Wastewater Treatment Plant Operator Certification Training

Module 5: Disinfection and Chlorination

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Unit 1 – Disinfection and Chlorination Principles

Learning Objectives

- State the purpose of disinfecting wastewater.
- Identify the three different types of chlorine used to disinfect wastewater.
- Describe the breakpoint chlorination curve.
- Identify alternate feed points and the use of chlorination in wastewater treatment.

Basic Principles

Disinfection is the process designed to kill or inactivate most microorganisms in wastewater, including essentially all pathogenic organisms. Contrast this to sterilization, which is the removal and destruction of all living microorganisms, including pathogenic and saprophytic bacteria, vegetative forms and spores.

Pathogenic organisms are bacteria, viruses, or cysts that can cause disease in a host.

Common Pathogenic Illnesses

Bacterial	Parasitic
• Salmonellosis	• Amoebic Dysentery
• Shigellosis	• Ascaris
• Typhoid Fever	• Giardiasis
• Cholera	• Cryptosporidium
• Paratyphoid	**Viral**
• Bacillary Dysentery	• Polio
• Anthrax	• Infectious Hepatitis

Pathogen Removal

Pathogen removal is important in the treatment of wastewater since the final discharge goes to bodies of water that serve as:

- Public water supplies
- Recreational uses
- Irrigation supplies

Pathogens may be removed by various treatment processes:

Treatment Process	Microorganism Removal	Type
Screening	10-20%	Physical Removal
Grit Removal	10-25%	Physical Removal
Primary Sedimentation	25-75%	Physical Removal
Chemical Precipitation	40-80%	Physical Removal
Trickling Filters	90-95%	Physical Removal
Activated Sludge	90-98%	Physical Removal
Chlorination	98-99%	Disinfection

Other Disinfection Treatment Processes:

- Ultraviolet Light
- Ozonation
- Sterilization

Chlorination

Chlorine and its various forms are powerful oxidants that will kill or inactivate most pathogenic organism that are harmful to human and animal life.

Chlorination chemicals are relatively:

- Easy to obtain
- Economical
- Effective
- Easy to apply

Typical forms of chlorine used in wastewater treatment are:

- Elemental chlorine
- Hypochlorite
- Chlorine Dioxide

Elemental Chlorine (Cl_2)

Elemental chlorine is provided in liquid form and delivered in 150 pound cylinders and one ton containers. For very large plants, it may be delivered in tank cars. Its concentration is 100% available chlorine.

Chlorine generally evaporates within its container and remains in the gaseous form. It is mixed with water prior to being introduced to the process flow stream. Under high demands, it may be removed from containers in liquid form and gasified in an evaporator prior to mixing with water.

Chemistry:

- Chlorine gas, free chlorine, reacts with water to form hypochlorous and hydrochloric acids.
  Chlorine + Water ⇨ Hypochlorous Acid + Hydrochloric Acid

- $Cl_2 + H_2O \Rightarrow HOCl + H^+ Cl^-$

In solutions that are dilute and have a pH above 4, the formation of HOCl (hypochlorous acid) is most complete and leaves little Cl_2 existing. The hypochlorous acid is a weak acid and is very poorly dissociated (broken up) at levels below pH 6. Thus any free chlorine or hypochlorite ion (OCl^-) added to water will immediately form either HOCL or OCl^- and what will be formed is controlled by the pH value of the water. This is extremely important since HOCL and OCl^- differ in disinfection ability. HOCl has a greater disinfection potential than OCl^-. Normally in wastewater with a pH of 7.3 (depends on temperature), 50% of the chlorine present will be in the form of HOCl and 50% in the form of OCl^-. A higher the pH level will result in a greater percent of OCl^-.

Hypochlorite (OCl^-)

Hypochlorite may be provided in several forms:

❶ Sodium Hypochlorite

- It is acquired as a liquid in the form of sodium hypochlorite (NaOCl), which is bleach. It may be obtained in carboys, or bulk delivery. In this form it is available in concentrations of 12.5% and 15%. This is the general form of hypochlorite used in most wastewater treatment plants.
- It may also be generated on site from the electrolysis of salt, (NaCl). In this form it is available in concentrations of approximately 0.7% to 0.9%.
- Sodium hypochlorite reacts with water to form hypochlorous acid and sodium hydroxide.
- Chemistry

