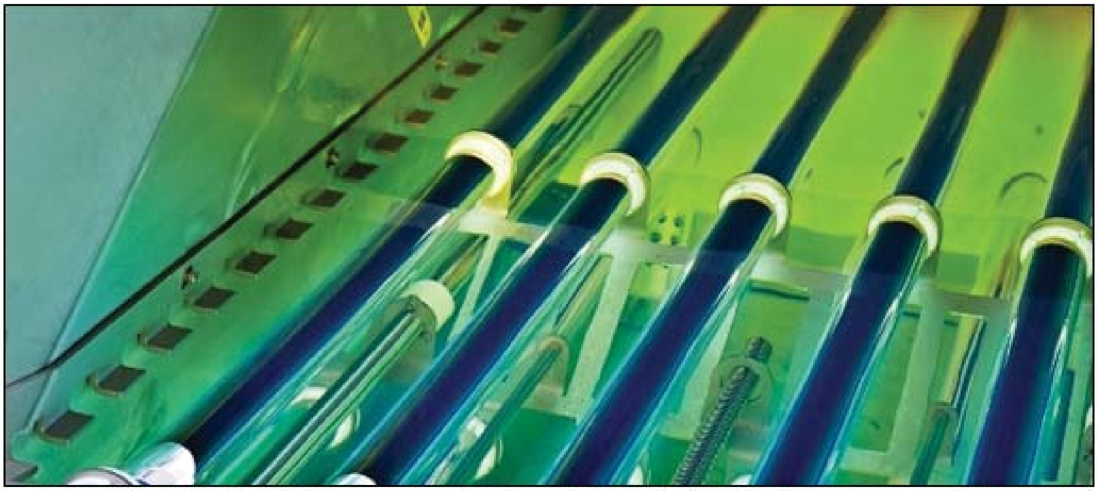
Wisconsin Department of Natural Resources
Wastewater Operator Certification

Basic Disinfection Study Guide

Subclass D



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Preface

The Disinfection Study Guide is an important resource for preparing for the certification exam and is arranged by chapters and sections. Each section consists of key knowledges with important informational concepts you need to know for the certification exam. This study guide also serves as a wastewater treatment plant operations primer that can be used as a reference on the subject.

Note on February 2016 edition: Key knowledges 1.3.4 and 2.4.4 were slightly revised.

In preparing for the exams:
1. Study the material! Read every key knowledge until the concept is fully understood and known to memory.

2. Learn with others! Take classes in this type of wastewater operations to improve your understanding and knowledge of the subject.

3. Learn even more! For an even greater understanding and knowledge of the subjects, read and review the references listed at the end of the study guide.

Knowledge of the study guide material will be tested using a multiple choice format. Every test question and answer comes directly from one of the key knowledges.

Choosing a test date:
Before choosing a test date, consider the time you have to thoroughly study the guides and the training opportunities available. A listing of wastewater training opportunities and exam dates is available at www.dnr.wi.gov by searching for the keywords “Operator Certification”.

Acknowledgements

The Disinfection Study Guide was the result of a collaborative effort of yearlong monthly meetings of wastewater operators, trainers, consultants, the Wisconsin Wastewater Operator Association (WWOA), and the Wisconsin Department of Natural Resources (WDNR). This study guide was developed as the result of the knowledge and collective work of following workgroup members:

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Part 1 - Chlorination

Chapter 1 - Theory and Principles

Section 1.1 - Definitions

1.1.1 Define breakpoint chlorination.

Breakpoint chlorination is the process of using chlorine's oxidative capacity to oxidize ammonia to nitrogen. At this point, free chlorine residual starts to appear.

1.1.2 Define chlorination.

Chlorination is the addition of chlorine and/or chlorine compounds to treated wastewater in order to achieve disinfection.

1.1.3 Define combined total chlorine.

Combined total chlorine is the amount of chlorine that has combined with ammonia to form chloramines or other chlorine compounds.

1.1.4 Define dechlorination and why it is required at wastewater treatment plants that use chlorine.

Dechlorination is the process of removing chlorine from treated effluent prior to discharge to surface water. Dechlorination is used to remove potentially toxic chlorine compounds that could injure fish and other aquatic life in the receiving water.

1.1.5 Define geometric mean and why it is used to average fecal coliform counts.

Geometric mean is a statistical measure of central tendency that minimizes the effect of outliers. It is different from an arithmetic average and is used because of geometric growth rates of bacteria (1, 2, 4, 8, 16, 32, etc.). When calculating a geometric mean, a zero value cannot be used in the calculation and therefore all zeros should use one (1) as the value.

1.1.6 Define fecal coliforms.

The organism used to determine the effectiveness of disinfection is a bacteria called fecal coliform, commonly found in the intestinal tracts of humans and other warm-blooded animals.

1.1.7 Define free available chlorine.

Free available chlorine is the amount of chlorine in water in the form of hypochlorous acid (HOCl) and hypochlorite ion (OCl-).

1.1.8 Define hypochlorination.

Hypochlorination is the use of liquid chlorine compounds to achieve disinfection.

1.1.9 Define pathogenic organisms and their source in wastewater.

Pathogenic organisms are disease-causing microorganisms. They include various bacteria, viruses, and parasites. The discharge of waterborne human wastes will contain these organisms from ailing individuals and would be expected to be present in wastewater entering a wastewater treatment plant.

1.1.10 Define total residual chlorine.

Total residual chlorine is the sum of free available chlorine and combined available chlorine. Monitoring requirements for discharge permits require total residual chlorine testing.

1.1.11 Define treatment facility overflow (TFO).

A TFO is a release of wastewater, other than through permitted outfalls, from a wastewater facility into a water of the state or the land surface. All TFOs must be reported to the Department of Natural Resources within 24 hours of their occurrence.

Section 1.2 - Pathogen Knowledge

1.2.1 List the prevalent diseases that can be contracted through wastewater exposure.

A. Gastroenteritis
B. Dysentery
C. Hepatitis B and C
D. Giardiasis
E. Upper respiratory illnesses

1.2.2 State the reasons for disinfecting treated wastewater.

Disinfection of treated wastewater is practiced to reduce the discharge of waterborne pathogenic organisms. This is done to protect public health as related to surface drinking water supplies and recreational use of downstream areas. Seasonal disinfection provides effluent disinfection during the period when recreational activities occur and are discontinued when use of the water is limited due to climatic conditions.

1.2.3 Explain the significance of using an indicator organism.

In the disinfection process, the destruction of the indicator organism would mean the likely destruction of pathogenic organisms. The indicator bacteria, fecal coliform, is not pathogenic, but is much easier and less costly to detect than individual pathogens. If fecal coliform bacteria are adequately controlled, it can be expected that other pathogenic bacteria are proportionally inactivated. The inactivation of viruses cannot be expected at the same rate as the indicator organism because viruses are more difficult to destroy.

Section 1.3 - Chlorination and Dechlorination Chemistry

1.3.1 List the physical properties of chlorine as a liquid and gas.

Figure 1.3.1.1

Property	Liquid	Gas	Note
Boiling point (at atmospheric pressure)	-29.2°F (-34°C)	Not applicable	
Density	88.8 lbs/ft³ at 60°F (16°C) or 11.9 lbs/gal	0.20 lbs/ft³ at 34°F (1.1°C) at 1 atmospheric pressure	The density of chlorine (liquid or gas) varies with temperature and pressure; being more dense at lower temperatures
Specific gravity	1.47 at 32°F (0°C) [Specific gravity of water is 1]	2.48 at 32°F (0°C) [Specific gravity of air is 1]	Specific gravity varies with temperature and pressure
Color	Clear amber	Greenish yellow	
Odor	**BOTH LIQUID AND GAS:** odor is penetrating and irritating; can be detected at 1 part of gas per 1 million parts of air (by volume)		
Solubility in water	Not very soluble in water; although more can be dissolved in water at lower temperatures	Not applicable	

1.3.2 Explain the relationship between chlorine dosage, chlorine demand, and chlorine residual.

A. Dosage
The dosage is the amount of chlorine fed to achieve disinfection and is normally reported as a concentration in milligrams per liter (mg/L) or pounds per day (lbs/day).

B. Demand
The demand is the amount of chlorine (mg/L) used to disinfect wastewater after a given contact time.

C. Residual
Residual is the amount of chlorine (mg/L) remaining after a given contact time.

A general expression of this relationship is:
Chlorine residual = chlorine dosage - chlorine demand

1.3.3 Discuss the chemical reactions, feed rates, and required contact times of common dechlorination compounds used in removing chlorine.

A. Sulfur dioxide
The reaction of sulfur dioxide reduces all forms of chlorine to chlorides and a residual of sulfates to form small amounts of hydrochloric and sulfuric acids.

Free chlorine (HOCl): $SO_2 + H_2O + HOCL \rightarrow 3H^+ + Cl^- + SO_4^{-2}$

Chloramines (NH2Cl): $SO_2 + 2H_2O + NH_2Cl \rightarrow NH_4^+ + 2H^+ + Cl^- + SO_4^{-2}$

The theoretical dosage for dechlorination requires 0.9 mg/L of sulfur dioxide for every 1 mg/L of total chlorine residual (a ratio of 0.9:1) to be removed. In most operating situations, the feed rate will be 1:1 to ensure all chlorine is removed. The contact time (assuming good mixing) is only about 2 minutes.

B. Sodium bisulfite
Sodium bisulfite reduces free chlorine to sodium bisulfate and hydrochloric acid. The chloramines are converted to sodium bisulfate, hydrochloric acid, and ammonium chloride.

Free chlorine: $NaHSO_3 + 3H_2O + Cl_2 \rightarrow NaHSO_4 + 2HCl$

Chloramines: $3NaHSO_3 + 3H_2O + NH_3 + 3Cl_2 \rightarrow 3NaHSO_4 + 5HCl + NH_4Cl$

The theoretical dosage for dechlorination requires 1.78 parts of pure sodium sulfite per 1 part chlorine or chloramines (a ratio of 1.78:1). In practice, the feed rate should be 10% in excess to ensure total chlorine removal. The reaction is almost instantaneous as with sulfur dioxide.

