the basis of actual quantity of chemicals applied can lead to incorrect conclusions regarding the finished water quality. In applications in which chlorine is injected before the ammonia, chlorine demand in the water will reduce the amount of chlorine available to form the combined residual. In such applications the *applied* ratio will be greater than the *actual* ratio of chlorine to ammonia-nitrogen leaving the plant.

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[17] *Heterotrophic* (HET-er-o-TROF-ick). Describes organisms that use organic matter for energy and growth. Animals, fungi, and most bacteria are heterotrophs.

[18] *Diatoms* (DYE-uh-toms). Unicellular (single cell), microscopic algae with a rigid, box-like internal structure consisting mainly of silica.

[19] *Nitrification* (NYE-truh-fuh-KAY-shun). An aerobic process in which bacteria oxidize the ammonia and organic nitrogen in water into nitrite and then nitrate.

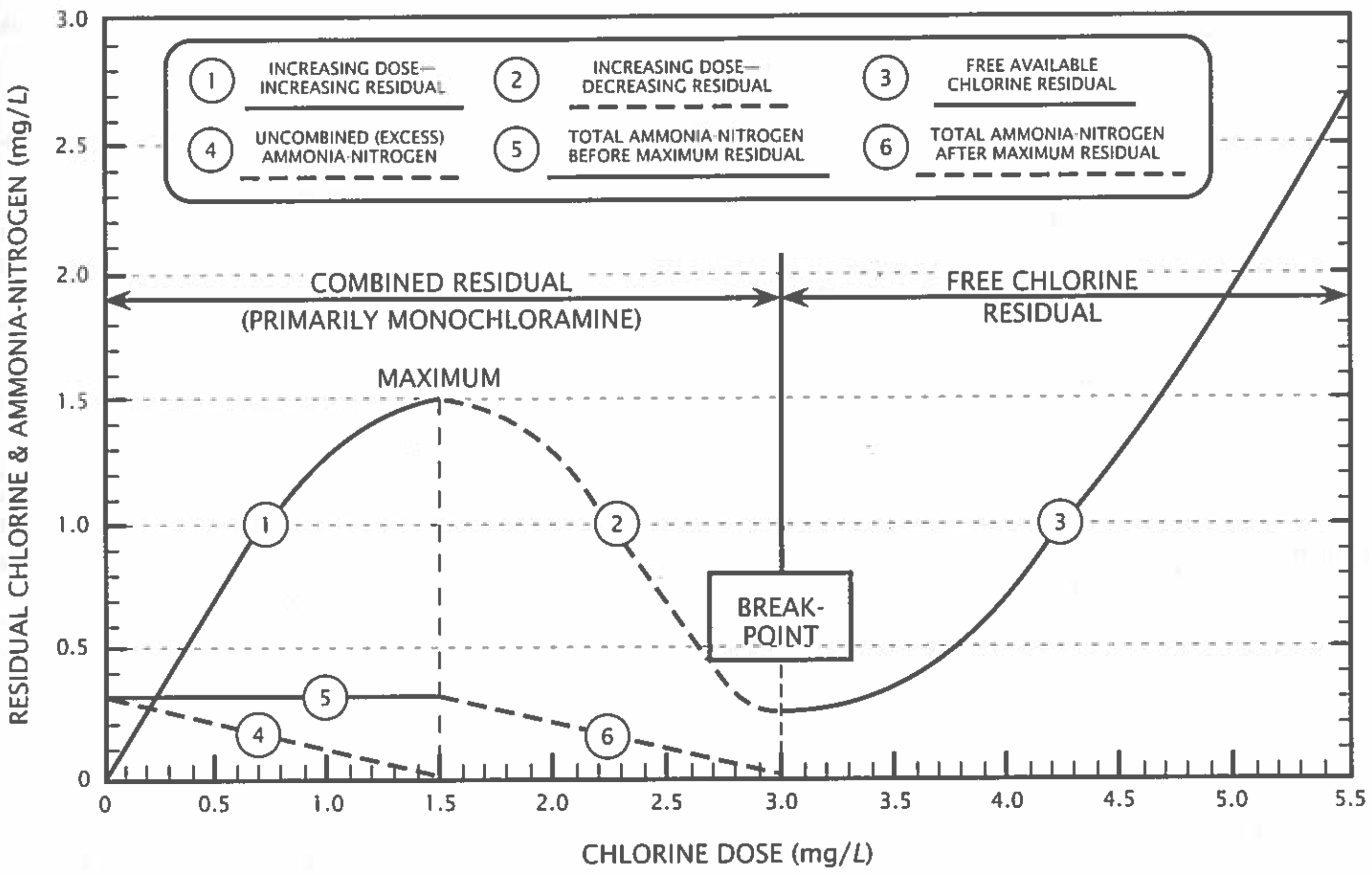


Fig. 5.4 Typical chloramination dose-residual curve

As an example, assume that an initial dosage of 5.0 mg/*L* results in a free chlorine residual of 3.5 mg/*L* at the ammonia application point; it can be concluded that a chlorine demand of 1.5 mg/*L* exists. If ammonia-nitrogen is applied at a dose of 1.0 mg/*L*, the applied chlorine to ammonia-nitrogen ratio is 5:1, whereas the actual ratio in water leaving the plant is only 3.5:1.

5.293 Special Water Users

Although chloramines are nontoxic to healthy humans, they can have a weakening effect on individuals with kidney disease who must undergo kidney dialysis. Chloramines must be removed from the water used in the dialysis treatments. Granular activated carbon and ascorbic acid are common substances used to reduce chloramine residuals. All special water users should be notified before chloramines are used as a disinfectant in municipal waters.

Also, like free chlorine, chloramines can be deadly to fish. They can damage gill tissue and enter the red blood cells causing a sudden and severe blood disorder. For this reason, all chloramine compounds must be removed from the water prior to any contact with fish.

5.294 Blending Chloraminated Waters

Care must be taken when blending chloraminated water with water that has been disinfected with free chlorine. Depending on the ratio of the blend, these two different disinfectants can cancel each other out resulting in very low disinfectant residuals. When chlorinated water is blended with chloraminated water, the chloramine residual will decrease after the excess ammonia has been combined (Figure 5.4). Knowing the amount of uncombined ammonia available is important in determining how much chlorinated water can be blended with a particular chloraminated water without significantly affecting the monochloramine residual. Knowing how much uncombined ammonia-nitrogen is available is also important before you make any attempt to boost the chloramine residual by adding chlorine.