  Sodium Hypochlorite + Water ⇨ Sodium Hydroxide + Hypochlorous Acid + Hypochlorite$^-$ + Hydrogen$^+$

  $2NaOCl + 2H_2O \Rightarrow 2NaOH + HOCl + OCl^- + H^+$

❷ Calcium Hypochlorite

- This chemical is available in granules, pellets, and powder. It may be delivered in cans, barrels, and drums. It must be mixed with water prior to its use. Concentrations may be prepared with 3% available chlorine.
- It is generally not used due to its higher cost, sludge forming characteristics, and explosive nature.
- Chemistry

  Calcium Hypochlorite + Water ⇨ Calcium Hydroxide + Hypochlorous Acid

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

Chlorine Dioxide (ClO_2)

Chlorine dioxide is a relatively unstable chemical and is manufactured at its point of use and introduced into the flow stream shortly thereafter.

- Chlorine dioxide is the result of a reaction between chlorine gas/water solution, and sodium chlorite. The reaction, under controlled conditions will result in a 2% solution having a theoretical available chlorine content of 26.1%.
  - Sodium Chlorite + Chlorine ⇨ Sodium Chloride + Chlorine Dioxide
  - $2NaClO_2 + Cl_2 \Rightarrow 2NaCl + 2ClO_2$
- The subsequent reaction of the chlorine dioxide with water when introduced to the process flow stream results in the following reaction:
  - Chlorine dioxide + Water ⇨ Chlorate Ion + Chlorite Ion + Hydrogen Ion
  - $2ClO_2 + H_2O \Rightarrow ClO_3$-+ ClO_2-+$2H^+$
- Due to its initial reaction with reducing agents generally found in wastewater, its strength as a disinfectant is greatly reduced.
- It is beneficial to use this form of disinfectant when pH levels of the treated water are above 8.5.

Chlorine Demand

Chlorine will react with wastewater and combine with many of its components. These components react and combine preferentially with chlorine prior to its reaction with pathogens. The demand by inorganic and organic materials is referred to as the **chlorine demand**. It is the difference between the amount of chlorine applied to the wastewater and the amount of free residual chlorine after a given contact time.

- Inorganic reducing materials commonly found in wastewater that take precedence in reacting with chlorine are:
  - Hydrogen sulfide
  - Ferrous iron
  - Manganese
  - Nitrite
- Ammonia (NH3) is found in all wastewaters and is the second level of reaction with chlorine. It combines with chlorine to form one of three forms of chloramine. The chloramine formed is dependent upon the pH of the water, and the initial ratio of chlorine to ammonia. The three forms are:
  - Monochloramine
  - Dichloramine
  - Trichloramine
- Organic compounds are the last to react with available chlorine in the wastewater and form chlororganic compounds. These too have slight disinfection capability.

Chlorine Residual

The chlorine that remains in combined forms having disinfecting properties plus any free chlorine is the **chlorine residual**. It is the component of the applied chlorine that is available for disinfection. The residual is available in three forms:

- Chloramines: A form of combined chlorine
- Chlororganic Compounds: A weak form of combined chlorine
- Free Chlorine: The strongest form of residual for disinfection.

- The sum of the chlorine demand and the chlorine residual is the chlorine dose.
  - Chlorine Dose = Chlorine Demand + Chlorine Residual, *where*
  - Chlorine Residual = Combined Chlorine Forms + Free Chlorine

Establishing Dosages

Chlorine dosage may be established from either bench scale laboratory testing, or actual measurement of field results from known plant operation. The results are suitable for establishing base feed rates, however real time corrections must be made to adjust for changing conditions. Since field conditions are not as controlled as laboratory tests, the actual dosage will generally be higher than those established in the laboratory.

Calculations to determine the chlorine dosage and chlorine demand as established by field conditions are illustrated in the following example:

Example 1.1: A chlorinator is set to feed 50 pounds of chlorine per 24 hours; the wastewater flow is at a rate of 0.85 MGD, and the chlorine as measured by the chlorine residual test after thirty minutes of contact time is 0.5 mg/L. Find the chlorine dosage and chlorine demand in mg/L.

