



Wisconsin Department of Natural Resources Wastewater Operator Certification

Advanced Disinfection Study Guide

February 2010 Edition



Photo of Sparta Wastewater Treatment Plant

Subclass E

Wisconsin Department of Natural Resources
Bureau of Science Services
Operator Certification Program
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Preface

This operator's study guide represents the results of an ambitious program. Operators of wastewater facilities, regulators, educators and wastewater businesses, jointly prepared the objectives and exam questions for this subclass.

How to use this study guide with references

In preparation for the exams you should:

1. Read all of the key knowledges for each objective.
2. Use the resources listed at the end of the study guide for additional information.
3. Review all key knowledges until you fully understand them and know them by memory.

It is advisable that the operator take classroom or online training in this process before attempting the certification exam.

Choosing A Test Date

Before you choose a test date, consider the training opportunities available in your area. A listing of training opportunities and exam dates is available on the internet at <http://dnr.wi.gov>, keyword search "operator certification". It can also be found in the annual DNR "Certified Operator" or by contacting your DNR regional operator certification coordinator.

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Table of Contents

Part 1 - Disinfection Advanced - Chlorination

Chapter 1 - Theory and Principles of Chlorination

Section 1.1 - Definitions	pg. 1
Section 1.2 - Pathogen Knowledge	pg. 1
Section 1.3 - Chlorine/Dechlorination Chemistry	pg. 1
Section 1.4 - Process Understanding/Performance Limiting Factors	pg. 4

Chapter 2 - Operation and Maintenance

Section 2.1 - Definitions	pg. 5
Section 2.2 - Methods	pg. 5
Section 2.3 - Equipment	pg. 6
Section 2.4 - Handling & Storage	pg. 6
Section 2.5 - Preventive Maintenance	pg. 9

Chapter 3 - Monitoring, Process Control, and Troubleshooting

Section 3.1 - Definitions	pg. 9
Section 3.2 - Sampling & Testing	pg. 10
Section 3.3 - Data Understanding & Interpretation	pg. 10

Chapter 4 - Safety

Section 4.1 - Definitions	pg. 12
Section 4.2 - Regulations & Procedures	pg. 12
Section 4.3 - Equipment	pg. 12
Section 4.4 - Chemical Considerations	pg. 13

Chapter 5 - Calculations

Section 5.1 - Calculating chlorination chemical feed rates and amount of chlorine used	pg. 14
Section 5.2 - Determining appropriate sample volumes for fecal coliform analysis.	pg. 18

Part 2 - Disinfection Advanced - Ultraviolet

Chapter 6 - Theory and Principles of Ultraviolet

Section 6.1 - Definitions	pg. 18
Section 6.2 - Pathogen Knowledge	pg. 19
Section 6.3 - Process Understanding/Performance Limiting Factors	pg. 19

Chapter 7 - Operation and Maintenance

Section 7.1 - Definitions	pg. 20
Section 7.2 - Methods	pg. 20
Section 7.3 - Equipment	pg. 21

Table of Contents

Section 7.4 - Preventive Maintenance	pg. 21
Chapter 8 - Monitoring, Process Control, and Troubleshooting	
Section 8.1 - Definitions	pg. 22
Section 8.2 - Sampling & Testing	pg. 22
Section 8.3 - Data Understanding & Interpretation	pg. 22
Chapter 9 - Safety	
Section 9.1 - Definitions	pg. 23
Section 9.2 - Regulations & Procedures	pg. 23
Section 9.3 - Equipment	pg. 23
Chapter 10 - Calculations	
Section 10.1 - Calculations	pg. 23

Part 1 - Disinfection Advanced - Chlorination

Chapter 1 - Theory and Principles of Chlorination

Section 1.1 - Definitions

- 1.1.1 Explain the difference between disinfection and sterilization.

Disinfection is a process designed to destroy most microorganisms to a safe level. Disinfection by chlorine does not destroy all pathogens. Sterilization is a process designed for complete destruction of all living microorganisms and is not used in wastewater treatment as it is unnecessary and extremely costly.

- 1.1.2 Define Breakpoint Chlorination

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

Section 1.2 - Pathogen Knowledge

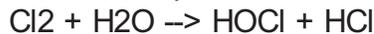
- 1.2.1 We currently have no key knowledges in this section.

Section 1.3 - Chlorine/Dechlorination Chemistry

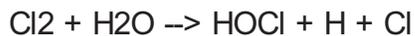
- 1.3.1 Discuss the reactions of gaseous chlorine and hypochlorites when mixed with water.

Gaseous Chlorine (Cl_2)

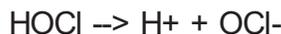
Gaseous chlorine mixed with water forms hypochlorous (HOCl) and hypochloric (HCl) acids, would be expressed as:



OR



The Hypochlorous Acid ionizes (depending on pH) to form hydrogen ions (H^+) and Hypochlorite ions (OCl^-), and would be expressed as:



Hypochlorous acid is a weak acid and is not dissociated (ionized) when the pH is less than 6. This is important, as hypochlorous acid (HOCl) has 40 to 80 times greater disinfection ability than the hypochlorite ion (OCl^-). In wastewater with a pH of 7.3 (depending on temperature), about 50% of the chlorine will be in the form of HOCl , and 50% in the form of OCl^- . The higher the pH level the greater the percent of OCl^- and the more chlorine required to achieve disinfection.