5.295 Chloramine Residuals

When measuring combined chlorine residuals (chloramines) in the field, analyze for total chlorine. No free chlorine should be present at chlorine to ammonia-nitrogen ratios of 3:1 to 5:1. Care must be taken when attempting to measure free chlorine with chloraminated water because the chloramine residual will interfere with the DPD method for measuring free chlorine. (See Section 5.5, "Measurement of Chlorine Residual," for more specific information about the methods commonly used to measure chlorine residuals, including the DPD method.)

5.296 Nitrification

Nitrification is an important and effective microbial process in the oxidation of ammonia in both land and water environments. Two groups of organisms are involved in the nitrification process: ammonia-oxidizing bacteria (AOB) (see Figure 5.5) and nitrite-oxidizing bacteria. Nitrification has been well recognized as a beneficial treatment for the removal of ammonia in municipal wastewater.

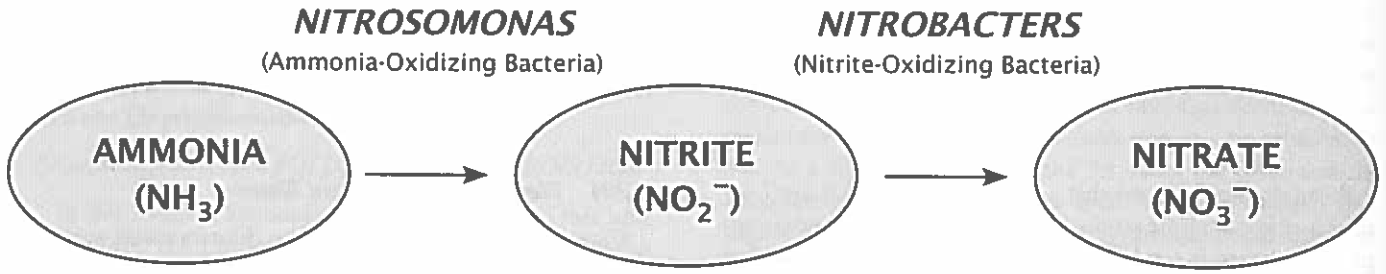
When nitrification occurs in chloraminated drinking water, however, the process may lower the water quality unless the nitrification process reaches completion. Incomplete or partial nitrification causes the production of nitrite from the growth of AOB (ammonia-oxidizing bacteria, see Figure 5.5). This nitrite, in turn, rapidly reduces free chlorine and can interfere with the measurement of free chlorine. The end result may be a loss of total chlorine and ammonia and an increase in the concentration of heterotrophic plate count bacteria.

Factors influencing nitrification include the water temperature, the detention time in the reservoir or distribution system, excess ammonia in the water system, and the chloramine concentration used. The conditions most likely to lead to nitrification when using chloramines are a pH of 7.5 to 8.5, a water temperature of 25 to 30°C, a free ammonia concentration in the water, and a dark environment. The danger in allowing nitrification episodes to occur is that you may be left with very low or no total chlorine residual.

5.297 Nitrification Prevention and Control

When using chloramines for disinfection, an early warning system should be developed to detect the signs that nitrification is beginning to occur so that you can prevent or at least control the nitrification process. The best way to do this is to set up a regularly scheduled monitoring program. The warning signs to watch for include: decreases in the ammonia level, total chlorine level, and pH; increases in the nitrite level; and an increase in heterotrophic plate count bacteria. In addition, action response levels should be established for chloraminated distribution systems and reservoirs. Normal background levels of nitrite should be measured and then alert levels should be established so that increasing nitrite levels will not be overlooked.

Nitrification is a biological process caused by naturally occurring ammonia-oxidizing bacteria. These bacteria feed on free ammonia and convert it to nitrite and then nitrate. They thrive in covered reservoirs during warm summer months and are very resistant to chloramine disinfection. The by-products of their biological breakdown can support the growth of coliform bacteria.



Factors Influencing

- Water Temperature
- Detention Time
- Excess Ammonia
- Chloramine Concentration

Early Warning Signs

- Decrease in Ammonia
- Decrease in Chlorine
- Decrease in pH
- Increase in Nitrite
- Increase in Plate Count Bacteria

Optimum Conditions

- pH 7.5-8.5
- Temp. 25-30°C
- Free Ammonia
- Dark Environment

Prevention and Control

- Decrease Detention Times
- Decrease Free Ammonia
- Increase Disinfection Dosage Ratio
- Breakpoint Chlorinate
- Establish a Flushing Program

Fig. 5.5 The nitrification process

An inexpensive way to help keep nitrite levels low is to reduce the detention times through the reservoirs and the distribution system, especially during warmer weather. Adding more chlorine to reservoir inlets and increasing the chlorine to ammonia-nitrogen ratio from 3:1 up to 5:1 at the treatment plant effluent will further control nitrification by decreasing the amount of uncombined ammonia in the distribution system. However, at a chlorine and ammonia-nitrogen ratio of 5:1, it is critical that the chlorine and ammonia feed systems operate accurately and reliably because an overdose of chlorine can reduce the chloramine residual.

Other strategies for controlling nitrification include establishing a flushing program and increasing the chloramine residual. A uniform flushing program should be a key component of any nitrification control program. Flushing reduces the detention time in low-flow areas, increases the water velocity within pipelines to remove sediments and biofilm that would harbor nitrifying bacteria, and draws higher disinfectant residuals into problem areas. Increasing the chloramine residual in the distribution system to greater than 2.0 mg/*L* is also effective in preventing the onset of nitrification.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 350.

5.2L An operator's decision to use chloramines as a disinfectant depends on what factors?

5.2M What are the three primary methods by which chloramines are produced?

5.2N Why is the *applied* chlorine to ammonia-nitrogen ratio usually greater than the *actual* chlorine to ammonia-nitrogen ratio leaving the plant?

5.2O Incomplete nitrification causes the production of nitrite, which produces what problems in disinfection of water?