$$\text{Chlorine Dose} = \frac{\text{Pounds of Chlorine}}{\text{Million pounds of water}}$$

$$= \frac{\text{50 lbs chlorine/day}}{\text{(0.85 MG/day)(8.34 lbs/gal)}}$$

$$= \frac{\text{59 lbs chlorine/MG}}{\text{8.34 lbs/gal}}$$

$$= 7.1 \text{ mg/L}$$

$$\text{Chlorine Demand} = \text{Chlorine Dose} - \text{Chlorine Residual}$$

$$= 7.1 \text{ mg/L} - 0.5 \text{ mg/L}$$

$$= 6.6 \text{ mg/L}$$

Breakpoint Chlorination

Breakpoint chlorination is related to the chlorine necessary to satisfy the inorganic, ammonia, and organic demands of the wastewater. Once achieved, additional chlorine applied to the wastewater is in the form of free chlorine. This is referred to as free chlorine residual.

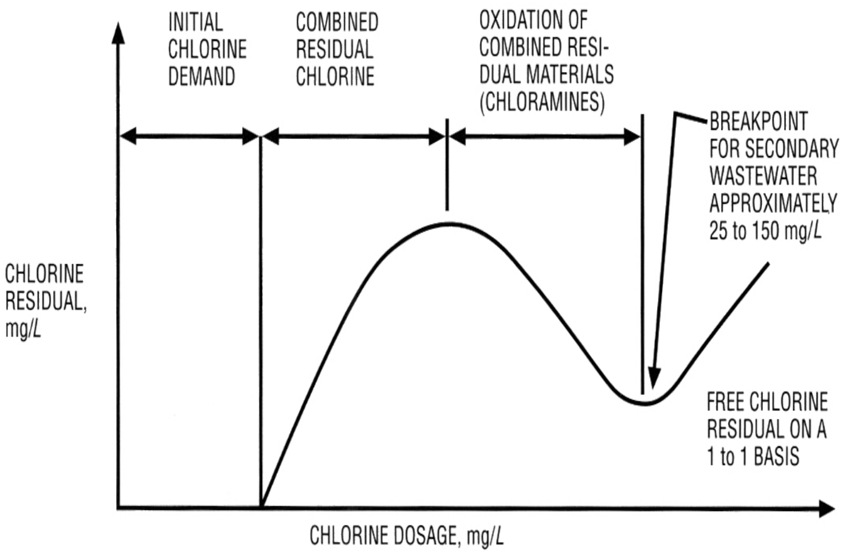

Figure 1.1 Breakpoint chlorination curve[1]

Factors Influencing Disinfection

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

- The proper point of injection into the flow stream and thorough mixing is essential to assure full treatment.

- Once chlorine is injected into the flow stream and mixed, the flow then goes into a chlorine contact basin. This is a tank designed to provide adequate detention time (contact time) to assure thorough reaction of chlorine to pathogens. The chlorine contact basin design is of critical importance to maximize the detention time through the basin, and minimize short-circuiting. Baffling within the basins helps minimize short circuiting and aids in mixing. Note that the length to width ration is 40:1, and that the unit is generally designed to provide 30 minutes of contact time at maximum month average flow, or 15 minutes of contact time at peak hourly flow.