Hypochlorites (OCl^-)

Usually, sodium hypochlorite (NaOCl) is used, rather than calcium hypochlorite [$\text{Ca}(\text{OCl})_2$], because calcium hypochlorite is more costly, causes calcium sludge, and is more dangerous to handle.

The sodium hypochlorite reaction with water is similar to gaseous chlorine, forming sodium hydroxide (NaOH), hypochlorous acid (HOCl), hypochlorite ion (OCl⁻), and hydrogen ion (H⁺). This is usually expressed as:



The hydrochloric acid ionizes the same as gaseous chlorine, and is pH dependent.



The main difference between chlorine gas and hypochlorite compounds is that gas tends to decrease pH, which favors hypochlorous acid formation. Hypochlorite compounds tend to increase pH with the occurrence of sodium hydroxide which favors hypochlorite ion formation.

1.3.2 Discuss the reaction of chlorine and ammonia.

Adding chlorine to treated wastewater, which has ammonia (NH₃), will cause a reaction, where hypochlorous acid (HOCl) reacts with ammonia to form chloramines. Chloramines are not effective disinfecting compounds. The reactions and type of chloramines formed are:



The formation of the various chloramines are pH dependent with monochloramine and dichloramine, both existing at normal wastewater pH's of 6.5 to 7.5 with pH levels below 5.5, dichloramine will exist itself, and at a pH below 4.0 only trichloramine will be found. The higher the effluent ammonia level, the higher the chlorine demand.

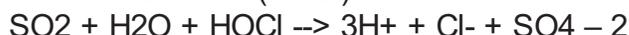
1.3.3 Discuss the chemical reactions, the feed rates, and the required contact times of the following common dechlorination compounds used in removing chlorine:

- A. Sulfur Dioxide (SO₂)
- B. Sodium Bisulfite (NaHSO₃)
- C. Sodium Metabisulfite (Na₂S₂O₅)

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.

For Free Chlorine (HOCl):



For Chloramines (NH₂Cl):



The theoretical dosage for dechlorination requires 0.9 mg/L of sulfur dioxide for every 1 mg/L of total chlorine residual 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.

For Free Chlorine:



For Chloramines:



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

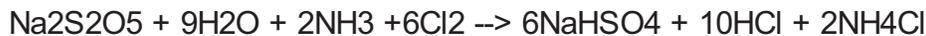
C. Sodium Metabisulfite

Sodium metabisulfite reduces free chlorine to form sodium bisulfate (NaHSO₄) and hydrochloric acid (HCl). The Chloramines are converted to sodium bisulfate, hydrochloric acid, and ammonium chloride (NH₄Cl).

For Free Chlorine:



For Chloramines:



The theoretical dosage for dechlorination requires 1.338 parts of pure sodium metabisulfite for each part of chlorine or chloramine. 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 List the physical properties of chlorine (liquid and gas) for the following:

- A. Boiling Point (at atmospheric pressure)
 - B. Density
 - C. Specific Gravity
 - D. Color
 - E. Odor
 - F. Solubility in Water
- A. Boiling Point (at atmospheric pressure)

Liquid = -29.2°F (-34°C)

B. Density

The density of chlorine (liquid or gas) varies with temperature and pressure. It is more dense at lower temperatures.

Liquid = 88.8 pounds/cubic foot at 60°F (16°C)
(11.9 pounds/gallon)

Gas = 0.20 pounds/cubic foot at 34°F (1.1°C)
At 1 atmosphere

C. Specific Gravity

Specific gravity varies with temperature and pressure.

Liquid = 1.47 at 32°F (0°C) (Water = 1)

Gas = 2.48 at 32°F (0°C) (Air = 1)

D. Color

Liquid = Clear amber

Gas = Greenish/yellow

E. Odor

For both liquid and gas, the odor is penetrating and irritating. The odor can be detected at one part of gas per one million parts of air (by volume).

F. Solubility in Water

Chlorine is not very soluble in water and more can be dissolved in water at lower temperatures.

Section 1.4 - Process Understanding/Performance Limiting Factors

- 1.4.1 Discuss the environmental significance of chlorinated compounds formed during the disinfection of wastewater.

Since chlorine is such a strong oxidizing chemical, it reacts with various constituents in wastewater, forming chlorine compounds. Common compounds would be the formation of chloramines. Chlorine compounds such as chloramines and trihalomethanes are significant as they are toxic to fish and other aquatic life and should be removed by dechlorination prior to discharge.

1.4.2 Discuss the effect on chlorination of the following:

- A. Mixing
- B. Contact Time
- C. Temperature
- D. pH
- E. Suspended Solids
- F. Organic and Inorganic Materials

A. Mixing

Good mixing at the point of application optimizes disinfection.