5.3 POINTS OF CHLORINE APPLICATION

5.30 Wells and Pumps[20]

5.300 Disinfecting New and Existing Wells

When a new well is completed, it is necessary to disinfect the well, pump, screen, and piping because they all could have been contaminated during construction. Consideration must also be given to the fact that the aquifer accessed by the well could have been contaminated, as well, during the drilling process. A 50-mg/*L* residual of free chlorine in contact with all surfaces is recommended. Disinfection is usually accomplished by using a chlorine solution applied into the well and the aquifer accessed by the well. To accomplish this process, the use of sodium hypochlorite is recommended. As previously mentioned, 50 mg/*L* is needed and 24 hours of contact time is recommended. At the end of this period, pump the well until all evidence of a chlorine residual is gone. Then, take a sample and test for *TOTAL COLIFORMS*[21] to determine the effectiveness of the chlorine dosage.

When disinfecting a well, the application of chlorine through the pump column pipe has certain advantages. Organic matter such as oil may be used during drilling and may end up floating on the water surface. Therefore, if the well is disinfected by injecting the chlorine solution through the vent pipe, the chlorine solution should have an initial concentration of about 1,000 mg/*L* because it must be able to penetrate the oil on the surface. If the chlorine solution is applied to the well by injecting the chlorine through the pump column pipe, a chlorine dosage of 100 mg/*L* is acceptable. By using the pump column pipe rather than the vent pipe, any drilling oil on the water surface is avoided and the large amount of chlorine is not needed.

5.301 Sample Problem

FORMULAS

To disinfect a well, the first step is to determine the volume of water in the well. There are three approaches to calculating the volume of water in a well.

1. Calculate the volume of water using the diameter of the casing and the depth of water.

$$\text{Volume, gal} = \frac{(0.785)(\text{Diameter, in})^2(\text{Depth, ft})(7.48\text{ gal/cu ft})}{144\text{ sq in/sq ft}}$$

2. When the depth of water in a well changes from time to time, many operators calculate a constant for their well in terms of gallons of water per foot of water in the well.

$$\text{Volume, gal/ft} = \frac{(0.785)(\text{Diameter, in})^2(7.48\text{ gal/cu ft})}{144\text{ sq in/sq ft}}$$

3. Sometimes, tables are available that allow you to find the volume in gallons per foot from the table if you know the diameter of the casing.

To find the pounds of chlorine needed to disinfect a well, we need to know the volume of water in gallons and the desired chlorine dose in milligrams per liter. Convert the volume in gallons to million gallons by dividing by 1,000,000.

$$\text{Volume, M Gal} = \frac{\text{Volume, Gal}}{1{,}000{,}000/\text{Million}}$$

$$\boxed{\text{Chlorine, lbs} = (\text{Volume, M Gal})(\text{Dose, mg}/L)(8.34\text{ lbs/gal})}$$

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[20] Also see Chapter 3, Section 3.5, "Disinfection of Wells and Pumps."

[21] *Total Coliforms.* See coliform testing procedures in Chapter 7, "Laboratory Procedures."

We can prove the above formula if we know that one liter of water weighs 1,000,000 mg.

$$\text{Chlorine, lbs} = (\text{Volume, M Gal})\left(\frac{\text{Dose, mg}}{1{,}000{,}000\text{ mg}}\right)(8.34\text{ lbs/gal})$$

Note that the dose is now in milligrams per million milligrams, or parts per million. Now, change the milligrams to pounds so we will have dose, pounds chlorine per million pounds of water.

$$\text{Chlorine, lbs} = (\text{Volume, M Gal})\left(\frac{\text{Dose, lbs}}{\text{M lbs}}\right)(8.34\text{ lbs/gal})$$

To calculate the gallons of sodium hypochlorite needed to disinfect a well, we need to know the pounds of chlorine needed and the percent available chlorine in the hypochlorite.

$$\text{Sodium Hypochlorite Solution, gallons} = \frac{(\text{Chlorine, lbs})(100\%)}{(8.34\text{ lbs/gal})(\text{Hypochlorite, \%})}$$

EXAMPLE 1

A new 200-foot deep well is to be disinfected with a 5-percent sodium hypochlorite solution. The top 150 feet of the well has a 12-inch casing and the bottom 50 feet has an 8-inch casing and well screen. The water level in the well is at 80 feet from the top of the well. Because this is a new well, the desired chlorine concentration in the initial dose should be 100 mg/*L*. How many gallons of 5-percent sodium hypochlorite will be needed?

Known		Unknown
Depth of Well, ft	= 200 ft	5% Hypochlorite, gallons
Hypochlorite, %	= 5%	
Chlorine Dose, mg/*L*	= 100 mg/*L*	
Top 150 ft	= 12-in casing	
Bottom 50 ft	= 8-in casing and screen	
Water Level, ft	= 80 ft from top	
or	= 120 ft from bottom	

1. Find the volume of water in the well. Use Table 5.4.

TABLE 5.4 VOLUME OF WATER IN WELL PER FOOT OF DEPTH

Casing Size, in	Volume, gallons per foot of depth
4	0.65
5	1.02
6	1.47
8	2.61
10	4.08
12	5.87
14	7.99
16	10.44
18	13.21
20	16.31

a. From 80 feet from top to 150 feet from top we have 70 feet (150 ft – 80 ft) of 12-inch casing.

From Table 5.4, 12-inch casing has 5.87 gallons of water per foot.

b. From 150 feet from top to 200 feet from top we have 50 feet (200 ft – 150 ft) of 8-inch casing.

From Table 5.4, 8-inch casing has 2.61 gallons of water per foot.

$$\begin{aligned}\text{Total Volume of Water, gallons} &= (\text{Length, ft})(\text{Volume, gal/ft})\\ &= (70\text{ ft})(5.87\text{ gal/ft}) + (50\text{ ft})(2.61\text{ gal/ft})\\ &= 411\text{ gal} + 131\text{ gal}\\ &= 542\text{ gallons of Water}\end{aligned}$$

If Table 5.4 were not available, we could calculate the approximate volume in gallons per foot of depth and the total volume of water in gallons.

a. For the 12-inch casing, calculate the volume in gallons per foot of depth.

$$\text{Volume, gal} = (\text{Area, sq ft})(\text{Depth, ft})(7.48\text{ gal/cu ft})$$

$$\begin{aligned}\text{Volume, gal/ft} &= (\text{Area, sq ft})(7.48\text{ gal/cu ft})\\ &= \frac{(0.785)(12\text{ in})^2(7.48\text{ gal/cu ft})}{144\text{ sq in/sq ft}}\\ &= 5.87\text{ gal/ft}\end{aligned}$$

b. For the 8-inch casing, calculate the volume in gallons per foot of depth.

$$\begin{aligned}\text{Volume, gal/ft} &= (\text{Area, sq ft})(7.48\text{ gal/cu ft})\\ &= \frac{(0.785)(8\text{ in})^2(7.48\text{ gal/cu ft})}{144\text{ sq in/sq ft}}\\ &= 2.61\text{ gal/ft}\end{aligned}$$

$$\begin{aligned}\text{Total Volume of Water, gallons} &= (\text{Length, ft})(\text{Volume, gal/ft})\\ &= (70\text{ ft})(5.87\text{ gal/ft}) + (50\text{ ft})(2.61\text{ gal/ft})\\ &= 411\text{ gal} + 131\text{ gal}\\ &= 542\text{ gallons of Water}\end{aligned}$$

This answer is the same as the 542 gallons we obtained using the values in Table 5.4.