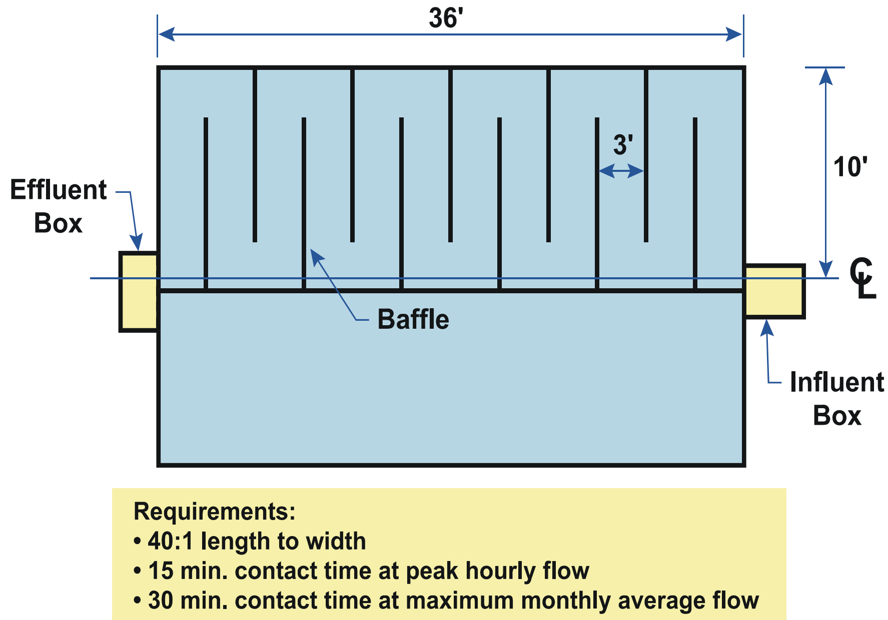

Figure 1.2 Typical layout - contact basin

- Effective pretreatment will lower the suspended solids and organic content of the wastewater stream allowing for efficient disinfectant use and exposure of the disinfectant to pathogens.

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

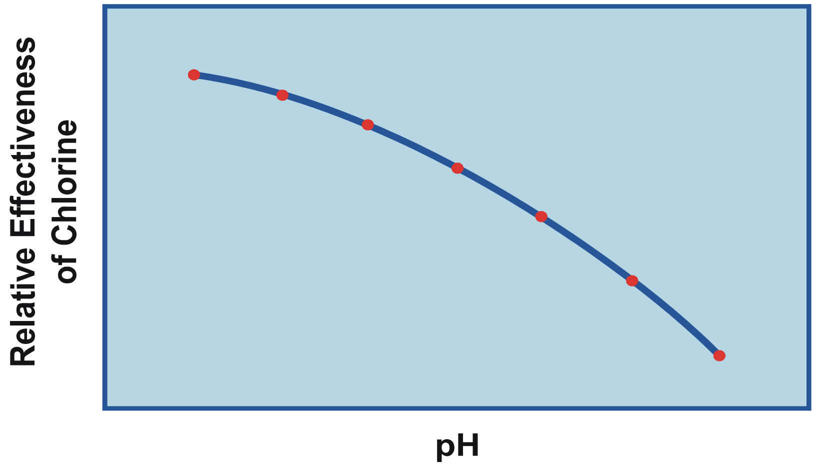

Figure 1.3 Relative effectiveness vs. pH

- Higher temperature will result in more efficient disinfection.

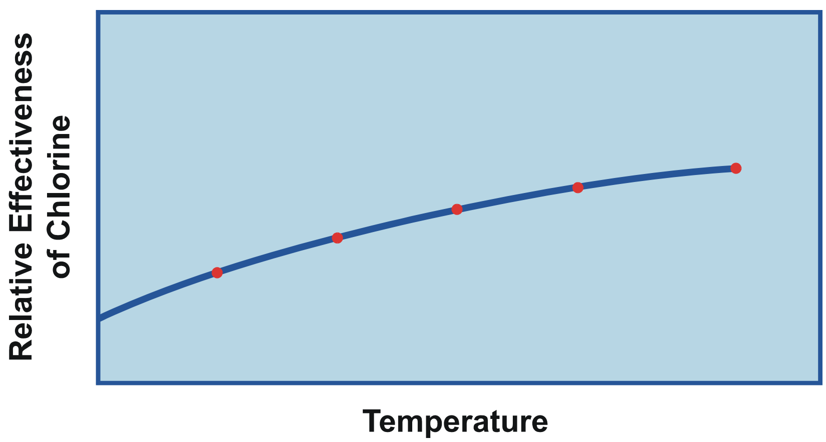

Figure 1.4 Relative effectiveness vs. temperature

- Higher dosages of disinfectant will result in more rapid disinfection.

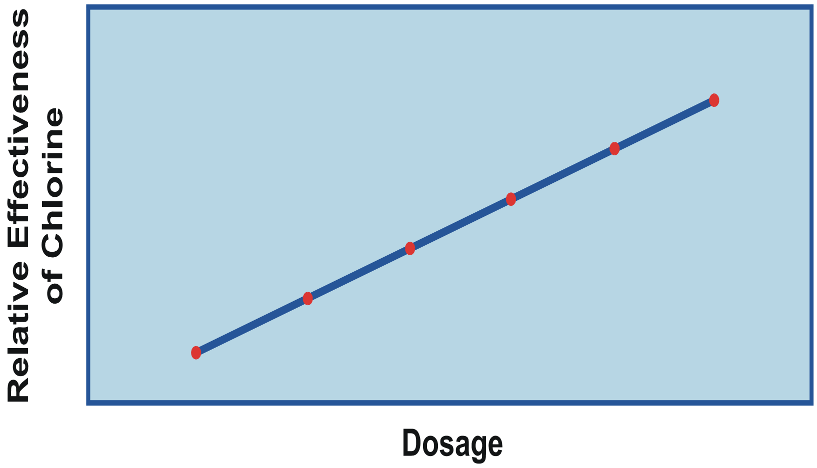

Figure 1.5 Relative effectives vs. dosage

- Longer detention time will result in a higher degree of disinfection.