B. Contact Time

The longer the contact time, the better the disinfection. The minimum contact times under average and peak flows are 60 minutes and 30 minutes, respectively.

C. Temperature

With higher temperatures of the wastewater, the rate of disinfection will occur more rapidly.

D. pH

The lower the pH of the wastewater, the more effective will be the disinfection. This is 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. This will cause 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 Describe a chlorine contact tank and its purpose.

A chlorine contact tank is located after the final treatment units and is typically a baffled basin. The channels (passes) usually have a large length to width ratio. The purpose of the contact tank is to provide sufficient detention time for the chlorine to react and achieve pathogen reduction.

Section 2.2 - Methods

2.2.1 Describe the following methods used to control chlorine and sulfur dioxide dosages:

- A. Manual Control
- B. Start-Stop Control
- C. Step-Rate Control
- D. Time-Program Control
- E. Flow-Proportional Control
- F. Chlorine Residual Control

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 that converts 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. This 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, varying the vacuum differential.

Section 2.3 - Equipment

2.3.1 Describe the difference in equipment (including valves) used for Sulfur Dioxide as compared to Chlorine.

The valves in a sulfur dioxide gas system are made of 316 Stainless Steel with Teflon seats. All other components of the systems are virtually identical.

2.3.2 Discuss properly sized rotameters.

A properly sized rotameter operates between 30 - 70% of the rotameter range. If operating outside of this range, it becomes more difficult to read and control.

Section 2.4 - Handling & Storage

2.4.1 Describe the materials used for the following in handling chlorine gas and liquid.

- A. Permanent Piping (gas and liquid)
- B. Temporary Connections (gas)
- C. Gaskets (gas)
- D. Valves (gas)

A. Permanent Piping

Chlorine Gas Permanent Piping under Pressure:

- Permanent piping for dry pressurized chlorine gas should be constructed from seamless carbon steel, schedule 80, with a one-inch diameter being adequate for most applications.
- Pipe with a diameter of 3/4 inch can be used for 150-pound cylinders or 1-ton tanks, but smaller sizes are not recommended.
- Permanent piping joints should be welded.
- 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.

Chlorine Gas Permanent Piping under Vacuum:

- Permanent piping for a dry vacuum chlorine gas should be constructed from PVC 80 Polyvinyl Chloride piping.
- Permanent PVC80 pipe joints should be solvent welded.
- All the piping should be cleaned and de-burred as it is installed. A dry air or inert gas purge of the process piping should be done before placing the system in service.
- Flexible polyethylene tubing can be used for vacuum transfer of chlorine gas for short distances (less than 50 feet).

Permanent Piping for Chlorine Solution (Chlorine Gas and Water):

- Permanent piping for chlorine solution should be constructed from schedule 80 Polyvinyl Chloride or flexible polyethylene tubing.
- 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.
- Permanent piping can be solvent welded or be threaded.

B. Temporary Connections

Temporary connections (150 lb cylinder or 1 ton tanks) to the permanent piping are:

- Pressurized Chlorine: Stainless steel and titanium tubing and fittings can be used for temporary connections on a pressurized gas chlorine system.
- Chlorine Gas under Vacuum: Polyethylene tubing and fittings can be used for a temporary connection on vacuum systems.

C. Gaskets

Recommended gasket materials for pressurized and vacuum gas chlorine systems are:

- Teflon
- Lead
- Compressed asbestos
- 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

Valves for Pressurized Chlorine:

- Forged carbon steel with monel seats and stems and metal to metal seats. 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.

Valves for Chlorine Gas under Vacuum:

- Valves constructed from polyvinyl Chloride (PVC Sch 80) with Teflon seats can be used. PVC 80 ball valves have to be replaced because the valve will become hard to open or close.
- Forged Carbon Steel with monel seats, Hastalloy C, or 316 Stainless Steel ball valves can also be used.

2.4.2 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 pounds per gallon. 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, because 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 to 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 the water or organic materials (petroleum-based oils, grease, or solvent) as the potential would exist for chemical reactions for fire.

2.4.3 Discuss the desirable temperature range for chlorine and sulfur dioxide gas systems.

Systems for chlorine and sulfur dioxide gas should be protected from extremes of temperature. As temperatures increase, the rate of vaporizing of the liquids in containers tends to increase. When temperatures decrease, the gas tends to condense. Rooms built

for the storage of containers and chlorinators or sulfonators should have provision for adequate heating above 50° F. It is best to keep piping systems and the chlorinator/sulfonator equipment at a temperature between 60 - 110° F.

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

150 pound cylinder

Chlorine: 4.0 pounds/hour

Sulfur Dioxide: 3.0 pounds/hour

1 Ton Tank

Chlorine: 20.8 pounds/hour

Sulfur Dioxide: 15.0 pounds/hour

Section 2.5 - Preventive Maintenance

- 2.5.1 Describe the cause of discoloration or corrosion on steel permanent piping systems 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. The discoloration is on the outside of the piping or fittings, indicates a chlorine leak. Maintenance would involve immediate repair of leaks.