2. Find the pounds of chlorine needed.

$$\begin{aligned}\text{Chlorine, lbs} &= (\text{Vol Water, M Gal})(\text{Chlorine Dose, mg}/L)(8.34\text{ lbs/gal})\\ &= (0.000542\text{ M Gal})(100\text{ mg}/L)(8.34\text{ lbs/gal})\\ &= 0.45\text{ lb Chlorine}\end{aligned}$$

3. Calculate the gallons of 5-percent sodium hypochlorite solution needed.

$$\begin{aligned}\text{Sodium Hypochlorite Solution, gallons} &= \frac{(\text{Chlorine, lbs})(100\%)}{(8.34\text{ lbs/gal})(\text{Hypochlorite, \%})}\\ &= \frac{(0.45\text{ lb})(100\%)}{(8.34\text{ lbs/gal})(5\%)}\\ &= 1.08\text{ gallons}\end{aligned}$$

A little over one gallon of 5-percent solution sodium hypochlorite should do the job.

The gravel in a gravel envelope well must be disinfected as the gravel is added to the well. This is accomplished by adding half a pound (227 gm) of 5-gram *HTH*[22] granules per ton of gravel.

When disinfecting a well that draws from more than one aquifer, remember that there is nearly always flow from one aquifer to another. Also, if water is flowing through a well, the procedures described in this chapter may not work very well because the flowing water will carry away the chlorine.

Once water from a well starts producing positive coliform test results, it is almost impossible to correct the problem with chlorine treatment. However, some wells will clear up after long periods of pumping (sometimes two years are required).

Disinfection of the well may not be accomplished the first time so this procedure may have to be repeated a second and possibly even a third time.

5.302 Procedures

Procedures described in this section are one method for disinfecting a well; however, other methods are available and may be used.

1. Calculate the volume of water in the well using the guidelines in Example 1.
2. Wash the pump column or drop pipe (pipe attached to the pump) with chlorine solution as it is lowered into the well. The chlorine solution can be fed through a hose to wash the pipe.
3. After the chlorine solution has been fed into the well, operate the pump so as to thoroughly mix the disinfectant with the water in the well. Pump until the water discharged has the odor of chlorine. Then, shut down the pump and let the water surge back down into the well. Repeat this procedure several times over an hour.
4. Allow the well to stand for 24 hours.
5. Pump the well to waste until all traces of chlorine are gone.
6. Take a bacteriological sample for analysis. Use the 24-hour membrane filter method for the quickest results.
7. If results of bacteriological analysis for total coliforms indicate unsafe conditions, repeat the disinfection procedure. Conditions are considered unsafe when the test results are positive (there are coliforms present). Stated another way, a well has been successfully disinfected if the results of a bacteriological analysis for total coliforms are negative (no coliforms).

5.303 Continuous Disinfecting of Wells

Normally, wells are treated by a single application of disinfecting solution, but because more and more groundwater sources are becoming contaminated, it is becoming a standard practice to disinfect wells on a continuous basis.

The type of disinfection installation to be used will depend on which type of chemical is to be used. From a safety standpoint, the use of hypochlorite is the safest. Normally, there are fewer hazards associated with hypochlorite compounds than with liquid or gaseous chlorine. However, liquid or gaseous chlorine is cheaper to use than hypochlorite, especially if large volumes of chlorine are required.

QUESTIONS

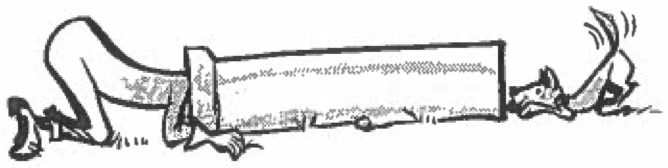
Write your answers in a notebook and then compare your answers with those on page 350.

5.3A When a new well is completed, why is it necessary to disinfect the well, pump, screen, piping, and the aquifer accessed by the well?

5.3B What are the advantages of disinfecting a well by applying chlorine through the pump column pipe rather than through the vent pipe?

5.3C How would you determine if a well has been successfully disinfected?

5.3D Why is it becoming standard practice to disinfect wells on a continuous basis?



5.31 Mains

5.310 Procedures

- Preventive Measures

One of the most effective steps in disinfecting water mains is to do everything possible to prevent the mains from becoming contaminated during construction and repair. Keep outside material such as dirt, construction materials, animals, rodents, and dirty water out of mains being installed or repaired. Inspect the interior of all pipes for cleanliness as the main is laid in the trench. Keep the trenches dry or dewatered. Install water-tight plugs in all open-end joints

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[22] *HTH.* High Test Hypochlorite. Calcium hypochlorite or $Ca(OCl)_2$.

whenever the trench is unattended for any length of time. An exception to the use of watertight plugs in the open ends of joints is when groundwater could cause the pipe to float. When a long pipeline is to be laid, it may not always be possible to keep a trench dry during the night when crews are not on duty.

- Preliminary Measures

Flush the mains before attempting to disinfect them. Flushing is not an alternative to cleanliness when laying or repairing mains. Flushing cannot be expected to remove debris caked on joints, crevices and other parts of the system. Flush the mains for at least 30 minutes using water flowing with a velocity of at least 2.5 ft/sec (0.75 m/sec). See Table 5.5 for flows required in gallons per minute (GPM) to flush various diameter mains with 2.5 ft/sec and 5.0 ft/sec flushing velocities.

TABLE 5.5 FLOWS REQUIRED FOR VARIOUS FLUSHING VELOCITIES

Line Size, inches	Flow Required, GPM[a]	
	Velocity, 2.5 ft/sec	Velocity, 5 ft/sec
4	100	200
6	220	440
8	390	780
10	610	1,220
12	880	1,760
14	1,200	2,400
16	1,570	3,140

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[a] Line should be flushed for at least 30 minutes.