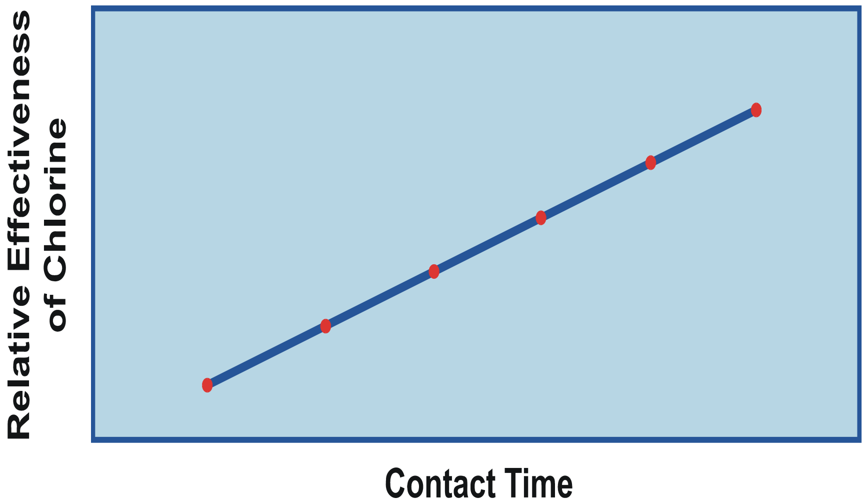

Figure 1.6 Relative effectiveness vs. contact time

- The type of organism to be treated will influence the efficiency of the process.
    - Viruses are killed quickly.
    - Bacteria cells are killed quickly.
    - Cysts and spores may be resistant.

In addition to disinfection, chlorine may serve other purposes and can be introduced into the flow stream at various points. When applied in this manner, care must be taken to avoid overdosing because this could adversely affect other plant processes.

- Collection System: Chlorine can be introduced into the collection system to:
  - Reduce septicity
  - Reduce BOD
  - Control odor
  - Protect structures from sulfuric acid
- Prechlorination: Chlorine can be introduced into the influent flow to the wastewater treatment plant to:
  - Control odor
  - Reduce BOD
  - Aid in settling
  - Control foaming
  - Help remove oil
  - Aid in disinfection
- Plant Chlorination: Chlorine can be introduced within the wastewater plant either within or prior to other processes to:
  - Control or prevent odor
  - Control or prevent corrosion
  - Control sludge bulking
  - Control digester foaming
  - Control filter ponding
  - Control filter flies
  - Aid in sludge thickening
- Chlorination prior to filtration: Chlorine can be introduced into the flow stream upstream of the filters to:
  - Kill algae and other large biological organisms
  - Prevent biological growths within the filter
- Post filtration chlorination: Chlorine is introduced into the contact basin influent as the final treatment for disinfection.

Key Points for Unit 1 – Disinfection and Chlorination Principles

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- Disinfection is the process designed to kill or inactivate microorganisms in wastewater, essentially pathogens which are microorganisms which can cause disease in a host. Sterilization is the process designed to kill all microorganisms.
- Chlorination is not the only method whereby pathogens are eliminated in the treatment process but is the most effective, removing 98% to 99% of the microorganisms.
- Other disinfection processes include ultraviolet light, ozonation and sterilization.
- Chlorine in its various forms including elemental chlorine, hypochlorite and chlorine dioxide are powerful oxidants (add or take on electrons) that react with water and its organic constituents.
- Chlorine demand is the difference between the amount of chlorine added to wastewater and the amount of residual chlorine remaining after a given contact time. Chlorine demand may change with dosage, time, temperature, pH, and nature and amount of the impurities in the water.