C. Sodium metabisulfite
Sodium metabisulfite reduces free chlorine to form sodium bisulfate ($NaHSO_4$) and hydrochloric acid (HCl). The chloramines are converted to sodium bisulfate, hydrochloric acid, and ammonium chloride (NH_4Cl).

Free Chlorine: $Na_2S_2O_5 + 3H_2O + 2Cl_2 \rightarrow NaHSO_4 + 2HCl$

Chloramines: $Na_2S_2O_5 + 9H_2O + 2NH_3 + 6Cl_2 \rightarrow 6NaHSO_4 + 10HCl + 2NH_4Cl$

The theoretical dosage for dechlorination requires 1.338 parts of pure sodium metabisulfite for 1 part of chlorine or chloramine (a ratio of 1.338:1). In practice, the feed rate should be 10% in excess to ensure total chlorine removal. The reaction is almost instantaneous as with sulfur dioxide.

1.3.4 Describe conditions affecting chlorine demand.

Treated wastewater can have a large number of complex substances and chemicals affecting chlorine demand. Since chlorine is a strong oxidizing agent, it will react with various substances and chemicals, using up chlorine.

Some of the conditions or parameters affecting chlorine demand include:
A. Mixing
B. Contact time
C. Total suspended solids (TSS)
D. Biochemical oxygen demand (BOD)
E. Nitrite
E. pH
F. Various compounds such as sulfides, ammonia (chloramines), ferrous iron, manganese, and numerous other chlororganic compound creating substances

1.3.5 Describe the relationship between total chlorine residual and the dosage of sodium bisulfite for dechlorination.

The dosage rate of sodium bisulfite ($NaSO_2$) to chlorine residual is 1 mg/L active sulfite ion to 1 mg/L of chlorine residual. The lower the chlorine residual, the less sodium bisulfite is needed for dechlorination.

1.3.6 Describe the relationship between total chlorine residual and the dosage of sulfur dioxide for dechlorination.

The dosage rate of sulfur dioxide (SO_2) to chlorine residual is 1 mg/L sulfur dioxide to 1 mg/L of residual chlorine. The lower the chlorine residual, the less sulfur dioxide is needed for dechlorination.

1.3.7 Discuss the reaction between chlorine and ammonia.

Adding chlorine to treated wastewater containing ammonia (NH_3) will cause a reaction where hypochlorous acid (HOCl) reacts with ammonia to form chloramines.

The reactions and type of chloramines formed are:

A. Monochloramine: $NH_3 + HOCl \rightarrow NH_2Cl + H_2O$
B. Dichloramine: $NH_2Cl + HOCl \rightarrow NHCl_2 + H_2O$
C. Trichloramine (nitrogen trichloride) $NHCl_2 + HOCl \rightarrow NCl_3 + H_2O$

The formations are pH dependent with monochloramine and dichloramine existing at normal wastewater pH of 6.5 to 7.5. With pH levels below 5.5, only dichloramine exists and at a pH below 4.0 only trichloramine is found. The higher the effluent ammonia level, the higher the chlorine demand.

Section 1.4 - Process Understanding and Performance Limiting Factors

1.4.1 Discuss the significance of discoloration to metal surfaces in chlorination application rooms.

Any discoloration or corrosion of gas piping would indicate a gas leak. The gas system should be shut down and repaired or replaced as quickly as possible.

1.4.2 Discuss the effect of mixing, contact time, temperature, pH, suspended solids, and organic and inorganic materials on chlorination.

A. Mixing
Good mixing at the chlorine application point optimizes disinfection.

B. Contact time
The longer the contact time, the better the disinfection. The minimum contact times under an average flow is 60 minutes and under peak flows is 30 minutes.

C. Temperature
The rate of disinfection will occur more rapidly with higher wastewater temperatures.

D. pH
The lower the pH of the wastewater, the more effective the disinfection, because more hypochlorous acid will be present and less of the hypochlorite ion. The hypochlorous acid is a much better disinfectant than the hypochlorite ion.

E. Suspended solids
High suspended solids from poor upstream treatment will reduce the effectiveness of disinfection. Suspended solids will contain higher concentrations of microorganisms and will tend to shield microorganisms from contact with the chlorine in solution, causing an increased chlorine demand to achieve disinfection.

F. Organic and inorganic materials
Since chlorine is such a strong oxidizing agent, it will react with various organic and inorganic materials using up chlorine and reducing the effectiveness of disinfection. If these materials are present, they will increase the chlorine demand and require larger amounts of chlorine to achieve the desired disinfection.

Chapter 2 - Operation and Maintenance

Section 2.1 - Definitions

2.1.1 List the most common methods for disinfecting treated wastewater.

A. Hypochlorination
B. Gaseous chlorination
C. Ultraviolet (UV) radiation

Section 2.2 - Methods

2.2.1 Identify chemicals used for dechlorination.

Chemicals used for dechlorination include sulfur dioxide and sulfite salts (sodium bisulfite, sodium metabisulfite, and potassium sulfite). All the sulfite salts come as an acidic liquid solution, except sodium metabisulfite which comes as a powder. Sulfite salts are oxygen scavengers and decrease oxygen levels in water. Being acidic solutions, they can also lower pH.

2.2.2 Identify chemicals used for hypochlorination.

The two compounds used for hypochlorination are sodium hypochlorite (NaOCL) and calcium hypochlorite [Ca(OCL)2]. Sodium hypochlorite is supplied as a liquid with different percentages (usually 12.5% by weight, 15% by volume) of chlorine. Calcium hypochlorite is supplied in a solid form (powder, granules, or tablets) and must be mixed with water for solution feeding. Tablets are usually 65% active chlorine. Of the two compounds, sodium hypochlorite is favored because calcium hypochlorite causes a precipitate.

2.2.3 Describe the procedure for opening the valve on chlorine cylinders and tanks.

Use only wrenches specifically designed for the valve by the manufacturer to open. Do NOT use an extension, an over-sized wrench could use too much torque and damage the valve. If the valve does not open easily, strike the end of the wrench to unseat the valve. Rotate the valve stem in a counter-clockwise direction. One full turn provides maximum discharge.

2.2.4 List the steps to start-up a gas chlorination system.

A. Place the cylinder securely on a scale
B. Remove the protective hood and the cap covering the outlet valve only using the proper

tools
C. Attach the vacuum regulator yoke assembly to the outlet valve
D. Open the chlorine outlet valve one half turn and then close the chlorine outlet valve
E. Using an ammonia hydroxide leak detector, check for chlorine leaks
F. Open the water supply inlet and outlet valves to the chlorine injector
G. Inspect the water supply and discharge piping for leaks
H. Connect the vacuum line and vent line to the vacuum regulator
I. Open the chlorine rate valve on the vacuum regulator
J. Check all chlorine connections with the ammonia hydroxide solution bottle for leaks
K. Inspect the chlorine system for proper operation
L. Monitor the system operation

2.2.5 List the steps for removing an empty 150-pound chlorine cylinder.

A. Close the chlorine cylinder outlet valve completely with the chlorine injector operating and making vacuum

B. Allow the chlorine system to withdraw all chlorine gas out of the vacuum regulator. The chlorine gas flow indicator ball will drop to the bottom of the flow tube and the loss of chlorine pressure indicator button will be sucked in flush or indicator dial will be allowed to spin.

C. Remove the vacuum regulator from the chlorine outlet valve.
1. Replace the outlet valve cap.
2. Replace the chlorine cylinder protective hood.
3. Move the empty chlorine cylinder to the empty cylinder storage area and secure with a safety chain.

2.2.6 Describe the following methods used to control chlorine and sulfur dioxide dosages.

A. Manual control
Feed rates, starting, and stopping are all done by hand

B. Start/stop control
Feed rates are adjusted by hand; starting and stopping are controlled by the starting of wastewater pumps, a flow switch, and a level switch

C. Step rate control
Feed rates are set according to the number of wastewater pumps in operation

D. Time program control
Feed rates are set on a timed basis corresponding to the times of flow changes using a time pattern transmitter, which uses a revolving cam designed to match historic flow variations

E. Flow-proportional control
Feed rates are varied using a system converting wastewater flow meter information to adjust the feed rate

F. Chlorine residual control
Chlorine residuals are measured by an analyzer, which determines total chlorine residual, and is used to adjust the feed rates and keep the chlorine residual at the desired level

The actual feed rate adjustment in the automatic control systems is accomplished by changing the feed rate valve position; thereby varying the vacuum differential.

2.2.7 Describe how the daily usage of chlorine is determined.

The total daily usage of chlorine is determined by measuring the weight of the chlorine on a daily basis and taking the difference between these daily readings. This difference is the amount of chlorine applied for the day.

2.2.8 Describe how to get a good mixing of the chlorine solution with the plant effluent and why it is important.

The chlorine solution is generally fed through diffusers designed to provide good dispersion. Good mixing can be obtained in open channels where there is sufficient turbulence to mix the chlorine solution with the plant effluent. Good mixing is important because it optimizes contact between the chlorine and the organisms thus allowing for the optimum use of chlorine and reliable reduction in pathogenic organisms. The chlorine contact basin provides the necessary time once the chlorine is mixed into the effluent to allow the chlorine time to affect the organisms and provide reliable reduction in pathogenic organisms.