Special care must be exercised to be sure fittings and valves are clean before disinfecting a main. Also, all air pockets or other conditions that would prevent proper disinfection should be eliminated. Many water mains contain mechanical joints. These joints have spaces that are difficult to chlorinate once they become filled with water. This is one reason why initial flushing may be ineffective. Some operators crush calcium hypochlorite tablets and place the crushed tablets in joints to improve the disinfection process.

If you wish to calculate the flow required in gallons per minute of any pipe diameter and flushing velocity not shown in Table 5.5, or if you wish to verify any numbers in Table 5.5, use the following procedure.

1. Calculate the cross-sectional area of the pipe in square feet. Use a 10-inch diameter pipe.

$$\text{Area, sq ft} = \frac{(0.785)(\text{Diameter, in})^2}{144 \text{ sq in/sq ft}}$$

$$= \frac{(0.785)(10 \text{ in})^2}{144 \text{ sq in/sq ft}}$$

$$= 0.545 \text{ sq ft}$$

2. Calculate the flow rate in cubic feet per second (CFS). Use a velocity of 5 feet per second and Q = AV.

$$\text{Flow Rate, CFS} = (\text{Area, sq ft})(\text{Velocity, ft/sec})$$

$$= (0.545 \text{ sq ft})(5 \text{ ft/sec})$$

$$= 2{,}725 \text{ CFS}$$

3. Convert the flow from cubic feet per second to gallons per minute.

$$\text{Flow Rate, GPM} = (\text{Flow, cu ft/sec})(7.48 \text{ gal/cu ft})(60 \text{ sec/min})$$

$$= (2.725 \text{ cu ft/sec})(7.48 \text{ gal/cu ft})(60 \text{ sec/min})$$

$$= 1{,}223 \text{ GPM}$$

NOTE: Table 5.5 shows a flow of 1,220 GPM because this is as close as you can read most flowmeters, as well as regulate the flow.

- Disinfection Alternatives

Three forms of chlorine commonly used for disinfection are chlorine gas, calcium hypochlorite, and sodium hypochlorite. If chlorine gas is used, a trained operator is required to operate the solution-feed chlorinator in combination with a booster pump. Applying gas directly from a cylinder is dangerous and, if proper mixing of chlorine and water is not obtained, a highly corrosive condition could develop.

Another danger is that water could be drawn back into the chlorine cylinder. A mixture of water and liquid chlorine will form a very concentrated hydrochloric acid solution. This acid solution could eat a hole in the wall of the cylinder and allow liquid or gaseous chlorine to escape. For these reasons, never use water on a chlorine leak. The corrosive action of chlorine and water will always make a leak worse.

Calcium hypochlorite is available in powder, granular, or tablet form at 65-percent available chlorine. Calcium hypochlorite is relatively soluble in water and can be applied by the use of a solution feeder. When using calcium hypochlorite (chlorine) tablets, the tablets will not dissolve readily if the water temperature is below 41°F (5°C), which will reduce the chlorine concentration in the water being disinfected. Temperature control of water is difficult, but you can control contact time. Therefore, if you are disinfecting when the water temperature is low, increase the contact time to achieve effective disinfection.

Calcium hypochlorite requires special storage to avoid contact with organic material. When organic material and calcium hypochlorite come in contact, the resulting chemical reactions can generate enough heat and oxygen to start and support a fire. When calcium hypochlorite is mixed with water, heat is given off. To adequately disperse the heat generated, the dry calcium hypochlorite should be added to the correct volume of water, rather than adding water to the calcium hypochlorite.

WARNING

Do not use HTH powder in pipes with solvent-welded plastic or screwed-joint steel pipe because a reaction between the joint compounds and the calcium hypochlorite could cause a fire or an explosion.

Sodium hypochlorite is available in liquid form at 5- to 15-percent available chlorine and can be fed by the use of a hypochlorinator. Sodium hypochlorite can lose from two to four percent of its available chlorine content per month at room temperatures. Therefore, manufacturers recommend a maximum storage period of 60 to 90 days.

See Section 5.4, "Operation of Chlorination Equipment," for procedures on how to operate equipment.

Three common methods of disinfecting mains are summarized in Table 5.6, "Chlorination Methods for Disinfecting Water Mains," and two methods are illustrated in Figures 5.6 and 5.7.

TABLE 5.6 CHLORINATION METHODS FOR DISINFECTING WATER MAINS

Chlorination Method Used	Maximum Chlorine Dose, mg/*L*[a]	Minimum Contact Time, hr	Minimum Chlorine Residual, mg/*L*
Continuous	50	24	25
Slug	500	3	300
Tablet[b]	50	24	25

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[a] AWWA Standard C651-99 recommends the following doses: Continuous, 25 mg/*L*; Slug, 100 mg/*L*; and Tablet, 25 mg/*L*. The minimum chlorine dose depends on whether you are disinfecting an existing main (high dose, 500 mg/*L*, and short contact time (5 minutes)), or a new main (use a continuous minimum residual of 25 mg/*L* for 24 hours). Use whatever dose you need that will produce no positive coliform test results.

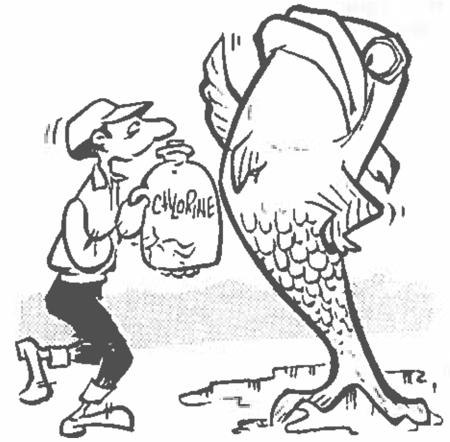
[b] Tablets must be placed at inside top of pipe when the pipe is being laid. Also, two tablets must be placed at all joints on both sides of the pipe at the half-full location. Place one ounce (28 gm) of HTH powder per inch (25 mm) of pipe diameter in the first length of pipe and again after each 500 feet (150 m) of pipe. This ensures that the first water entering the spaces at joints will have a high chlorine residual. Fill the pipe with water at velocities of less than 1 ft/sec.