- 2.5.2 State why it important to periodically replace the temporary flexible tubing connections from the chlorine containers to the permanent piping for cadmium-plated soft copper and 316 stainless steel.

The gradual loss of flexibility or severe crimping/kinking requires replacement of the tubing. If the tubing screeches when bending, it also indicates corrosion and should be replaced.

Chapter 3 - Monitoring, Process Control, and Troubleshooting

Section 3.1 - Definitions

- 3.1.1 Define the following terms:

A. Free Available Chlorine

B. Combined Total Chlorine

C. Total Residual Chlorine

A. Free Available Chlorine

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

B. Combined Available Chlorine

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

C. 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.

3.1.2 Define Level of Detection (LOD).

The lowest level at which a pollutant concentration can be positively detected above background interference.

Section 3.2 - Sampling & Testing

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

44.5 ± 0.5°C for 24 hours ± 1 hour and the Petri dishes are incubated upside down.

3.2.2 Describe the analyses used to measure the overall effectiveness of a chlorination/dechlorination system.

- Total residual chlorine less than 37 ug/L
- Fecal coliforms less than or equal to 400 cfu/100 mL based on a geometric mean

3.2.3 Describe the method for determining the number of fecal coliforms in the disinfected water.

Normally, a series of dilutions of a wastewater effluent sample are filtered to incubate fecal coliform. The dilutions should be of a volume to yield 20-60 colonies per filter membrane, which is dependent upon effluent quality. The complete testing procedure can be found in Standard Methods 9222 D.

Section 3.3 - Data Understanding & Interpretation

3.3.1 State the acceptable range for fecal coliform colony counts when using the membrane filter technique, and discuss the use of colony counts in the determinations 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:

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

Normally, a series of dilutions of a wastewater effluent sample are filtered to incubate fecal coliform. The dilutions should be of a volume to yield 20 to 60 colonies per filter membrane, which is dependent upon effluent quality.

3.3.2 List the materials that can cause an increase in chlorine demand.

- Chlorine reacts with many materials that will cause an increased chlorine demand. Some of the inorganic materials would be hydrogen sulfide, ammonia, ferrous iron, manganese, and nitrites.
- Chlorine will also react with any organic materials forming chlororganic compounds. When a treatment plant partially nitrifies, the chlorine demand exerted by nitrites can consume significant quantities of chlorine.

3.3.3 State the possible causes and corrections for chlorine residual problems and consequences.

A. Chlorinator will not feed chlorine (or low feed rates)

B. Variations in chlorine residual

C. Coliform count fails to meet permit requirements

A. Chlorinator will not feed chlorine (or low feed rates)

- Possible Cause: No chlorine supply.

- Correction: Check chlorine supply and pressure gauges to ensure that chlorine is available.

- Possible Cause: Inadequate injector vacuum.

- Correction: Clogged or damaged injector. Check injector operations, injector water supply, injector equipment. Repair or replace as needed.

- Possible Cause: Air leak in chlorinator.

- Correction: Retighten connections. Replace faulty diaphragms, ruptured tubing, defective seals, or replace as needed.

- Possible Cause: Plugged diffuser.

- Correction: Check back pressure on the chlorine water supply and clean diffuser.

- Possible Cause: Gas Flow rate valve (v-notch orifice) closed or out of adjustment.

- Correction: Open or adjust the gas flow rate valve (v-notch orifice).

B. Variations in chlorine residual

- Possible Cause: Chlorine contact tank detention time too short, solids deposition in the tank, short-circuiting within the tank, or poor sampling location.

- Correction: Check detention time for the tank, remove (clean) solids from the tank, dye test to determine short-circuiting, and add baffles as needed. Sample at other locations.

- Possible Cause: Chlorine diffuser blocked, damaged, or poor location for chlorine dispersion. Inadequate chlorine feedrates or feed rates too high.

- Correction: Clean diffuser and repair or replace damaged parts. Change diffuser location or add supplemental mixing to improve dispersion.

- Possible Cause: Inadequate chlorine feed rates or feed rates too high.

- Correction: Check for any changes in chlorine demand and adjust feed rates, including any repairs necessary to the "automatic" feed system.

- Possible Cause: Poor effluent quality.

- Correction: Evaluate upstream processes and wastewater characteristics.

C. Coliform count fails to meet permit requirements

- Possible Cause: Chlorine residual too low.

- Correction: Check chlorine residual and increase the chlorine feed rate. Check chlorine pressure reducing valve as it may be damaged and allowing chlorine to escape to the vent line. Disassemble and repair the valve.

- Possible Cause: Inadequate chlorination equipment capacity.

- Correction: Replace with equipment necessary to supply enough chlorine.

- Possible Cause: Solids build-up in the contact tank.

- Correction: Clean the chlorine contact tank.

- Possible Cause: Short-circuiting in the contact tank.

- Correction: Dye test the tank to confirm short-circuiting. Install baffles or add

supplemental mixing to stop short-circuiting.