Section 2.3 - Equipment

2.3.1 Explain the following for chlorine and sulfur dioxide 150-pound cylinders and 1-ton tanks.

A. Weight of a full cylinder or tank
1. Full 150-pound cylinder: Contains 150 lbs of product but actually weighs approximately 240 to 270 lbs
2. Full 1-ton tank: Contains 2,000 lbs of product but actually weighs approximately 3,500 lbs

B. Cylinder or tank handling
1. 150-pound cylinder: Should be moved with a well-balanced hand truck with the cylinder clamped securely. The cylinder can be rolled in a vertical position for short distances. The protective hood should always be in place when moving a cylinder.
2. 1-ton tank: Should be moved with a suitable tank lifting beam with hooks that attach to the end of the tank. A hoist or crane with a minimum of 2-ton capacity can be used to move the tank. Trunion rollers should be available to properly position the tank. The valve bonnet should always be in place when moving a tank.

C. Cylinder or tank storage
1. 150-pound cylinder: Should be stored vertically and secured to a wall or other immovable structure with cylinder protective hood in place.
2. 1-ton tanks: Should be stored on their sides in properly designed cradles to

support the tank and keep the valves vertically one above the other.

D. Form of the chemical (gas or liquid)
1. Full cylinders and tanks: At room temperature contain 75% to 85% liquid

2.3.2 Discuss the purpose of a fusible plug.

A fusible plug is a safety device used to prevent excessive pressure and possible rupture in case of fire or other causes of high temperatures. A fusible plug melts at temperatures of 158ºF to 165ºF (70ºC to 74ºC).

2.3.3 Describe the location of fusible plug(s) on 150-pound cylinders and 1-ton tanks.

The fusible plug for 150-pound cylinders is located on the cylinder valve. The fusible plugs for 1-ton tanks are located on the tanks ends, with 3 or 4 on each end.

2.3.4 Describe a yoke adaptor connection used on chlorine cylinder valves.

The yoke adaptor connection is used to connect the cylinder valve to the piping system. It is a device specially designed to fit the cylinder valve.

2.3.5 Explain the purpose of the following parts of a vacuum operated gas chlorinator and dechlorinator.

A. Vacuum regulating valve
A vacuum regulating valve is designed to regulate chlorine or sulfur dioxide gas from varying supply pressures to a constant vacuum which measures about 20 inches of water.

B. Gas flow-rate valve (V-notch variable orifice)
The gas flow-rate valve and its size regulate the amount of flow of gas to the system.

C. Rotameter
A rotameter is a graduated vertical tube containing a ball or float used to visually measure the gas flow rate to the system.

D. Injector
An injector is a water jet aspirator creating a vacuum which pulls the gas from the cylinder or tank through the system.

2.3.6 Explain why sulfonator and chlorinator equipment are NOT interchangeable.

The two look identical, except the internal components (O-ring plastic material and valve seat material) are different. The valve seat material for the sulfonator is stainless steel; the chlorinator uses titanium silver. The O-ring material for the sulfonator is Hypalon and for the chlorinator it is Viton.

2.3.7 Describe the difference between chlorine and sulfur dioxide cylinders.

The cylinders and tanks are identical, but color-coded. The chlorine cylinder and tank is color-coded silver or blue and the sulfur dioxide cylinder and tank is color-coded red.

2.3.8 Describe the following parts of a calcium hypochlorination system.

A. Product contact tank
The product contact tank has tabular or granular calcium hypochlorite submerged and dissolved in water to form a liquid chlorine solution.

B. Solution storage tank
The solution storage tank stores the chlorine solution before being applied to the wastewater effluent.

C. Application pump
The application pump typically is a centrifugal pump that conveys the chlorine solution from the storage tank to the diffuser.

D. Solution diffuser
The solution diffuser is a perforated PVC pipe used to disperse the chlorine solution over the contact area.

2.3.9 Given the following problems with a gas chlorination system, state the causes and corrective actions for each.

Figure 2.3.9.1

Problem	Cause	Corrective Action
Low gas flow	Empty cylinder	Replace cylinder
	Cylinder valve is closed	Open the valve
Frosting of the cylinder	Gas withdrawal rate from the cylinder is too high	Add more cylinders to meet chlorine feed requirements
	Chlorine leaks to vent	Repair, service, or clean the pressure reducing valve to eliminate the leak
Loss of vacuum	Injector diaphragm is damaged	Check injector water pump and service as needed
	Diffuser or diffuser discharge line is plugged	Clean the diffuser and discharge piping

Section 2.4 - Handling and Storage

2.4.1 Explain how chlorine is withdrawn from a cylinder.

From a cylinder, gas is always delivered in an upright position.

2.4.2 Explain how chlorine is withdrawn as a gas or liquid from 1-ton tanks.

For a 1-ton tank, the chlorine is delivered as a gas from the upper valve and as a liquid from the bottom valve.

2.4.3 Discuss the requirements for the storage of chlorine gas.

A. Type of room and location
The chlorine storage room should be a gas tight room separated from all other portions of the building or in another separate building.

B. Door opening and location
The door to the chlorine storage room should be on the outside wall with the door opening outward. The door should have a warning sign indicating chlorine is present and have quick exit panic or emergency hardware.

C. Storage room window
A clear glass air tight window should be installed in the door or wall to allow viewing of the room without entering.

D. Storage room temperature
The storage room should be supplied with adequate heating and cooling to maintain a temperature between 64°F and 110°F. Cold temperatures will not allow liquid chlorine to vaporize.

E. Storage room ventilation
Forced mechanical ventilation capable of providing one complete air exchange per minute is required. The intake of the ventilation system must be near the floor, because chlorine is heavier than air. The exhaust of the ventilation system location should not contaminate the air inlet to any buildings or inhabited areas. The ventilator and room lights must turn on automatically when the door is opened. Manual operation of the ventilation system must be provided with switches located outside of the room.

F. Chlorinator location (150-pound cylinders and 1-ton tanks)
When using 150-pound chlorine cylinders, the chlorinator may be located within the storage room. When using 1-ton tanks, the chlorinators should be in a separate room.

2.4.4 Describe the materials used in handling chlorine gas and liquid.

A. Permanent piping
1. Chlorine gas permanent piping under pressure
    a. Permanent piping for dry pressurized chlorine gas should be constructed from seamless carbon steel, schedule 80; a 1-inch diameter is adequate for most applications.
    b. Pipe with a 3/4-inch diameter can be used for 150-pound cylinders or 1-ton tanks, but smaller sizes are not recommended.
    c. Permanent piping joints should be welded.
    d. All piping needs to be cleaned before being placed in service. Use an approved solvent to remove all grease and oil and a dry air or inert gas purge to remove all residual solvent.
2. Chlorine gas permanent piping under vacuum
    a. Permanent piping for a dry vacuum chlorine gas should be constructed from PVC (polyvinyl chloride) 80 piping.

b. Permanent PVC 80 pipe joints should be solvent welded.
c. All the piping should be cleaned and burrs removed as it is installed. A dry air or inert gas purge of the process piping should be done before placing the system in service.
d. Flexible polyethylene tubing can be used for vacuum transfer of chlorine gas for short distances (less than 50 feet).

3. Permanent piping for chlorine solution (chlorine gas and water)
   a. Permanent piping for chlorine solution should be constructed from PVC 80 or flexible polyethylene tubing.
   b. Rubber lined steel piping can also be used to transfer chlorine solution, but has limited application as it cannot be easily altered by field application.
   c. Permanent piping can be solvent welded or be threaded.

B. Temporary connections
1. Pressurized chlorine
   a. Stainless steel and titanium tubing and fittings can be used for temporary connections on a pressurized gas chlorine system.
2. Chlorine gas under vacuum
   a. Polyethylene tubing and fittings can be used for a temporary connection on vacuum systems.

C. Gaskets
1. Recommended gasket materials for pressurized and vacuum gas chlorine systems
   a. Teflon
   b. Lead
   c. Compressed asbestos
   d. Ordinary rubber or plastic should never be used. A new gasket must be used anytime a new connection is made or a connection is changed.

D. Valves
1. Valves for pressurized chlorine
   a. Forged carbon steel with monel seats and stems can be used.
   All materials for valves should be as approved by the Chlorine Institute and will be tagged by the manufacturer for the specific use. All valves should be carefully inspected for proper preparation, especially that they are free of all grease or oil. If in question, new valves should be degreased with an approved solvent and thoroughly dried to remove all solvent by purging with dry air or inert gas.
2. Valves for chlorine gas under vacuum
   a. Valves constructed from PVC 80 with Teflon seats can be used. Without Teflon, the valve will become hard to open or close.
   b. Forged carbon steel with monel seats, Hastalloy C, or 316 stainless steel ball valves can also be used.

2.4.5 Describe the factors that affect hypochlorination chlorine dosages.

A. Solution strength

B. Product dilution
C. Storage length (age causes deterioration)
D. Storage conditions (heat, light, certain chemicals, etc)
E. Metering pump accuracy

2.4.6 Describe the parts of a sodium hypochlorination system.

A. Positive displacement metering pump
A positive displacement metering pump is used to pump set amounts of chlorine solution to the chlorine contact tank. The dosage can be regulated by adjusting the step pulley drive belts, stroke length, and solution concentrations.

B. Solution and storage tank
Sodium hypochlorite is supplied as a liquid. Liquid storage tanks (plastic or fiberglass) should be protected against heat, light, and iron compounds, all of which will cause deterioration of the chlorine solution.

C. Solution diffuser
The diffuser is a perforated PVC pipe used to disperse the chlorine solution in the contact area.

2.4.7 Discuss mixing and storage requirements when using sodium and calcium hypochlorite.

A. Sodium hypochlorite (NaOCl)
Sodium hypochlorite is supplied only as a solution containing up to 15% available chlorine and weighing 10 lbs/gal. No mixing is required. Often, it is diluted up to 50% to reduce the rate of deterioration. Lower strength solutions will deteriorate much less rapidly, but requires sufficient tank storage to accommodate the increase in volume. The storage tanks should be constructed of polyethylene and hypochlorite resistant fiberglass resin.

All tanks should be protected against heat and light, both will increase deterioration. The solution tanks need to be protected from contamination or inorganic reducing materials, such as hydrogen sulfide, ferrous iron, manganese, and nitrite. All of these materials will cause deterioration of the chlorine solution.