1. *NEW MAINS*

All pipes, fittings, valves, and other items that will not be disinfected by the filled line must be precleaned and disinfected. Valve bonnets and other high spots where cleaning may not be effective due to air pockets should be precleaned and chlorinated. Calcium hypochlorite tablets may be crushed and placed in joints and hydrant branches to assist in the total disinfection process.

When applying chlorine by either the continuous or slug method, be sure that the chlorine fed is well mixed with the water used to fill the pipe. Solution feeders can be used to inject chlorine into the water (continuous or slug method) used to disinfect the main. If possible, recycle the flows from the continuous method to minimize the use of chlorine and any problems that might be encountered from disposal of water with a high chlorine residual.

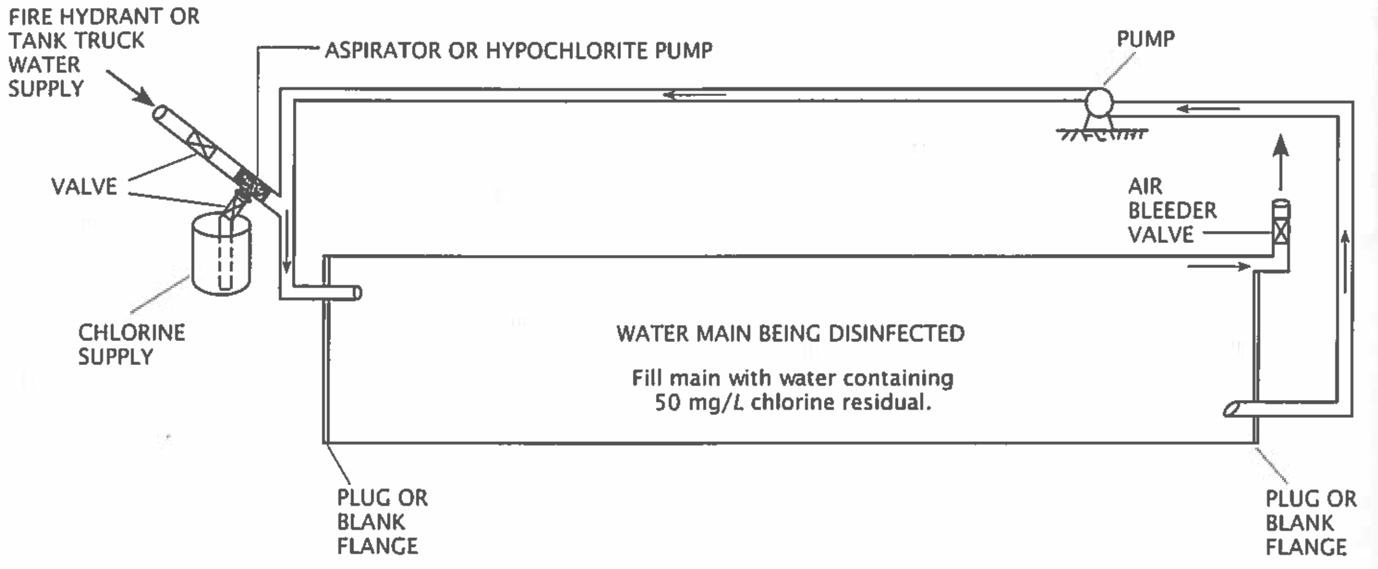
Care must be exercised when disposing of all water with a high chlorine residual (greater than 1 mg/*L*). Possible means of disposal include sanitary sewers, storm sewers, or on land; however, the water should not be disposed of in a manner that will cause an adverse impact on the environment. If sanitary sewers are used, there should be adequate dilution and travel time so there will be no chlorine residual when the water reaches the wastewater treatment plant. Be sure to notify the plant operator in advance. If a storm sewer is used, be sure there is no chlorine residual remaining when the water reaches the receiving waters (creek, river, or lake). Chlorine is toxic to fish and other aquatic life. Land disposal may be acceptable if percolation rates are high and there are no nearby wells pumping groundwater.



2. *MAIN REPAIRS*
   a. If repairs are made with the line continuously full of water and under pressure, no disinfection is required.
   b. Where lines are opened:
      (1) Dewater open trench areas using trash pumps.
      (2) Flush and swab all portions of all pipe, fittings, and materials used in repairs that will be in contact with the water supply with a 5-percent hypochlorite solution.
      (3) Flush system.
      (4) Disinfect the main. Slug disinfection is recommended, if practical, using a 500-mg/*L* dosage and 30-minute minimum contact time.

- Flushing After Disinfection

Flush lines after disinfection under all alternative procedures until residual chlorine is less than 1 mg/*L*. Velocity of



CHLORINE SUPPLY

Can use hypochlorite and premix solution prior to injection.

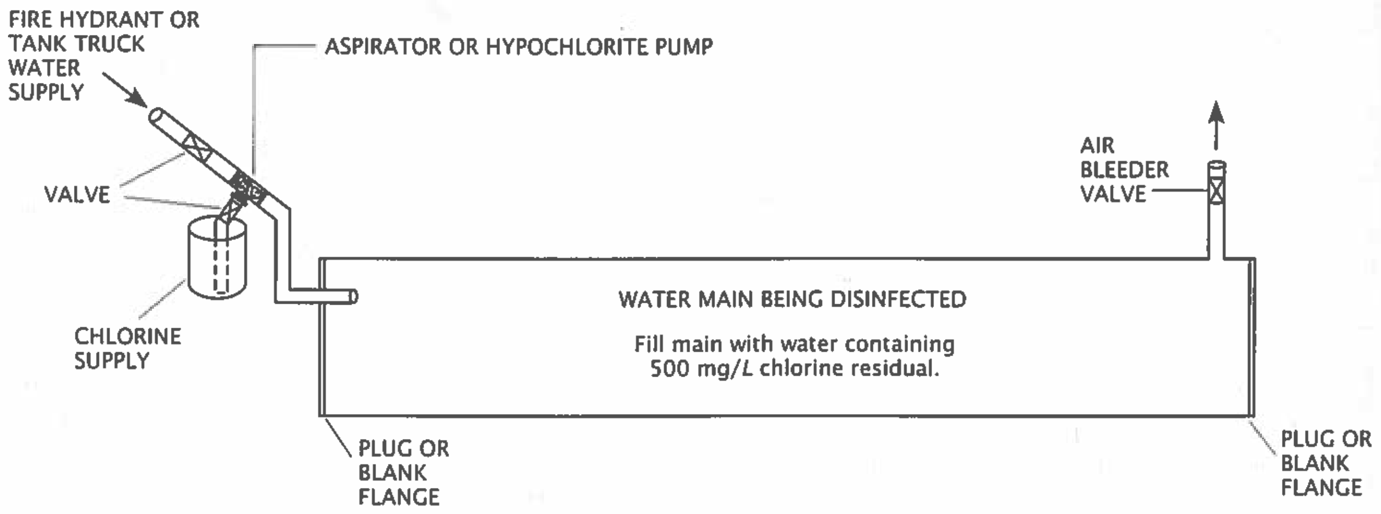
FILLING MAIN

Water and chlorine solution should be added until main is completely full. Allow air to escape through air bleeder valve.