- Possible Cause: Contact tank detention time is too short.
 - Correction: Evaluate the contact detention time. A dye test can confirm the calculation.
- Possible Cause: Effluent quality.
 - Correction: Evaluate upstream processes and wastewater characteristics.

3.3.4 Describe the significance of chlorine level of detection when reporting chlorine results.

Test methods for total residual chlorine, approved in ch. NR 219 – Table B. Wis. Adm. Code, normally achieve a limit of detection of about 20 to 50 micrograms per liter and a limit of quantitation of about 100 micrograms per liter. Reporting of test results and compliance with effluent limitations for chlorine residual shall be as follows:

- Sample results which show no detectable levels are in compliance with the limit. These test results shall be reported on Wastewater Discharge Monitoring Report Forms as “<100ug/L”. (Note: 0.1 mg/L converts to 100 ug/L)
- Samples showing detectable traces of chlorine are in compliance if measured at less than 100 ug/L, unless there is a consistent pattern of detectable values in this range. These values shall also be reported on Wastewater Discharge Monitoring Report Forms as “<100 ug/L.” The facility operating staff shall record actual readings on logs maintained at the plant, shall take action to determine the reliability of detected results (such as re-sampling and/or calculating dosages), and shall adjust the chemical feed system if necessary to reduce the chances of detects.
- Samples showing detectable levels greater than 100 ug/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 ug/L. Calculated values shall then be compared directly to the average or mass limitations to determine compliance.

Chapter 4 - Safety

Section 4.1 - Definitions

4.1.1 We currently have no key knowledges in this section.

Section 4.2 - Regulations & Procedures

4.2.1 We currently have no key knowledges in this section.

Section 4.3 - Equipment

4.3.1 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.

- 4.3.2 Discuss the types of emergency leak repair kits for chlorine, and when repair kits are required.

There are three 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 one 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.

- 4.3.3 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, should be easily accessible, and should be 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" - that would cause a delay should equipment be needed.

Section 4.4 - Chemical Considerations

- 4.4.1 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.

- 4.4.2 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.

- 4.4.3 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, because of a possible violent reaction between chlorine and the solvent.

- 4.4.4 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.

Chapter 5 - Calculations

Section 5.1 - Calculating chlorination chemical feed rates and amount of chlorine used

- 5.1.1 Given data, calculate the chlorine demand of an effluent.

GIVEN: Chlorine Dosage = 10 mg/L and Chlorine Residual = 3 mg/L

FORMULA/SOLUTION:

Chlorine Demand = Chlorine Dosage - Chlorine Residual

= 10 mg/L - 3 mg/L

= 7 mg/L

- 5.1.2 Given data, calculate the amount of sodium hypochlorite to feed in gallons per day.

GIVEN:

WWTP Flow = 0.500 MGD

12.5% Sodium Hypochlorite

Weight of 1 Gallon Solution = 10 pounds per gallon

Desired Chlorine Dosage = 10 mg/L

FORMULA/SOLUTION:

Pounds Per Day (lbs/day) = Flow (MGD) x Concentration (mg/L) x 8.34 lbs/MG/mg/L

= 0.500 MGD x 10 mg/L x 8.34 lbs/MG/mg/L

= 41.7 lbs chlorine/day

Gallons of Sodium Hypochlorite to Add = (lbs chlorine/day) ÷ [(weight of solution (lbs)) × (% active chlorine ÷ 100)]

= 41.7 lbs Chlorine/day ÷ (10 lbs/gal × 0.125)

= 33.36 gallons per day

- 5.1.3 Given data, calculate the sulfur dioxide dosage required (in pounds) to neutralize the chlorine residual.

GIVEN:

Plant Flow = 2.0 MGD

Chlorine Residual = 0.4 mg/L

Sulfur Dioxide Dosage = 1.1 pounds per pound of chlorine

FORMULA/SOLUTION:

$$\begin{aligned}\text{Pounds per Day} &= \text{Flow (MGD)} \times \text{Concentration (mg/L)} \times 8.34 \text{ lbs/MG/mg/L} \\ &= 2.0 \text{ MGD} \times 0.4 \text{ mg/L} \times 8.34 \text{ lbs/MG/mg/L} \\ &= 6.67 \text{ Pounds per Day (chlorine)}\end{aligned}$$

FORMULA/SOLUTION:

$$\begin{aligned}\text{Sulfur Dioxide to Feed} &= \text{Pounds per Day (chlorine)} \times \text{Dosage Rate} \\ &= 6.67 \text{ lbs/day} \times 1.1 \text{ lbs sulfur dioxide/lb of chlorine} \\ &= 7.34 \text{ Pounds per day sulfur dioxide}\end{aligned}$$

- 5.1.4 Given data, calculate the sodium bisulfite required (in pounds) to neutralize the chlorine residual.