B. Calcium hypochlorite [Ca(OCl)2]
Calcium hypochlorite is normally supplied as a solid (tablets, granules, or powder) and must be mixed with water for use. The mixing of calcium hypochlorite with water forms a precipitate (calcium hydroxide) and, with hard water, more sludge is formed. It is normally necessary to decant to a second tank to eliminate the sludge and prevent clogging of solution lines or the diaphragm metering pump. The liquid storage of the mixed calcium hypochlorite is the same as for sodium hypochlorite. The storage of the dry calcium hypochlorite requires that it be stored in its original container in a dry location. It should not be allowed to come in contact with water or organic materials (petroleum-based oils, grease, or solvent) as the potential would exist for a chemical fire started by a reaction.

2.4.8 Discuss the desired temperature range for chlorine and sulfur dioxide gas systems.

Chlorine and sulfur dioxide gas systems should be protected from extreme temperatures.

As temperatures increase, the rate of vaporizing of the liquids in containers increases. When temperatures decrease, the gas condenses. Rooms built for container storage and chlorinators or sulfonators should have provision for adequate heating above 50°F. It's best to keep piping systems and the chlorinator and sulfonator equipment at temperatures between 60°F and 110°F.

2.4.9 List the maximum withdrawal rates, under vacuum, from 150-pound cylinders and 1-ton tanks for chlorine and sulfur dioxide gas at room temperature (70ºF) and what alternatives can be used if higher rates are required.

A. 150-pound cylinder
   1. Chlorine: 4.0 lbs/hr
   2. Sulfur dioxide: 3.0 lbs/hr

B. 1-ton tank
   1. Chlorine: 20.8 lbs/hr
   2. Sulfur dioxide: 15.0 lbs/hr

Section 2.5 - Preventive Maintenance

2.5.1 Define preventive maintenance.

Preventive maintenance is a comprehensive planned program of daily, weekly, monthly, annual, and seasonal inspection and repair of equipment. This would involve a record system of needed maintenance, frequency of maintenance, documenting performance of the required maintenance, providing historical trends, and procedures used for maintenance. Preventive maintenance would involve a spare parts inventory to ensure continuous operations of equipment. A good preventive maintenance program keeps equipment functioning, ensures good efficiency, reduces equipment down time, and saves money in the long-term operation of equipment and the plant.

2.5.2 List the maintenance tasks for gas chlorinator and sulfonator systems.

A. Weigh the containers on a regular basis.
B. Inspect and clean the vacuum regulators.
C. Inspect seal O-rings and gaskets; replace if needed. Inspect the temporary flexible connections to the main pipeline on a routine basis and replace if needed. Immediately replace any temporary connection that has any discoloration or is kinked.
D. Inspect and clean the pressure relief valves (if a pressure system).
E. Clean the rotameter when deposits are noticed in the glass tube or the float sticks.
F. Clean the gas flow rate valve (v-notch variable orifice) when cleaning the rotameter.
G. Inspect, service, and test the leak detection system (if the system is so equipped).
H. Inspect and clean the injector system and pump.
I. Check all equipment and piping for leaks, discoloration, apparent moisture and repair or replace if necessary.

2.5.3 List the maintenance tasks for hypochlorination systems.

A. Clean the positive displacement metering pump regularly.

B. Replace diaphragms as needed.
C. Alternate the use of the metering pumps and operate them briefly at all speeds.
D. Check and operate all valves in the piping system.
E. Use the proper oil and maintain oil levels in all pumps.
F. Inspect and clean the tanks using safety precautions, such as confined space, if applicable.

2.5.4 Describe the cause of discoloration or corrosion on steel permanent piping equipment for chlorine.

The cause of discoloration or corrosion on steel piping equipment is the reaction of chlorine and moisture attacking the steel, forming ferric chloride. It appears as a greenish-yellow or brown residue. Any discoloration on the outside of the piping or fittings indicates a chlorine leak and needs to be immediately repaired.

2.5.5 Explain why a chlorine contact tank should be regularly cleaned.

The low velocity of flow through a chlorine contact tank results in the deposition of solids. Small gas bubbles on the water surface of the chlorine contact tank, caused by denitrification (nitrogen gas), are an indication of solids buildup in the tank and can cause solids to float to the surface. Biological growths can grow on the walls of the tank. These solids and growths can buildup in the tanks and increase the chlorine demand. Proper cleaning will reduce the amount of chlorine required.

2.5.6 State why it is important to periodically replace the temporary flexible tubing connections.

The temporary flexible tubing connections run from the chlorine containers to the permanent piping made of cadmium-plated soft copper and 316 stainless steel. The gradual loss of flexibility or severe crimping and kinking requires tubing replacement. If the tubing screeches when bent, it also indicates corrosion on the tubing and should be replaced.

Chapter 3 - Monitoring, Process Control, and Troubleshooting

Section 3.1 - Definitions

3.1.1 Define limit of detection (LOD).

LOD is the lowest level at which a pollutant concentration can be positively detected above background interference.

Section 3.2 - Sampling and Testing

3.2.1 Discuss the laboratory test method most commonly used to measure fecal coliforms in wastewater treatment plants.

The most commonly used test method is the membrane filter technique (Standard Method 9222 D). The colonies for fecal coliform are various shades of blue against a light blue background.

3.2.2 Describe the incubator temperature and time for the membrane filter technique.

The incubator temperature is set at 44.5°C (± 0.2°C) for 24 hours (± 1 hour). The petri dishes containing the control and effluent samples are incubated upside down.

3.2.3 List reasons why fecal coliforms are used as an indicator organism.

A. Always present in domestic wastewater
B. Easy, fast, and economical laboratory test
C. Indicative of pathogen destruction

3.2.4 Discuss the discharge permit limit for fecal coliform.

The discharge permit limit for fecal coliform is 400 colony forming units (cfu) per 100 mL of sample, based on a monthly geometric mean (average).

3.2.5 Discuss the results used to measure the overall effectiveness of a chlorination and dechlorination system.

A. Total residual chlorine less than 37 µg/L
B. Fecal coliforms less than or equal to 400 cfu per 100 mL based on a geometric mean

3.2.6 Explain the type of fecal coliform sample to be taken, sample holding time, and sample preservation requirements.

The type of sample to be collected is a grab sample taken in a sterile bottle after dechlorination. If there is any residual chlorine present, sodium thiosulfate is added to the sample. The holding time is 6 to 24 hours, preferably 6 hours. To preserve the sample, cool immediately to 6°C or less without freezing.

3.2.7 State the acceptable range for fecal coliform colony counts when using the membrane filter technique and discuss the use of colony counts in the determination of fecal coliform density.

The acceptable range for fecal coliform using the membrane filter method would be 20 to 60 colonies per filter membrane. The fecal coliform density is reported as fecal coliform per 100 mL and is calculated using membrane filter counts within the acceptable range (20 to 60 colonies) using:

$$\text{Fecal coliform/100 mL} = (\text{colonies counted} \times 100) \div \text{mL of sample filtered}$$

Normally, a series of dilutions of a wastewater effluent sample are filtered then incubated. The dilutions should be of a volume to yield 20 to 60 colonies per filter membrane, dependent upon effluent quality.

3.2.8 Explain the type of residual chlorine sample to be taken, the sample holding time, and sample preservation requirements.

The type of sample to be collected is a grab sample collected after dechlorination. The analysis should begin immediately upon sample collection (no longer than 15 minutes from the time of collection) as chlorine dissipates rapidly.

3.2.9 State the reason for total residual chlorine limits.

Chlorine is acutely and chronically toxic to aquatic organisms. The acute toxic chlorine limit is 37 µg/L, as a daily maximum limit. Where there is little dilution in the receiving water, a chronic concentration limit may also be needed. Exceeding these limits can harm aquatic life.

3.2.10 List the three recommended testing methods for total chlorine residual.

A. Iodometric back titration (Standard Method 4500 CL C) using amperometric endpoint detection method (Standard Method 4500 CL D)
B. DPD spectrophotometric method (Standard Method 4500 CL G)
C. Specific ion electrode method (Standard Method 4500 CL I)

Section 3.3 - Data Understanding and Interpretation

3.3.1 Discuss Wisconsin Pollutant Discharge Elimination System (WPDES) permit reporting and effluent compliance for total chlorine residual.

Test methods for total residual chlorine normally achieve a limit of detection (LOD) of 20 to 50 µg/L and a limit of quantitation (LOQ) of about 100 µg/L.

Test result reporting and compliance with effluent limits for chlorine residual shall be as follows:

A. Sample results which show no detectable levels of chlorine are in compliance with the limit. These test results shall be reported on the Discharge Monitoring Report (DMR) as <100 µg/L [NOTE: 0.1 mg/L = 100 µg/L].

B. Samples showing detectable traces of chlorine are in compliance if measured less than 100 µg/L, unless there is a consistent pattern of detectable values in this range. These values shall also be reported on the DMR as <100 µg/L. The facility operating staff shall record actual readings on logs maintained at the plant, will take action to determine the reliability of detected results (such as sampling and/or calculating dosages), and will adjust the chemical feed system if necessary to reduce the chances of detectable levels of chlorine.

C. Samples showing detectable levels greater than 100 µg/L shall be considered as exceedances and shall be reported as measured. To calculate average or mass discharge values, a 0 (zero) may be substituted for any test result less than 100 µg/L. Calculated values shall then be compared directly to the average or mass limitations to determine compliance.

3.3.2 Discuss the management and environmental concerns of overdosing chlorine and dechlorination products.

A. Dissolved oxygen (DO) depletion and lower pH in the effluent and receiving stream (dechlorination chemicals are acidic and oxygen scavengers)
B. Chlorine toxicity in the receiving stream, affecting fish and aquatic organisms
C. Biomonitoring (whole effluent toxicity or WET) impacts
D. Effluent biochemical oxygen demand (BOD) increase (due to oxygen uptake of dechlorination chemicals)

3.3.3 Discuss the causes and corrective actions for wide variations in chlorine residuals in the final effluent caused by upstream treatment processes, chlorine contact tank, and chlorine solution diffuser.