  Chlorine Demand, mg/l = Chlorine Applied, mg/l – Chlorine Residual, mg/l
- Residual Chlorine is the amount of chlorine remaining after a given contact time and under specified conditions.
- Chlorine Dose = Chlorine Demand + Chlorine Residual
- Breakpoint Chlorination is the addition of chlorine to wastewater until the chlorine demand has been satisfied and further additions of chlorine results in a residual that is directly proportional to the amount added beyond the breakpoint.
- Chlorine is used in wastewater treatment not only for disinfection but can be added at various points throughout the wastewater treatment system to control odor , reduce BOD, or for vector control, control sludge bulking, foaming control and as an aid to sludge thickening.

☑ Exercise for Unit 1 – Disinfection and Chlorination Principles

1. Disinfection is the process designed to __________ or ____________________ most microorganisms in wastewater including essentially all pathogenic organisms.

2. Pathogenic organisms consist of _______________, _______________, or __________ that can cause disease in a host.

3. List three physical processes used in wastewater treatment that are useful in removing some of the microorganisms.
   a. ___________________________
   b. ___________________________
   c. ___________________________

4. The most commonly used disinfection process for wastewater treatment is:
   a. Ultraviolet light
   b. Ozonation
   c. Chlorination
   d. Sterilization

5. Chlorine and its various forms are powerful oxidants that will kill or inactivate most pathogenic organisms that are harmful to human and animal life. Typical forms of chlorine used in wastewater treatment are:
   a. Elemental chlorine
   b. Hypochlorite
   c. Chlorine dioxide
   d. All of the above

6. Calculate the chlorine dosage required if it is desired to have a chlorine residual of 0.5 mg/l and the chlorine demand is 6.0 mg/l.

____
____
____

7. Baffling is used in chlorine contact chambers to aid in mixing and to prevent

___________________________________.

8. Chlorine is widely used as a disinfectant in wastewater treatment, but it can also be used to:
   a. Control odor
   b. Reduce BOD
   c. Control foaming
   d. Aid in sludge thickening
   e. All of the above

[1] John Brady, William Garber and James F. Stahl, "Chapter 10: Disinfection and Chlorination," in *Operation of Wastewater Treatment Plants, Volume II*, (Sacramento, CA: California State University, Sacramento Foundation, 2001), p. 352.

Unit 2 – Chlorination Process Control

Learning Objectives

- List the alternative ways in which chlorine feed can be controlled.
- Describe what chlorine residual is and identify the types of chlorine residuals expected to be present during disinfection.
- Describe the common methods used for measuring chlorine residual in wastewater operations.
- Determine the feed rate using the chlorination control nomograph.

Manual

- In this mode of operation an operator manually starts and stops the chlorine feed system, and adjusts the feed rate. For a gas feed system this would involve setting the plug positioner on the chlorinator. For a feed pump, it would involve either setting a pump speed, or the stroke position for the diaphragm. Once set the feed rate remains constant.

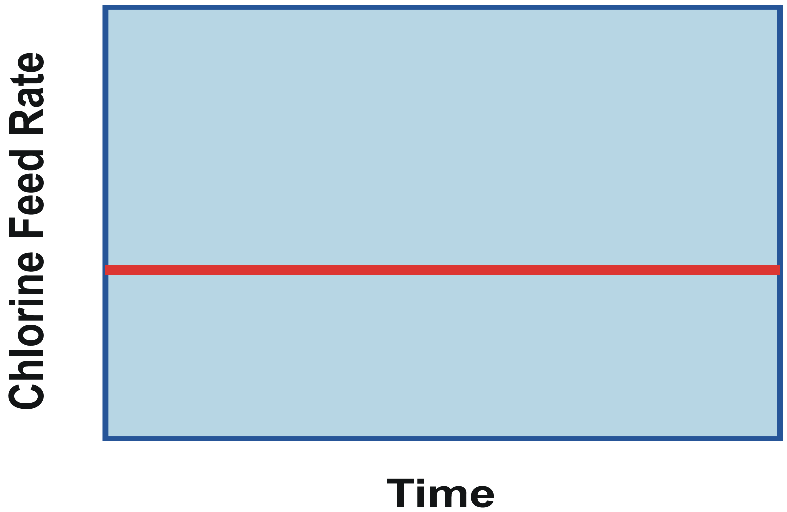


Figure 2.1 Manual Control

- Typical applications: chlorination of sewage flow in a manhole for odor control where flow and chlorine demand are anticipated to be relatively constant.

Start-Stop

- In this mode of operation an operator manually adjusts the chemical feed rate; however, the equipment is started or stopped based on a sensor that indicates flow through the system.