GIVEN:

Plant Flow = 750,000 GPD

Chlorine Residual = 0.2 mg/L

Sodium Bisulfite Dosage = 1 mg/L sulfite per 1 mg/L chlorine

FORMULA/SOLUTION 1:

$$\begin{aligned}\text{Pounds per Day} &= \text{Flow (MGD)} \times \text{Concentration (mg/L)} \times 8.34 \text{ lbs/MG/mg/L} \\ &= 0.750 \text{ MGD} \times 0.2 \text{ mg/L} \times 8.34 \text{ lbs/MG/mg/L} \\ &= 1.25 \text{ Pounds per day chlorine}\end{aligned}$$

FORMULA/SOLUTION 2:

$$\begin{aligned}\text{Sodium bisulfite to Feed} &= \text{Pounds per day [chlorine]} \times \text{Dosage Rate} \\ &= 1.25 \text{ lbs/day chlorine} \times 1.0 \text{ mg/L sulfite per 1 mg/L chlorine} \\ &= 1.25 \text{ Pounds per day sodium bisulfite}\end{aligned}$$

- 5.1.5 Given data, calculate the amount of hypochlorite solution needed.

GIVEN:

Plant Flow = 2.0 MGD

Chlorine Dosage = 10 mg/L

% Available Chlorine = 12.5%

Specific Gravity = 1.19

Weight per Gallon = 10 lbs/gal

FORMULAS AND SOLUTION

Formula:

$$\begin{aligned}\text{Pounds per Day} &= \text{Flow (MGD)} \times \text{Concentration (mg/L)} \times 8.34 \text{ lbs/MG/mg/L} \\ &= 2 \text{ MGD} \times 10 \text{ mg/L} \times 8.34 \text{ lbs/MG/mg/L} \\ &= 166.8 \text{ Pounds per day}\end{aligned}$$

Alternate Formula:

$$\text{Pounds of Solution} = \text{Pounds per Day} \div \% \text{ Available Chlorine}$$

$$= 166.8 \text{ lbs per day} \div 0.125$$
$$= 1334 \text{ Pounds of Solution}$$

Formula 3a: Volume of Solution = Pounds of Solution \div Pounds per Gallon

Formula 3b: Volume of Solution = Pounds of Solution \div (Specific Gravity \times 8.34 lbs/gallon)

$$= 1334 \text{ lbs} \div 10 \text{ lbs/gal} \text{ --OR-- } 1334 \text{ lbs} \div (1.19 \times 8.34 \text{ lbs/gal})$$

$$= 133 \text{ Gallons of Hypochlorite Solution}$$

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

GIVEN:

Weekly Fecal Coliform Sample Results (cfu/100mL) = 10, 20, 18, 50

FORMULA/SOLUTION:

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

Formula:

$$\text{Geometric Mean} = \text{nth root of } [FC1 \times FC2 \times FC3 \times FC4 \dots]$$

where n = number of samples

FC# = fecal coliform result of each sample

$$\text{Geometric Mean} = 4\text{th root of } [10 \times 20 \times 18 \times 50]$$

$$= 4\text{th root of } 180,000$$

$$= 21$$

Alternate Formula:

$$\text{Geometric Mean} = \text{AntiLog } [\text{Sum of Log Data} \div \text{Number of Values}]$$

$$\text{Log of } 10 = 1.000$$

$$\text{Log of } 20 = 1.3010$$

$$\text{Log of } 18 = 1.2553$$

$$\text{Log of } 50 = 1.6989$$

$$\text{Geometric Mean} = \text{AntiLog } [(1.000 + 1.3010 + 1.2553 + 1.6989) \div 4]$$

$$= \text{AntiLog } [5.253 \div 4]$$

$$= \text{AntiLog } [1.313]$$

$$\text{Geometric Mean} = 21$$

5.1.7 Given data, calculate the detention time in a chlorine contact tank.

GIVEN:

Average Daily Flow = 2.0 MGD and a Chlorine Contact Tank Baffled to provide 4 passes with dimensions of Length = 40 feet, Width = 40 feet, and Depth = 8 feet

Neglecting the thickness of baffle walls, find the detention time in minutes at average daily flow.

FORMULAS & SOLUTION:

Formula 1: Volume (cubic feet) = Length × Width × Depth

Formula 2: 1 Cubic Foot = 7.5 gallons

Formula 3: Detention Time (minutes) = Detention Volume (gal) ÷ Flow Rate (GPM)

Detention volume (gal) = 40 ft × 40 ft × 8 ft × 7.5 gallons/ft³
= 96,000 gallons

Detention Time = 96,000 gal ÷ 2,000,000 gal per day = 0.048 day
0.048 day × 24 hr per day × 60 min per hr = 69.12 minutes
= 69 minutes

- 5.1.8 Given data, calculate a fecal coliform density from the colony counts on membrane filters.

GIVEN:

Sample volumes and Colony Counts:

Sample Volume	Colony Counts
10 mL	58 cfu
5 mL	21 cfu
1 mL	4 cfu

NOTE: Before calculating the individual fecal coliform density on membrane filters, it is necessary to use only those values in the recommended range (20 to 60 colonies per filter). The density is then calculated and an arithmetic average of the individual calculations is used.