EMPTYING MAIN

Use caution when disposing of disinfecting solution. If discharging to sewer system be sure that the plant operator is notified. Discharge water to sewer very slowly over a period of time rather than in one large slug.

Fig. 5.6 Disinfection of a water main by the continuous method



CHLORINE SUPPLY

Recommend using hypochlorite. Tablets can be used, but not as effective.

FILLING MAIN

Water and chlorine solution should be added until water comes out air bleeder valve.

EMPTYING MAIN

Discharge disinfecting solution to sewer if available. Notify plant operator. If sewer not available, haul to nearest wastewater plant. Discharge to sewer or at plant very slowly and dilute if necessary so a shock load will not reach plant.

Fig. 5.7 Disinfection of a water main by slug method

flushing is not critical if the preventive and preliminary procedures described above were adequately performed.

- Testing After Disinfection

After disinfection and prior to placing the line in service, bacteriological tests (24-hour membrane filter) are required as follows:

1. In a chlorinated water system, test at least one sample for each section disinfected.
2. Test at least two samples for each section disinfected in an unchlorinated water system.
3. For long lines, test samples along line. Line in excess of 2,500 feet (750 meters) is considered a long line.

If bacteriological tests are unsatisfactory, disinfection must be repeated. Repeat of the tablet method, of course, is impossible and an alternative procedure must be used. A suggested procedure is to flush the main again and then take additional samples. Be sure the sample tap is satisfactory because many unsatisfactory samples from new mains are the result of using poor sample taps such as fire hydrants and blow-off valves.

If samples are still unsatisfactory, dewater the main as completely as possible. Use air compressors to blow out all remaining water. Refill the empty main with water containing a chlorine residual between 50 and 100 mg/*L*. Allow this water to stand in the main for 48 hours. Flush the main again and resample. Also, collect samples from the water entering the main to be sure that this water is not the source of the positive coliform test results.

5.311 Emergency or Maintenance Disinfection

Mains may be disinfected by spraying a high concentration of chlorine on the insides of the mains. This method is often used for disinfecting sections of a water main where a break is repaired or where a crew has cut into an existing main, or in the very short (less than 100 feet or 30 meters) extension of an existing main. This method is frequently used when the main must be quickly returned to service and you cannot wait for a 24-hour contact time.

Spray with a solution of 1- to 5-percent (10,000 to 50,000 mg/*L*) chlorine at a pressure of 100 psi (690 kPa or 7 kg/sq cm). An ordinary pressure type stainless-steel fire extinguisher will do the job. Spray the complete interior of each section of pipe or fitting as it is lowered into the trench. The stainless-steel extinguisher will not corrode as rapidly from contact with the chlorine solution if the interior of the extinguisher tank is lined with a protective coating, such as a chlorinated rubber or an epoxy coating.

5.312 Disinfection Specifications

If water mains are to be disinfected by others as part of a contract, the following should be included in the specifications:

1. Specify AWWA C651-99 as the standard for disinfection procedures to be followed.
2. Specify where flushing may be done, the rates of flushing, and the location of suitable drainage facilities.
3. Specify the form of chlorine to be used and the method of application.
4. Specify the type, number, and frequency of samples for bacteriological tests.
5. Specify the method of taking samples.
6. Specify who is responsible for testing and specify the use of a certified laboratory.

5.313 Areas of Disinfection Problems

When disinfecting mains, there are certain aspects that are most likely to cause problems. Joints and connections must be thoroughly cleaned before the mains are disinfected. Whenever anyone connects a service line into a main, they must use clean tools and materials. Each service line should be disinfected before being connected to a water main.

Some water supply systems may be lax with their disinfection practices. Personnel working for these systems are sometimes inadequately trained, underpaid, and understaffed. They use the excuse that they have neither the time nor the budget to adequately disinfect new mains and existing mains after repairs.

> There is no excuse or reason for ever placing a line in service that has not been adequately disinfected and confirmed by the 24-hour membrane filter test for coliforms.

5.314 Sample Problem

FORMULAS

Use the same formulas that are used to disinfect a well.

EXAMPLE 2

A new 6-inch water main 500 feet long needs to be disinfected. An initial chlorine dose of 400 mg/*L* is expected to maintain a chlorine residual of over 300 mg/*L* during the three-hour disinfection period. How many gallons of 5-percent sodium hypochlorite solution will be needed?

Known	Unknown
Diameter of Pipe, in = 6 in	5% Hypochlorite, gallons
Length of Pipe, ft = 500 ft	
Chlorine Dose, mg/*L* = 400 mg/*L*	
Hypochlorite, % = 5%	

1. Calculate the volume of water in the pipe in gallons.

$$\text{Pipe Volume, gallons} = \frac{(0.785)(\text{Diameter, in})^2(\text{Length, ft})(7.48\text{ gal/cu ft})}{144\text{ sq in/sq ft}}$$

$$= \frac{(0.785)(6\text{ in})^2(500\text{ ft})(7.48\text{ gal/cu ft})}{144\text{ sq in/sq ft}}$$

$$= 734\text{ gallons of Water}$$

2. Determine the pounds of chlorine needed.

$$\text{Chlorine, lbs} = (\text{Volume, M Gal})(\text{Dose, mg}/L)(8.34\ \text{lbs/gal})$$

$$= (0.000734\ \text{M Gal})(400\ \text{mg}/L)(8.34\ \text{lbs/gal})$$

$$= 2.45\ \text{lbs Chlorine}$$

3. Calculate the gallons of 5-percent sodium hypochlorite solution needed.

$$\text{Sodium Hypochlorite Solution, gallons} = \frac{(\text{Chlorine, lbs})(100\%)}{(8.34\ \text{lbs/gal})(\text{Hypochlorite, }\%)}$$

$$= \frac{(2.45\ \text{lbs})(100\%)}{(8.34\ \text{lbs/gal})(5\%)}$$

$$= 5.9\ \text{gallons}$$

Six gallons of 5-percent sodium hypochlorite solution should do the job.