Figure 3.3.3.1

Problem	Cause	Corrective Action
Wide variations in chlorine residuals in the final effluent	Upstream treatment processes performing poorly	Poorly performing secondary treatment with high BOD, suspended solids, or ammonia can cause high chlorine demand, correct upstream processes
	Inadequate detention time, short-circuiting, deposition of solids, poor mixing in the contact tank	Correct detention time; add baffles to stop short-circuiting; routinely clean to minimize deposition of solids; add mechanical mixers to improve dispersion of chlorine within the effluent
	Blockage of chlorine solution diffuser, damaged diffuser, or incorrect diffuser location	Perform more adequate routine cleaning and repair of any damaged parts; relocate the diffuser; change the type of diffuser to improve the mixing of the chlorine solution with the treated wastewater

3.3.4 List the possible causes of fecal coliform levels exceeding the discharge permit levels for chlorination systems.

A. Poor upstream treatment
B. Chlorine feed rate too low
C. Inadequate capacity of chlorination equipment
D. Solids buildup in the contact tank
E. Short-circuiting in the contact tank
F. Detention time in the contact tank too short
G. Poor mixing in the contact tank

3.3.5 List the possible causes of high chlorine residuals following dechlorination.

Successful dechlorination results in very low to non-detectable total residual chlorine. If chlorine residuals are too high following dechlorination, the problem may be:

A. The chlorine feed rate is too high for the dechlorination dosage
B. Inadequate dechlorination feed rate
C. Dechlorination equipment malfunction or failure
D. Inadequate mixing of the dechlorination chemicals
E. Chlorine demand of the treated wastewater has decreased with no change in chlorine

3.3.6 Discuss how to determine if mixing is a problem in the chlorine contact tank.

Inadequate mixing can lead to fluctuating chlorine residuals and violations of the fecal coliform discharge limit. Samples taken along the length of the contact tank should show a consistant chlorine residual and low numbers of fecal coliform bacteria.

3.3.7 State the possible causes and corrective actions for chlorine residual problems.

Figure 3.3.7.1

Problem	Cause	Corrective Action
Chlorinator will not feed chlorine	No chlorine supply	Check chlorine supply and pressure gauges to ensure that chlorine is available
	Inadequate injector vacuum	Clogged or damaged injector; check injector operations, water supply, and equipment; repair or replace as needed
	Air leak in chlorinator	Retighten connections; replace any damaged diaphragms, tubing, seals
	Plugged diffuser	Check back pressure on the chlorine water supply and clean diffuser
	Gas flow rate valve (v-notch orifice) closed or out of adjustment	Open or adjust the gas flow rate valve
Variations in chlorine residual	Contact tank detention time too short, solids deposition, short-circuiting, or poor sampling location	Check detention time for the tank, remove solids from the tank, dye test to determine short-circuiting, and add baffles as needed; Sample at other locations
	Chlorine diffuser blocked, damaged, or poor location for dispersion; inadequate or too high feed rates	Clean diffuser and repair or replace damaged parts; change diffuser location or add supplemental mixing to improve dispersion
	Inadequate chlorine feed rates or feed rates too high	Check for any changes in chlorine demand and adjust feed rates, including any repairs necessary to the automatic feed system
	Poor effluent quality	Evaluate upstream processes and wastewater characteristics
Coliform count fails to meet permit requirements	Chlorine residual too low	Check chlorine residual and increase the feed rate; check chlorine pressure reducing valve for damage and allow chlorine to escape to the vent line; disassemble and repair valve
	Inadequate chlorination equipment capacity	Replace with equipment necessary to supply enough chlorine
	Solids build up in the contact tank	Clean the chlorine contact tank
	Short-circuiting in the contact tank	Dye test to confirm; install baffles or add supplemental mixing to stop short-circuiting
	Contact tank detention time is too short	Evaluate the contact detention time; a dye test can confirm the calculation
	Effluent quality	Evaluate upstream processes and wastewater characteristics

Chapter 4 - Safety

Section 4.1 - Regulations and Procedures

4.1.1 Discuss the response an operator should take if there is a chlorine leak.

Chlorine leaks must be taken care of immediately before they become much worse. Corrective measures should be undertaken only by trained personnel wearing proper safety equipment. All other persons should leave the danger area until conditions are safe.

4.1.2 List the items that should be included in safety programs for chlorine and sulfur dioxide usage.

A. Establish a formal plant safety program
B. Provide written specific safety procedures
C. Provide Safety Data Sheets (SDS)
D. Develop a preventive maintenance program
E. Set up a training plan for leak detection equipment, leak repair kits, and respiratory protection
F. Establish a written emergency procedure plan that includes emergency phone numbers
G. Know and follow pertinent local, state, and federal requirements as appropriate

4.1.3 Explain the importance of having a standby person available when working with chlorine or sulfur dioxide systems.

In the event of an accident or an emergency, a second person can assist, be available to obtain emergency help, and provide first aid.

4.1.4 Describe how to locate small leaks of chlorine gas or sulfur dioxide.

Small leaks of chlorine gas can be located using an atomizer filled with ammonia hydroxide solution. When this solution reacts with chlorine gas, a white smoke of ammonium chloride forms indicating a leak. Small leaks of sulfur dioxide can be located using an atomizer filled with sodium hypochlorite solution. In both instances, a white cloud or smoke indicates a leak.

Section 4.2 - Equipment

4.2.1 Discuss the types of respiratory protection that should be used when working with chlorine or sulfur dioxide.

The only types of respiratory protection for working with chlorine or sulfur dioxide would be a self-contained breathing apparatus (SCBA) with compressed air or oxygen or a supplied air type breathing apparatus providing air from an airline (airline respirator). Canister type gas masks are usually inadequate and ineffective for protection and do not provide protection in the event of an oxygen deficient atmosphere or if other toxic gases are present. An emergency escape respirator should always be on hand when working with chlorine or sulfur dioxide cylinders.

4.2.2 Describe the type of respiratory protection that should be provided when working with chlorine or sulfur dioxide leaks.

Respiratory protection should be a SCBA or some other form of positive pressure air breathing device. The SCBA must fit properly and be used by trained personnel.

4.2.3 Discuss where chlorine safety equipment should be stored.

Safety equipment, such as a SCBA or chlorine repair kits, should not be located in the chlorine storage room, but located outside and nearby the chlorine room where they can be obtained quickly in case of an emergency.

4.2.4 Describe the storage location for safety equipment used when working with chlorine or sulfur dioxide.

The safety equipment (respiratory protection, repair kits, and ammonia leak detection solutions) should be located close to the chlorine storage or chlorination rooms, easily accessible, and routinely inspected to be sure everything is in working order. The equipment should not be stored in areas where a leak is likely to occur (chlorine or sulfur dioxide storage room or chlorinator/sulfonator room) and should not be locked-up, causing a delay should equipment be needed.

4.2.5 Discuss the significance of discoloration or corrosion in chlorine application rooms.

Any discoloration or corrosion of gas piping systems, including joints, would indicate a gas leak has been or is occurring.

4.2.6 Discuss what items should not be in a chlorine storage room for chlorine gas and hypochlorites.

Paints, solvents, gasoline, ammonia, or other organic material should not be stored in a chlorine storage room. Any of these materials could cause a violent chemical reaction if a chlorine leak occurs because chlorine is such a strong oxidizing agent.

4.2.7 Explain the safety concerns for a chlorine cylinder or tank.

A. Packing retainer nut
Always check the packing retainer nut for cracks, breakage, or damage; a broken packing nut can cause gas leakage.

B. Cylinder valves
Cylinder valves should not be used to regulate flow. Flows are regulated with a gas flow rate valve. Do not open the cylinder or tank valve more than one turn. One full turn provides maximum discharge and forcing the stem beyond the full open position could damage the internal valve stem threads, possibly causing a leak and might make it impossible to close the valve.

C. Gaskets
Always change gaskets when changing any connections; once a gasket is used, it is compressed and not reusable. These gaskets are made of compressed asbestos or lead.

D. Protective hood
Never transport cylinders or tanks without fastening the cylinder protective hood. Accidental strikes on the unprotected valve end could cause breakage and a possible leak.

E. Fusible plug

Never tamper with a fusible plug. The fusible plug is designed to melt and release pressure under high temperatures.

4.2.8 Describe what should be done if a chlorine leak around a valve stem is discovered.

Contact the chlorine supplier because new Teflon packing material has high torque requirements. Operator adjustment is dangerous because the entire valve may loosen from the cylinder or tank.

4.2.9 Discuss the types of emergency leak repair kits for chlorine and when repair kits are required.

There are 3 types of repair kits designated for repairing or emergency capping of chlorine containers (which can also be used for sulfur dioxide). The chlorine institute emergency kit A is for 150- and 500-pound cylinders, kit B is for 1-ton containers, and kit C is for tank cars and tank barges. These kits contain all necessary tools and instructions, but do not have respiratory equipment. Some of the equipment would include: wrenches, hammer, plugs, clamps, chains, gaskets, hack saw, bolt cutters, and various devices to cap the container valves.

4.2.10 Discuss why soapy water is not used for leak detection for chlorine gas or sulfur dioxide gas.

The use of soapy water or any form of water with a gas leak will form an acid (hydrochloric for chlorine and sulfuric for sulfur dioxide) which is very corrosive and will only make the leak worse. Use only an ammonia squeeze bottle or an ammonia swab to provide an ammonia vapor in the vicinity of the suspected leak. The ammonia vapor with chlorine will form a white smoke.