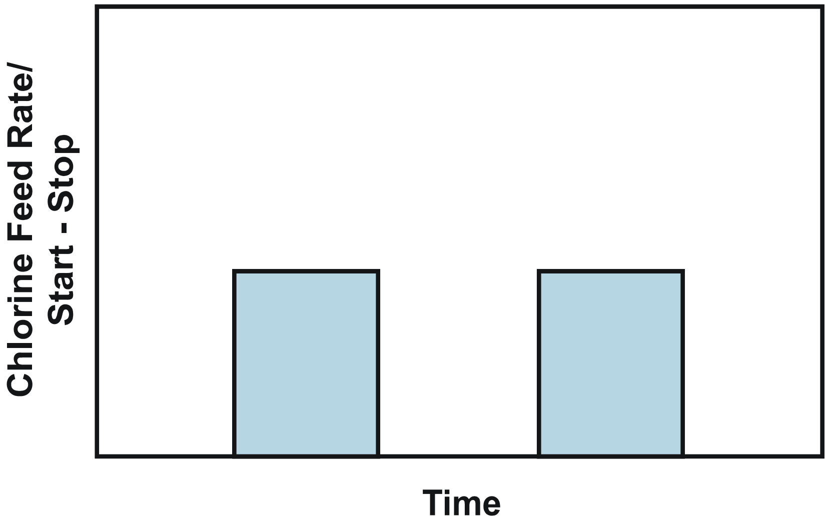


Figure 2.2 Start Stop Control

- Typical applications: chlorination of flow through a lift station that operates intermittently.

Step-Rate Control

- This mode of operation provides for incremental changes in the chlorine feed rate that take place as pumps are brought on or off line.

- Each incremental change in flow brought about by the additional deletion of a pump is complemented by an incremental increase or decrease in a change of chlorine applied. This could be accomplished by starting and stopping feed equipment, or repositioning controls on the feeders.

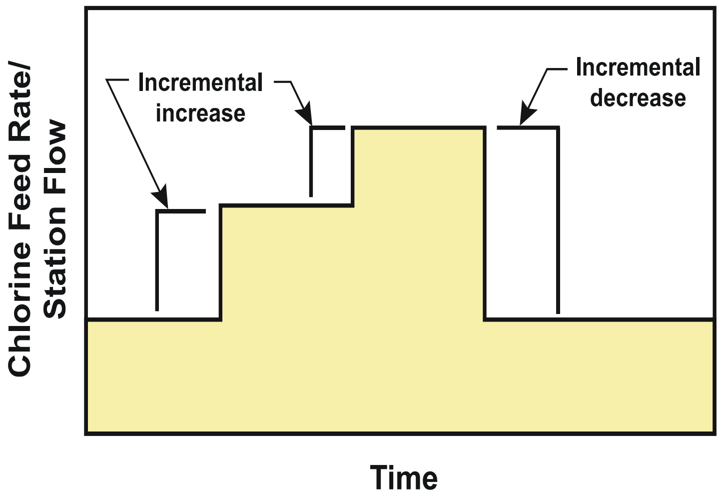


Figure 2.3 Step Rate Control

- Typical applications are: chlorination of a collection system lift station by dosing in increments based on the number of lift pumps operating.

Timed-Program Control

- In this mode of operation, the chlorine feed rate is stepped up or down based upon a time of day timer. The timer is set to mimic the increases and decreases in flow rates that take place during a normal day's flow cycle. This could be accomplished by a stepping timer, or a cam controller set to mimic the anticipated flow pattern.