5.32 Tanks

5.320 Procedures

Procedures for disinfecting tanks are similar to those used for mains. Thoroughly clean the tank after construction, maintenance, or repairs. Add chlorine to the water used to fill the tank during the disinfection process and mix thoroughly. Maintain a chlorine residual of at least 50 mg/*L* for at least six hours and preferably for 24 hours. When the disinfection procedure is completed, carefully dispose of the disinfection water using the same procedures as for disposal of water used to disinfect mains.

When disinfecting large tanks that hold more than a million gallons, it may not be practical or economical to fill and drain the tank with a disinfecting solution with a high chlorine residual. A solution to this problem is to fill the tank, increase the chlorine residual slightly, collect samples, and run bacteriological tests while keeping the tank full of water (see Special Note, Section 5.34). If results from the 24-hour membrane filter tests are acceptable, the tank may be placed in service. If necessary, dilute the tank contents as the water flows into the distribution system.

Another approach to disinfecting large tanks is to spray the walls with a jet of water containing a chlorine residual of 200 mg/*L*. Thoroughly spraying the walls with water with a high chlorine residual is an effective means of disinfecting large tanks. After the tank has been sprayed, allow the tank to stand unused for 30 minutes before filling. Fill the tank with distribution system water that has been treated with chlorine to provide a residual of 3 mg/*L*. Let the water in the tank stand for 3 to 6 hours. Operators doing the spraying should wear a self-contained breathing apparatus because the chlorine fumes from the spray water are very unpleasant and could be hazardous to your health. Be sure to provide plenty of ventilation.

See *WATER DISTRIBUTION SYSTEM OPERATION AND MAINTENANCE,* Section 5.82, "Disinfection of Storage Facilities," for a more detailed discussion of three different methods of disinfecting water storage tanks. Typically, only one method is used for a particular storage facility disinfection, but combinations of the three methods' chlorine concentrations and contact times may be used.

5.321 Sample Problem

FORMULAS

Use the same formulas used to disinfect wells.

EXAMPLE 3

A new service storage reservoir needs to be disinfected before being placed in service. The tank is 8 feet high and 20 feet in diameter. An initial chlorine dose of 100 mg/*L* is expected to maintain a chlorine residual of over 50 mg/*L* during the 24-hour disinfection period. How many gallons of 5-percent sodium hypochlorite solution will be needed?

Known

Diameter of Tank, ft = 20 ft
Height of Tank, ft = 8 ft
Chlorine Dose, mg/*L* = 100 mg/*L*
Hypochlorite, % = 5%

Unknown

5% Hypochlorite, gallons

1. Calculate the volume of water in the tank in gallons.

$$\text{Tank Volume, gallons} = (0.785)(\text{Diameter, ft})^2(\text{Height, ft})(7.48\ \text{gal/cu ft})$$

$$= (0.785)(20\ \text{ft})^2(8\ \text{ft})(7.48\ \text{gal/cu ft})$$

$$= 18{,}800\ \text{gallons}$$

2. Determine the pounds of chlorine needed.

$$\text{Chlorine, lbs} = (\text{Vol Water, M Gal})(\text{Chlorine Dose, mg}/L)(8.34\ \text{lbs/gal})$$

$$= (0.0188\ \text{M Gal})(100\ \text{mg}/L)(8.34\ \text{lbs/gal})$$

$$= 15.68\ \text{lbs Chlorine}$$

3. Calculate the gallons of 5-percent sodium hypochlorite solution needed.

$$\text{Sodium Hypochlorite Solution, gallons} = \frac{(\text{Chlorine, lbs})(100\%)}{(8.34\ \text{lbs/gal})(\text{Hypochlorite, }\%)}$$

$$= \frac{(15.68\ \text{lbs})(100\%)}{(8.34\ \text{lbs/gal})(5\%)}$$

$$= 37.6\ \text{gallons}$$

Thirty-eight gallons of 5-percent sodium hypochlorite solution should do the job.

5.33 Water Treatment Plants

For additional information on disinfection at water treatment plants, see Chapter 4, "Small Water Treatment Plants," Section 4.5, "Disinfection," in this manual and *WATER TREATMENT PLANT OPERATION,* Volume I, Chapter 7, "Disinfection," in this series of operator training manuals.

5.34 Sampling

SPECIAL NOTE

Whenever you collect a sample for a bacteriological test (coliforms), be sure to use a sterile plastic or glass bottle. If the sample contains any chlorine residual, sufficient sodium thiosulfate should be added to neutralize all of the chlorine residual. Usually, 0.1 mL of 10-percent sodium thiosulfate per 4-ounce bottle before sterilization is sufficient, unless you are disinfecting mains or storage tanks. If the chlorine residual in the sample is greater than 15 mg/L, more "thio" is required to neutralize the chlorine.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 350.

5.3E How can water mains be kept clean during construction or repair?

5.3F Before a water main is disinfected, the main should be flushed. How long should the main be flushed and what flushing velocity should be used?

5.3G What areas in a water main require special care for successful disinfection?

5.3H List three forms of chlorine commonly used for disinfection.

5.3I What precautions should be taken when disposing of water with a high chlorine residual?

End of Lesson 1 of 2 Lessons on DISINFECTION

Please answer the discussion and review questions next.

DISCUSSION AND REVIEW QUESTIONS

Chapter 5. DISINFECTION

(Lesson 1 of 2 Lessons)

At the end of each lesson in this chapter, you will find some discussion and review questions. The purpose of these questions is to indicate to you how well you understand the material in the lesson. Write the answers to these questions in your notebook.

1. Why is drinking water disinfected?
2. If a water is disinfected, will it be safe to drink?
3. What is the chlorine demand of a water?
4. How would you determine the chlorine dose for water?
5. Why should a chlorine residual be maintained in a water distribution system?
6. Why would you consider recycling water used to disinfect a water main when using the continuous chlorination method?
7. How would you dispose of the water used to disinfect a water main if it has a high chlorine residual (greater than 1 mg/*L*)?