Section 4.3 - Chemical Considerations

4.3.1 State the reasons why sodium bisulfite or sodium metabisulfite might be used instead of sulfur dioxide for dechlorination.

One reason to use sulfites for dechlorination would be a safety consideration, as they do not pose the toxic concerns of sulfur dioxide gas. Another reason would be that sulfite systems are relatively easy to operate, involving only a solution tank and metering pumps. At small plants, it would be a low cost system with limited operation and maintenance concerns.

4.3.2 Explain what effect chlorine or sulfur dioxide gas has when released into a moist environment.

If chlorine or sulfur dioxide gases are mixed with moist atmospheres, they form hypochloric or sulfuric acid, respectively. These two acids are very corrosive compounds that can attack metals and other equipment causing severe damage. This is why an operator should never use water on a chlorine or sulfur dioxide leak, as the acids formed will only make the leak worse.

4.3.3 Describe chemical disinfection safety concerns.

A. Chlorine gas
Chlorine gas is 2.5 times heavier than air, extremely toxic, and very corrosive in moist

environments. The characteristic sharp odor of chlorine is noticeable at low concentrations. The gas is detectable at 1 part of gas per million parts of air (ppm). With large leaks, high concentrations may be fatal after only a few breaths. Extreme care must be exercised when working with chlorine.

B. Sodium hypochlorite (liquid bleach)
Sodium hypochlorite (liquid bleach) is a strong alkaline (basic) and corrosive solution. The mixing of sodium hypochlorite with any acid solution will cause the immediate release of chlorine gas. Hypochlorites are destructive to wood, corrosive to most metals, and will adversely affect the skin, eyes, and other body tissues with which they come into contact (MOP FD-10).

C. Calcium hypochlorite (tablets, pellets, and granules)
Calcium hypochlorite comes as a dry form (tablets, pellets, or granules) and is unstable under normal atmospheric conditions. Reactions may occur spontaneously with numerous chemicals including turpentine, oils, water, and paper. Calcium hypochlorite, therefore, should be stored in dry locations and used with equipment free of organics. Serious fire and explosion hazards exist when using this material (MOP FD-10).

D. Sulfur dioxide
Sulfur dioxide is a colorless gas and has about the same density as chlorine, about 2.4 times heavier than air. It has a very strong pungent odor. The gas is detectable at low concentrations and is immediately dangerous at high concentrations. Inhaling sulfur dioxide will cause sulfurous acid to form on mucus membranes (eyes, throat, lungs, and skin), causing severe irritation and may be fatal after only a few breaths. Extreme care must be exercised when working with sulfur dioxide.

E. Sodium bisulfite
Sodium bisulfite is an acidic liquid solution. It is an oxygen scavenger which decreases oxygen levels in an enclosed environment. If sodium bisulfite (an acid) is mixed with sodium hypochlorite (a base), an immediate uncontrolled release of chlorine gas will occur. Cleaning any sodium bisulfite equipment with any base will result in an acid-base reaction producing heat and a possible explosion.

4.3.4 Explain why a release of liquid chlorine is much worse than a gas leak.

When liquid chlorine is released, one volume of liquid will evaporate to produce almost 460 volumes of gas because of liquid chlorine's high rate of evaporation.

4.3.5 State why permanent piping should be free of chlorine before any welding is done.

All piping and equipment must be free of chlorine and purged with inert gas before welding as the temperature of welding is high enough to cause the steel pipe to burn. Steel in a chlorine atmosphere will ignite and burn at temperatures above 483°F.

4.3.6 Discuss the importance of removing oil and grease residues from all piping equipment and the procedures used for cleaning this equipment.

During maintenance procedures or new installation, all equipment and piping should be degreased to remove oil and grease before being placed in service. Chlorine will react with organic materials, usually causing heat or violent reactions. Equipment degreasing can be accomplished using a suitable non-flammable solvent. It is extremely important to remove all solvent after degreasing by evaporation and a dry air purge of all piping to avoid a possible violent reaction between chlorine and the solvent.

Chapter 5 - Calculations

Section 5.1 - Calculations

5.1.1 Given data, calculate the amount of chlorine used (lbs/day).

GIVEN:
[MGD = million gallons per day]

Flow = 0.60 MGD
Chlorine dosage = 8 mg/L

FORMULA AND SOLUTION:

Chlorine feed rate (lbs/day) = flow (MGD) × chlorine conc. (mg/L) × 8.34
= 0.60 MGD × 8 mg/L × 8.34
= 40 lbs/day

5.1.2 Given data, calculate the amount of sodium hypochlorite to feed (gallons per day or gpd).

GIVEN:

Flow = 0.500 MGD
12.5% sodium hypochlorite
Solution weight = 10 lbs/gal
Desired chlorine dosage = 10 mg/L

FORMULAS AND SOLUTION:

Chlorine (lbs/day) = flow (MGD) × desired chlorine dosage (mg/L) × 8.34
= 0.500 MGD × 10 mg/L × 8.34
= 41.7 lbs/day chlorine

Sodium hypochlorite to add (gals) = chlorine (lbs/day) ÷ [(solution wt. (lbs)) × (% active chlorine ÷ 100)]
= 41.7 lbs/day chlorine ÷ (10 lbs/gal × 0.125)
= 33.36 gpd

5.1.3 Given chlorine scale readings, calculate the amount of chlorine used (lbs/day).

GIVEN:

Chlorine scale readings:
Day 1 = 204 lbs

Day 2 = 167 lbs

FORMULA AND SOLUTION:

Daily use (lbs) = day 2 (lbs)- day 1 (lbs)
= 204 lbs - 167 lbs
= 37 lbs

5.1.4 Given data, calculate the chlorine demand (mg/L) of the effluent.
GIVEN:

Chlorine dosage = 10 mg/L
Chlorine residual = 3 mg/L

FORUMULA AND SOLUTION:

Chlorine demand (mg/L) = chlorine dosage (mg/L) - chlorine residual (mg/L)
= 10 mg/L - 3 mg/L
= 7 mg/L

5.1.5 Given data, calculate the applied chlorine dosage (mg/L).
GIVEN:

Flow = 0.500 MGD
Chlorine feedrate = 30 lbs/day

FORMULA AND SOLUTION:

Chlorine dosage (mg/L) = chlorine feedrate (lbs/day) ÷ (flow (MGD) × 8.34)
= 30 lbs/day ÷ (0.500 MGD × 8.34)
= 7.2 mg/L

5.1.6 Given data, calculate the detention time (mins) in the chlorine contact tank.
Neglecting the thickness of baffle walls, find the detention time (mins) at average daily flow.

GIVEN:

Average daily flow = 2.0 MGD
Chlorine contact tank baffled to provide 4 passes
Tank length = 40 ft
Tank width = 40 ft
Tank depth = 8 ft
1 cubic foot = 7.48 gals

FORMULAS AND SOLUTION:

Volume (gals) = length (ft) × width (ft) × depth (ft) × 7.48 gals/ft^3
= 40 ft × 40 ft × 8 ft × 7.48 gals/ft^3
= 95,744 gals

Flow rate (gpm) = flow rate (gpd) ÷ 1,440 mins/day
= 2,000,000 gpd ÷ 1,440 mins/day
= 1,389 gpm

Detention time (mins) = volume (gals) ÷ flow rate (gpm)
= 95,744 gals ÷ 1,389 gpm
= 69 mins

5.1.7 Given data, calculate the sulfur dioxide dosage required (lbs) to neutralize the chlorine residual.

GIVEN:

Plant flow = 2.0 MGD
Chlorine residual = 0.4 mg/L
Sulfur dioxide dosage = 1.1 lbs/1 lb of chlorine

FORMULA AND SOLUTION:

Chlorine residual (lbs/day) = flow (MGD) × chlorine conc. (mg/L) × 8.34
= 2.0 MGD × 0.4 mg/L × 8.34
= 6.67 lbs/day of chlorine

Sulfur dioxide to feed = chlorine (lbs/day) × dosage rate
= 6.67 lbs/day × 1.1 lbs sulfur dioxide/1 lb of chlorine
= 7.34 lbs/day sulfur dioxide

5.1.8 Given data, calculate the amount of available chlorine (lbs) in one gallon of sodium hypochlorite.

GIVEN:

Active chlorine = 12.5%
Chlorine weight = 10 lbs/gal

FORMULA AND SOLUTION:
[NOTE: percent is expressed as a decimal]

Chlorine lbs/gal = solution (lbs/gal) × (active chlorine (%) ÷ 100)
= 10 lbs/gal × 0.125
= 1.25 lbs/gal

5.1.9 Given data, calculate the sodium bisulfite required (lbs) to neutralize the chlorine residual (mg/L).

GIVEN:

Plant flow = 750,000 gpd
Chlorine residual = 0.2 mg/L
Sodium bisulfite dosage rate = 1 mg/L sulfite per 1 mg/L chlorine

FORMULAS AND SOLUTION:

Chlorine (lbs/day) = flow (MGD) × chlorine conc. (mg/L) × 8.34
= 0.750 MGD × 0.2 mg/L × 8.34
= 1.25 lbs/day chlorine

Sodium bisulfite to feed = chlorine (lbs/day) × dosage rate
= 1.25 lbs/day chlorine × 1.0 mg/L sulfite per 1 mg/L chlorine
= 1.25 lbs/day sodium bisulfite

5.1.10 Given data, calculate approximate effluent sample size (mL) to use for a fecal coliform test using an estimated fecal coliform concentration (colony forming unites per 100 mL or cfu/100 mL)

GIVEN:

Estimated fecal coliform concentration = 200 cfu/100 mL

FORMULAS AND SOLUTION:

[NOTE: Before calculating the sample size (mL) to filter, use fecal coliform colonies in the recommended range (20 to 60 cfu). This means an upper value and lower value for the sample amount to filter must be calculated.]