FORMULA & SOLUTION:

Fecal Coliform/100 mL = (100 × # colonies counted) ÷ (# mLs of sample filtered)

Then average this calculation for each dilution that yields between 20 - 60 colonies

[10 mL dilution] Fecal Coliform/100 mL = (58 × 100) ÷ 10 = 5800 ÷ 10 = 580

[5 mL dilution] Fecal Coliform/100 mL = (21 × 100) ÷ 5 = 2100 ÷ 5 = 420

Thus, Fecal Coliform/100 mL = 580 + 420 = 1000 ÷ 2 = 500

NOTE: The 1mL dilution with 4 colonies is not used as it is outside the recommended range.

- 5.1.9 Given data, calculate the discharge of chlorine into a receiving water and resultant annual environmental fee.

GIVEN:

Plant Flow = 0.150 MGD

Average Chlorine Residual = 0.02 mg/L

Cost (\$) per lb Chlorine = 1 ÷ Limit (mg/L)

Adjustment Factor = 2.451

Limit = 0.038 mg/L

FORMULAS & SOLUTION:

Formula:

lbs of Chlorine Discharged per day = Flow (MGD) × Residual Chlorine Concentration (mg/L) × 8.34 lbs/MG/mg/L

Alternate Formula:

Annual NR101 cost = Avg. lbs/Day of Chlorine Discharged × 365 days/yr × Cost/lb × Adj. Factor

lbs chlorine/day = Flow (MGD) × Chlorine Residual (mg/L) × 8.34 lbs/MG/mg/L
= 0.150 MGD × 0.02 mg/L × 8.34 lbs/MG/mg/L
= 0.025 lbs/day

Annual NR 101 Cost = lbs chlorine/day × 365 days/yr × cost/lb × Adj. Factor
= 0.025 lbs × 365 days/yr × \$26.32/lb × 2.451
= \$588.65

Section 5.2 - Determining appropriate sample volumes for fecal coliform analysis.

- 5.2.1 Given data, calculate approximate sample size to be applied to a membrane filter using an estimated coliform density.

GIVEN:

Estimated Fecal Coliform Concentration = 200/100 mL

FORMULA & SOLUTION:

mL of Sample to Filter = (Fecal Coliform Colonies × 100) ÷ Estimated Fecal Concentration

NOTE: Before calculating the mL of sample to filter, it is necessary to use fecal coliform colonies in the recommended range (20 to 60 colonies per filter). This means that an upper value and lower value for the amount of sample to filter must be calculated.

Since the method requires only using dilutions with between 20 and 60 colonies:

Smallest volume to filter = (20 colonies × 100) ÷ 200 cfu per 100 mL = 10 mL

Greatest volume to filter = (60 colonies × 100) ÷ 200 cfu per 100 mL = 30 mL

If the estimate of 200 fecal coliform per 100 mL is correct, the range of sample size to filter is 10 to 30 mL.

Part 2 - Disinfection Advanced - Ultraviolet

Chapter 6 - Theory and Principles of Ultraviolet

Section 6.1 - Definitions

6.1.1 Describe ultraviolet (UV) disinfection.

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

6.1.2 Define photoreactivation.

Photoreactivation is the ability of microorganisms to repair cellular damage caused by ultraviolet 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.

Section 6.2 - Pathogen Knowledge

6.2.1 Discuss the operational effectiveness of ultraviolet disinfection.

When properly designed and operated, ultraviolet disinfection is very effective for inactivation of bacteria and viruses. Effectiveness increases with less complex organisms and with decreasing cell wall thickness. Some viruses are sensitive to ultraviolet radiation – much more than chlorine. Higher organisms are less sensitive and cysts are only affected to a limited extent.

6.2.2 Describe the photochemical change that takes place in microorganisms due to UV radiation.

Proteins and nucleic acids are strong absorbers of UV radiation at 254 nm, and thus impair the ability of the microorganisms to reproduce.

Section 6.3 - Process Understanding/Performance Limiting Factors

6.3.1 Describe the factors that control the dosage of ultraviolet radiation.

The dosage of ultraviolet 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 build-up of deposits on the sleeves.

6.3.2 List and discuss the causes of poor disinfection results from ultraviolet systems.

A. Quartz sleeves fouled from organic slimes or grease, from inorganic calcium or magnesium carbonate scale (hardness scale), or iron. This fouling reduces ultraviolet radiation.

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

C. Ultraviolet lamps 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 too high in the reactor unit, causing some of the effluent to be too far away from the lamps, which reduces the effectiveness of the disinfection.

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

6.3.3 State the primary wavelength at which photochemical change occurs.

254 nm is the primary wavelength for photochemical change. UV radiation is generated using mercury vapor lamps that emit about 85-90% of their light at 254 nm in low pressure lamps.

6.3.4 List the advantages and disadvantages of using ultraviolet radiation for wastewater disinfection.

ADVANTAGES

Ultraviolet radiation has several advantages including: possible low capital costs, low operation and maintenance costs, smaller space requirements, and no chemical usage (no toxic compound formation and less operational safety considerations).