Smallest volume to filter (mL) = (fecal colonies (cfu) × 100) ÷ est. fecal conc. (cfu/100 mL)
= (20 cfu × 100 mL) ÷ 200 cfu/100 mL
= 10 mL

Largest volume to filter (mL) = (fecal colonies (cfu) × 100) ÷ est. fecal conc.
= (60 cfu × 100 mL) ÷ 200 cfu/100 mL
= 30 mL

If the estimate of 200 cfu/100 mL is correct, the sample (mL) range to filter is 10 to 30 mL.

5.1.11 Given fecal coliform test results, calculate the fecal coliform geometric mean.

GIVEN:

Week 1 fecal coliform = 10 cfu/100 mL
Week 2 fecal coliform = 20 cfu/100 mL
Week 3 fecal coliform = 18 cfu/100 mL
Week 4 fecal coliform = 50 cfu/100 mL

FORMULAS AND SOLUTION:

The geometric mean can be calculated using either of the following two formulas:

n = number of samples
FC# = fecal coliform weekly result
Geometric mean = nth root of [FC1 × FC2 × FC3 × FC4 × etc.]
= 4th root of (10 cfu/100 mL × 20 cfu/100 mL × 18 cfu/100 mL × 50 cfu/100 mL)
= 4th root of 180,000
= 21 cfu/100 mL

OR

Geometric mean = anti-log (sum of log data ÷ number of values)
Log of 10 cfu/100 mL = 1.000
Log of 20 cfu/100 mL = 1.3010
Log of 18 cfu/100 mL = 1.2553
Log of 50 cfu/100 mL = 1.6989
= anti-log [(1.000 + 1.3010 + 1.2553 + 1.6989) ÷ 4 results]
= anti-log [5.253 ÷ 4 results]
= anti-log [1.313]
= 21 cfu/100 mL

5.1.12 Given data, calculate a fecal coliform concentration (cfu/100 mL) from the membrane filter colony counts (cfu).

GIVEN:

Filter 1 sample volume = 1 mL
Filter 1 colony count = 4 cfu

Filter 2 sample volume = 5 mL
Filter 2 colony count = 21 cfu

Filter 3 sample volume = 10 mL
Filter 3 colony count = 58 cfu

[NOTE: Before calculating the fecal coliform concentration from each filter, eliminate any filter with a colony count out of the recommended range (20 to 60 cfu). Then calculate each sample fecal coliform concentration and arithmetic mean (average).]

FORMULAS AND SOLUTION:

Filter 1 colony count out of the recommended range and is eliminated.

Filter 2 fecal coliform (cfu/100 mL) = (100 × colony count) ÷ sample size (mL)

= (100 × 21 cfu) ÷ 5 mL
= 2,100 ÷ 5 mL
= 420 cfu/100 mL

Filter 3 fecal coliform (cfu/100 mL) = (100 × colony count) ÷ sample size (mL)
= (100 × 58 cfu) ÷ 10 mL
= 5,800 ÷ 10 mL
= 580 cfu/100 mL

Final test result (cfu/100 mL) = (sum of sample results) ÷ # of usable samples
= (580 cfu/100 mL + 420 cfu/100 mL) ÷ 2 samples
= 1,000 ÷ 2 samples
= 500 cfu/100 mL

Part 2 - Ultraviolet

Chapter 6 - Theory and Principles

Section 6.1 - Definitions

6.1.1 Define photoreactivation.

Photoreactivation is the ability of microorganisms to repair cellular damage caused by ultraviolet (UV) radiation. When injured organisms are exposed to light energy at wavelengths between 310 and 500 nanometers (nm), cell function can be restored. These repair mechanisms allow UV inactivated microorganisms to regain viability following the disinfection process.

6.1.2 Describe UV disinfection.

UV disinfection uses a light source just below the visible wavelengths range of light. UV radiation inactivates bacteria and some viruses by destroying cellular material preventing the bacterial cell from reproducing.

6.1.3 Define UV dosage.

The UV dosage delivered by a UV system is a product of UV intensity and detention (seconds). The delivered dose in a flow-through UV system will depend on the intensity of radiation and duration of exposure. Dose is expressed as milliwatts (mW) - second per square centimeter ($mW\text{-}s/cm^2$).

6.1.4 Define UV intensity.

UV intensity is a measure of radiative power per unit of exposed area. It is a function of lamp life, lamp fouling, and configuration and placement of the lamps in the channel. Intensity is expressed as milliwatts per square centimeter (mW/cm^2).

6.1.5 Define UV transmittance.

UV transmittance is a measure of water quality and the ability of the wastewater to transmit UV light, expressed as %T.

Section 6.2 - Process Understanding and Performance Limiting Factors

6.2.1 Explain the difference between disinfection and sterilization.

Disinfection is a process designed to destroy most microorganisms until down to a safe level, although it does not eliminate all of the organisms in the wastewater. In ultraviolet (UV) disinfection, the UV rays are absorbed by the cells of microorganisms, destroying the genetic material in such a way that the organisms are no longer able to grow or reproduce, essentially leaving them sterile. Although UV disinfection renders the microorganisms sterile, it does not eliminate all of the organisms; therefore it is not a form of sterilization, defined as the eradication of all living organisms in a given area.

6.2.2 Discuss how a typical UV unit functions.

Treated wastewater is exposed to UV radiation and disinfection effectiveness is a function of UV intensity and exposure time. Wastewater flows through a chamber or channel containing mercury vapor lamps in quartz glass tubes. The UV lamps resemble fluorescent tubes and are spaced close together to ensure good mixing and exposure of the microorganisms. The UV units are relatively small compared to a chlorine contact tank for a given flow.

6.2.3 Describe the effluent characteristics that can inhibit the effectiveness of UV disinfection.

The main effluent characteristics that can inhibit UV disinfection are dissolved, colloidal, and particulate materials that interfere with the passage of light through water. Suspended solids, in particular, can block the transmission of the UV rays, reducing the effectiveness of disinfection.

6.2.4 Describe advantages of UV disinfection.

A. Short contact time
B. No residual toxicity
C. No chemicals to handle
D. Minimal space requirements
E. Relatively easy UV system inspections
F. Relatively simple UV system maintenance

6.2.5 Describe the factors that control the dosage of UV radiation.

The dosage of UV is dependent on the energy from the lamp (intensity) and the exposure time to the UV radiation. These two factors can be significantly reduced: if the wastewater effluent is colored or has high turbidity (high suspended solids), by the hydraulic design of the reactor, by the age of the UV lamps (a reduction in intensity), and by a buildup of deposits on the sleeves.

6.2.6 List the causes of poor disinfection results from UV systems.

A. Quartz sleeves fouled from organic slimes or grease, from inorganic calcium or magnesium carbonate scale (hardness scale), or iron, reducing UV radiation

B. Hydraulic flow rate is too high, reducing detention time through the reactor

C. UV lamps are too old, reducing the intensity of the radiation

D. Deterioration of quartz sleeves as they age, causing cloudiness, and reducing intensity of the radiation

E. Water level is too high in the reactor unit, causing some of the effluent to be too far away from the lamps, reducing the effectiveness of the disinfection

F. Poor quality of upstream effluent, causing high turbidity (high suspended solids), reducing transmission of radiation

6.2.7 List the advantages and disadvantages of using UV radiation for wastewater disinfection.

A. Advantages
UV radiation has several advantages including: possible low capital costs, low O&M costs, smaller space requirements, and no chemical usage (no toxic compound formation and less

operational safety considerations).

B. Disadvantages
The presence of certain dissolved solids, high suspended solids, and low UV transmittance of the treated wastewater reduces UV radiation effectiveness for disinfection. There is a need to clean the lamps to remove scale formation and any buildup of organic materials on the lamps. Safety considerations include: protecting the eyes and skin from UV radiation and taking precautions involving the electrical components of the system.

Chapter 7 - Operation and Maintenance

Section 7.1 - Definitions

7.1.1 Define fouling.

Fouling occurs when the ability to deliver radiation from the bulbs is impeded by organic or inorganic material accumulating on the quartz sleeves.

7.1.2 Describe a lamp, sleeve, module, and bank in a ultraviolet (UV) system.

A. Lamp
A lamp is the UV radiation source, either low-pressure or medium-pressure mercury lamps with low or high intensities.

B. Sleeve
Quartz glass sleeves house the lamps and are what makes the contact with the water.

C. Module
A module includes the number of lamps assembled in each metal support frame.

D. Bank
A bank includes the number of modules placed in the channel next to each other spanning the flow stream.

Section 7.2 - Equipment

7.2.1 Describe a ballast.

A ballast is an electrical device providing a starting voltage for and maintaining a continuous current to the lamps.

7.2.2 List the ultraviolet (UV) system types.

A. Low-pressure mercury lamp
B. Medium-pressure mercury lamp
C. Low-pressure/high-intensity

7.2.3 Discuss the differences between the three types of UV lamps.

A. Low-pressure lamps
Low-pressure lamps maximize the conversion of electricity to UV radiation for greater efficiency and are the least expensive.

B. Medium-pressure lamps
Medium-pressure lamps reduce the number of lamps needed compared to low-pressure lamps, significantly reducing operating and lamp replacement costs and allows for installation in smaller spaces.

C. Low-pressure/high-intensity lamps
Low-pressure/high-intensity lamps operate at higher temperatures allowing the lamp to emit higher UV output. Lamps can be turned down to conserve energy and prolong lamp life.

7.2.4 Discuss the reason for UV lamp replacement and state the expected life of UV lamps.

As UV lamps age, the intensity of the UV radiation is gradually reduced and the lamps will need to be replaced. The determining factor for lamp replacement would be increasing fecal coliform density. The lamps can have an operating life of greater than 14,000 hours. When using routine fixed-time replacement, the time of lamp replacement can vary from 7,500 to 12,500 hours.

7.2.5 Discuss the main components of a UV disinfection system.

A. Mercury vapor lamps
Mercury vapor lamps are the source of UV radiation and can be low pressure, medium pressure, or low pressure/high intensity.

B. Reactor
The reactor is the channel the wastewater flows through during treatment and is either contact or non-contact. In contact reactors, the lamps are enclosed in quartz sleeves, and must be kept clean. In non-contact reactors, the UV lamps are suspended outside a transparent conduit through which the water flows.

C. Ballasts
Ballasts provide a starting voltage for the lamps and maintain a continuous current to the lamps.

7.2.6 Describe how UV radiation is generated.

UV radiation is generated by passing an electrical current through a mixture of mercury vapor and argon under pressure.

7.2.7 Discuss the benefits of proper mixing in a UV system.

Proper mixing is usually achieved by proper flow channel design in a UV system and helps distribute microorganisms across different UV gradients for varying lengths of time to achieve disinfection.

7.2.8 Describe the deterioration of the quartz sleeves used in UV systems and state the expected life of the quartz.

With continued use, the quartz structure will degrade, resulting in a cloudiness of the quartz. This causes a loss of light transmission, reducing lamp intensity, and disinfection efficiency. This deterioration is called solarization of the quartz structure. The expected life of the quartz sleeves will vary.

7.2.9 Discuss the operational controls for UV disinfection.

In smaller plants (less than 1.0 million gallons per day or MGD) running the system at all times, the system controls are relatively simple. Larger plants with multichannel and multibank systems, control can be by automatic-flow proportional pacing to reduce power costs. A critical operating requirement for the newer open channel systems is to control the water level in the channel to ensure that the water elevation does not rise too high above the lamps, decreasing disinfection effectiveness. A water level too low would expose the lamps and expose operators to harmful radiation. Water elevations should be controlled using downstream weirs or automatic level control gates.

Section 7.3 - Preventive Maintenance

7.3.1 List the maintenance concerns for ultraviolet (UV) disinfection systems.

A. Clean the organic and inorganic buildup on the surfaces of the sleeves
B. Replace UV lamps due to the limited life
C. Maintain a spare parts inventory including lamps, sleeves, ballasts, and other system components
D. Clean channel containing the UV lamps

7.3.2 Describe the steps to be taken to correct lamp fouling.

Improving upstream treatment processes helps reduce fouling of the UV sleeves. When cleaning is needed, a dilute acid or commercial detergent can be used.

7.3.3 Describe the physical methods of cleaning UV quartz lamps, including equipment and chemicals used.

It is important the quartz surfaces of the lamps be maintained as clean as possible of the organic materials and inorganic carbonates buildup (hardness scale) which reduces the effectiveness of disinfection. Early UV systems (in closed reactors) used ultra-sonic cleaning to remove deposits. UV systems using horizontal lamps in modules are cleaned by physically removing a module of lamps and cleaning with citric acid or Lime-A-Way®. Some UV systems employ an automatic wiper system to wipe the sleeves on a preset schedule with online automatic cleaning systems. These systems are available with either a mechanical wiper physically wiping the sleeve or a chemical and mechanical cleaning system utilizing an acid cleaner between two wipers to clean the sleeves. Most installations use a rack provided to hang the module while cleaning. The frequency of cleaning varies widely (from weekly to yearly). The fecal coliform density test is used to determine when there is need for cleaning.

7.3.4 Discuss the types of chemicals that can be used to clean quartz sleeves.

Citric acid, phosphoric acid, and commercial bathroom cleaners are the main chemicals used for cleaning the sleeves. Food grade cleaning solutions are recommended allowing the spent solution to be safe to return to the plant headworks. Identifying the fouling material can help determine the best cleaning solution to use for removal.

Chapter 8 - Monitoring, Process Control, and Troubleshooting

Section 8.1 - Sampling and Testing

8.1.1 Describe the testing used to measure the performance of a ultraviolet (UV) system.

Changes in process performance can result from hydraulic loading, lamp aging, lamp fouling, or variations in effluent quality (especially suspended solids). The main criterion for replacing UV lamps is primarily the effluent fecal coliform test.

Section 8.2 - Data Understanding and Interpretation

8.2.1 List the possible causes of fecal coliform levels exceeding the discharge limits for ultraviolet (UV) disinfection units.

A. Poor effluent quality (high suspended solids or low UV transmittance)
B. Dirty lamps
C. Age of the UV lamps (reduced intensity)
D. System not in full operation
E. Hydraulics (high flows and low detention times)

8.2.2 Describe how UV is affected by effluent turbidity, especially dissolved and particulate suspended solids.

The main effluent characteristic inhibiting UV disinfection is suspended solids. Suspended solids block the transmission of the UV rays, reducing the effectiveness of disinfection. For best UV disinfection results, the effluent suspended solids should be as low as possible.

8.2.3 Describe the effect on the quality of UV disinfection of suspended solids, certain soluble organic and inorganic chemicals, high iron content or color, and visible light.

A. Suspended solids in the effluent
UV systems provide the best disinfection when suspended solids in the treated wastewater are low (less than 15 mg/L). Higher suspended solids tend to shield the microorganisms from the UV radiation, reducing the effectiveness of the disinfection. If suspended solids are consistently greater than 25 mg/L, they may prevent the UV system from meeting the fecal coliform limits. It is very important that the upstream treatment units be well operated to minimize the amount of suspended solids reaching the UV disinfection system. A final filtration system prior to UV radiation will increase the effectiveness of the disinfection.

B. Certain soluble organic and inorganic chemicals
Certain soluble organic and inorganic chemicals can impair the transmission of UV radiation at 254 nm. This is known as UV absorbance and can be determined using a spectrophotometric measurement. All of the exact chemicals causing UV absorbance are not known, but organic and ammonia-nitrogen are two that do reduce UV transmission. A well-nitrified effluent (ammonia and organic nitrogen of less than 2 mg/L) will produce better disinfection using UV radiation.

C. High iron or color in the effluent
The use of iron salts for phosphorus removal can leave some ferric iron in the secondary effluent and cause absorption of the radiation in the UV range. An effluent having a

discernible color can also interfere with the transmission of UV radiation.

D. Visible light on UV treated effluent (photoreactivation)
The damage caused to microorganisms by the UV radiation can (to a limited extent) be repaired by exposure to sunlight in the visible range of 310 to 490 nm. This photoreactivation occurs within minutes after exposure to the reactivating light. Generally, viruses do not have repair ability, but many higher organisms do photorepair, causing an increase in fecal coliform concentrations.

Chapter 9 - Safety

Section 9.1 - Definitions

9.1.1 Discuss the harmful effects of direct exposure to ultraviolet (UV) light.

Direct exposure to eyes and skin can damage eyesight and cause serious burns. Proper personal protective equipment (PPE), such as a face shield and clothing, should be used. Follow all manufacturer and employer safety procedures.

Section 9.2 - Regulations and Procedures

9.2.1 Discuss the personal protective equipment (PPE) requirements when working with ultraviolet (UV) disinfection equipment.

PPE should include a full face shield, gloves, and all exposed skin covered. Long pants and long-sleeved shirts should always be worn around UV equipment.

9.2.2 Discuss the safety concerns related to UV electrical equipment.

UV equipment utilizes high voltage electricity; therefore follow all lock-out/tag-out procedures before working on equipment. Because of the proximity to water, proper grounding is critical and be sure all electrical connections and switches are water tight.

Section 9.3 - Equipment

9.3.1 Discuss the risk of exposure to ultraviolet (UV) radiation if the water level in the UV channel gets too low.

UV quartz sleeves and lamps must remain submerged and below the water surface at all times. Should the water level drop below the UV sleeves and lamps, the direct exposure to UV radiation significantly increases and can result in burns and eyesight damage.

9.3.2 Discuss the proper disposal of UV lamps.

UV lamps contain mercury which is a hazardous material and should be disposed of properly.

9.3.3 Discuss the safety concerns with cleaning solutions used to clean UV equipment.

Many of these cleaning solutions are acidic, so the proper personal protection equipment (PPE) should be used when working with them. Acid-resistant gloves, face shields, rubber aprons, and boots are recommended. The cleaning solutions should be used in a well-ventilated area. If using strong acids, training and having the proper spill kits are recommended.

References and Resources

1. **UW WATER LIBRARY**

   Most of the resources listed on this page can be borrowed through the UW Water Library as part of a partnership between the UW Water Library, the Wisconsin Wastewater Operator Association (WWOA), Central States Water Environmental Association (CSWEA), and the Wisconsin Department of Natural Resources. Instructions for borrowing materials from the UW Water Library can be found by visiting the website provided below, clicking on 'WISCONSIN RESIDENTS', and then clicking on 'HOW TO BORROW MATERIALS'.

   www.aqua.wisc.edu/waterlibrary

2. **OPERATION OF MUNICIPAL WASTEWATER TREATMENT PLANTS (2008)**

   Water Environmental Federation (WEF) (2008). Manual of Practice (MOP) No. 11 vol. I, II, III (6th ed.). New York, New York: McGraw-Hill

   www.wef.org

3. **OPERATION OF WASTEWATER TREATMENT PLANTS**

   Office of Water Programs, California State University, Sacramento (2008). Operation of Wastewater Treatment Plants (7th ed.). Sacramento, California: University Enterprises, Inc., California State University

   www.owp.csus.edu

4. **STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER**

   American Public Health Association, American Waterworks Association, and Water Environment Federation (WEF) (22nd ed.)

   www.standardmethods.org

5. **WASTEWATER DISINFECTION**

   Water Environmental Federation (WEF) (1996). Manual of Practice FD-10 (MOP FD-10). Alexandria, VA

   www.wef.org

6. **THE CHLORINE MANUAL**

   The Chlorine Institute (1997). (6th ed.). Washington, D.C.

   www.CL2.com

7. **NR 110 SEWERAGE SYSTEMS**

   Wisconsin Administrative Code Chapter NR 110: Sewerage Systems (2014)

   https://docs.legis.wisconsin.gov