DISADVANTAGES

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

6.3.5 Discuss how radiation wavelengths are measured and compare the UV wavelength with the visible light wavelength.

All forms of radiation are measured using wavelengths. The unit of measurement is a nanometer, which is one billionth of a meter. Visible light occurs from the longest (red) at 800 nm to the shortest (violet) at 400 nm. UV radiation is below the wavelength of visible light and is much shorter, in the range of 240-260 nm.

Chapter 7 - Operation and Maintenance

Section 7.1 - Definitions

7.1.1 We currently have no key knowledges in this section.

Section 7.2 - Methods

7.2.1 Describe the different operational controls for UV systems.

1. Bank(s) on all the time at 100% power
2. Multiple banks, on or off at 100% power, based on flow
3. Variable power, based on flow, to adjust lamp output
4. Variable power, based on UV transmittance (UVT), to adjust lamp output

A combination of any of the above can be used.

Section 7.3 - Equipment

7.3.1 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.

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

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

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

A. Low Pressure Lamps maximize the conversion of electricity to UV radiation for greater efficiency. They are the least expensive lamps.

B. Low Pressure/High Output lamps operate at higher temperatures, which allows the lamp to emit higher UV output. Lamps can be turned down to conserve energy and prolong lamp life.

C. Medium Pressure lamps reduce the number of lamps needed compared to low pressure lamps. This significantly reduces operating and lamp replacement costs, and allows for installation in smaller spaces.

7.3.4 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.

7.3.5 Discuss the effect of effluent temperature on lamp output.

Liquid temperatures between 15 and 25° C will typically result in lamp temperature conditions that are near optimum for low-pressure lamps (85% of maximum output.) At temperatures above or below this range, outputs fall significantly. Medium-pressure lamps operate in much wider temperature range, and effluent temperature is not a factor.

7.3.6 Discuss the operational controls for ultraviolet disinfection.

System controls are relatively simple with smaller plants (less than 1.0 MGD) having the system in operation at all times. With larger plants with multichannel and multi-bank 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. This would decrease 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 7.4 - Preventive Maintenance

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

It is important that the quartz surfaces of the lamps be maintained as clean as possible as the build-up of organic materials and inorganic carbonates (hardness scale). Hard water can reduce 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. UV systems with on-line automatic cleaning systems are available. These systems are available with either a mechanical wiper which physically wipes the sleeve or a chemical/mechanical cleaning system which utilizes an acid cleaner between two wipers to clean the sleeves. Most installations use a rack that is provided to hang the module while the cleaning is being done. The frequency of cleaning varies widely (from weekly to yearly), with fecal coliform density determining the need for cleaning.

Chapter 8 - Monitoring, Process Control, and Troubleshooting

Section 8.1 - Definitions

- 8.1.1 We currently have no key knowledges in this section.

Section 8.2 - Sampling & Testing

- 8.2.1 We currently have no key knowledges in this section.

Section 8.3 - Data Understanding & Interpretation

- 8.3.1 Describe the affect on the quality of ultraviolet disinfection of the following situations:

- A. Suspended Solids in the Effluent
- B. Certain Soluble Organic and Inorganic Chemicals
- C. High Iron Content or Color in the Effluent
- D. Visible Light on Ultraviolet Treated Effluent (Photo Reactivation)

- A. Suspended Solids in the Effluent

Ultraviolet 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 ultraviolet radiation, reducing the effectiveness of the disinfection. If suspended solids are consistently greater than 25 mg/L they may prevent the ultraviolet 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 that reach the ultraviolet disinfection system. A final filtration system prior to ultraviolet 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

ultraviolet radiation at 254 nm. This is known as ultraviolet absorbance and can be determined using a spectrophotometric measurement. All of the exact chemicals causing ultraviolet absorbance are not known, but organic and ammonia-nitrogen are two that do reduce ultraviolet transmission. A well-nitrified effluent (ammonia and organic nitrogen of less than 2 mg/L) will produce better disinfection using ultraviolet 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 this can cause absorption of the radiation in the ultraviolet range. An effluent that has a discernible color can also interfere with the transmission of ultraviolet radiation.

D. Visible Light on Ultraviolet Treated Effluent (Photo-reactivation)

The damage caused to microorganisms by the ultraviolet radiation can (to a limited extent) be repaired by exposure to sunlight in the visible range of 310-490 nm. This photo-reactivation occurs within minutes after exposure to the reactivating light. Generally, viruses do not have repair ability, but many higher organisms do photo-repair. This occurrence can cause an increase in fecal coliform concentrations.

Chapter 9 - Safety

Section 9.1 - Definitions

9.1.1 We currently have no key knowledges in this section.

Section 9.2 - Regulations & Procedures

9.2.1 We currently have no key knowledges in this section.

Section 9.3 - Equipment

9.3.1 Discuss the risk of exposure to 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/lamps, the direct exposure to UV radiation significantly increases and can result in burns and eyesight damage.

Chapter 10 - Calculations

Section 10.1 - Calculations

10.1.1 We currently have no key knowledges in this section.

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