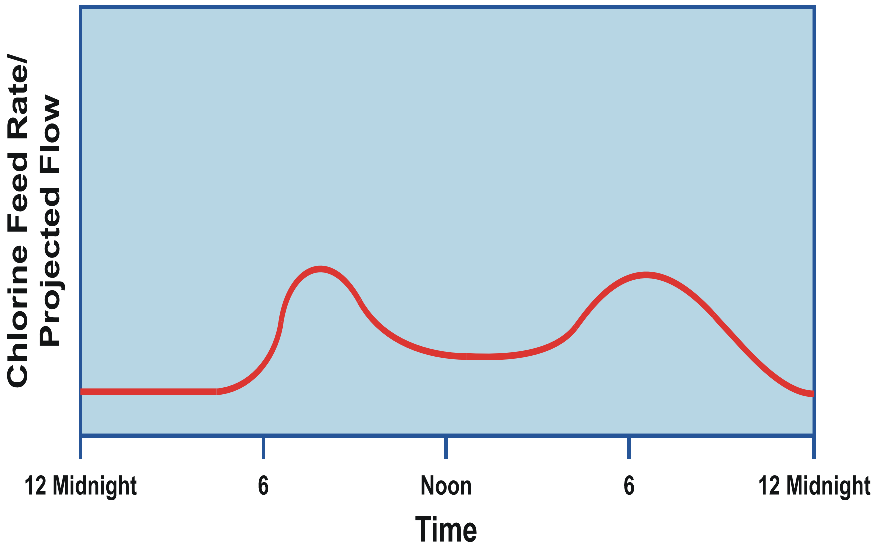


Figure 2.4 Timed Program Control

- Typical applications: chlorination of a collection system based on anticipated or historical 24-hour requirements such as for control of septicity.

Flow-Proportional Control

- In this mode of operation, the chlorine feed rate is modulated up or down in proportion to flow. Meters of various types are used to input a flow signal to the chlorine feed system to vary the delivery of chemical to the point of application.

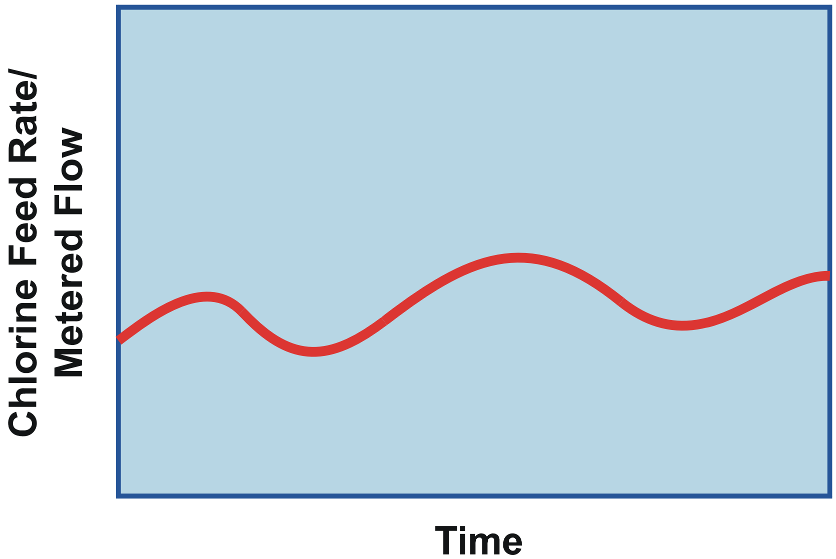


Figure 2.5 Flow Proportional Control

- Typical applications: chlorination of headworks, sludge return lines and final effluent.

Chlorine Residual Control

- In this mode of operation chlorine feed rate is modulated up or down to maintain the residual within a desired band of operation. A chorine residual analyzer is utilized to monitor the residual and initiate a corrective signal to the chlorine feeder. The monitoring and feed rate adjustment are made on a timed cycle to allow the system to adjust for the time involved in making a feed adjustment, and the time until it is sampled.
- Typical applications: post-chlorination.

Compound Loop Control

- In this mode of operation, the chlorine feed rate is adjusted for both flow, as described in the Flow-Proportional Control mode, and residual as described in the Chlorine Residual Control Mode. The system requires that a band or setpoint chlorine residual be input into the control that becomes the target for the controller to maintain.
- Typical application: post-chlorination.

Measurement of Chlorine Residual

Chlorine residual occurs in wastewater in several forms:

- Monochloramine
- Dichloramine
- Free Chlorine

Due to the amount of ammonia in wastewater, the residual generally takes the form of monochloromine or dichloromine. When sampled at the effluent of a wastewater plant, the residual is a measurement of the disinfection power of the chlorine. When monitored at points upstream in the treatment process, it measures the effectiveness of the chlorine in these applications. When measured at the point of wastewater discharge to a receiving stream it measures the effectiveness of the dechlorination process to assure that residuals do not impact downstream fish or aquatic life.

Measurement of chlorine residual is accomplished in wastewater plants generally utilizing one of four methods:

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

DPD Titrimetric: This method is a colorimetric used for wastewaters that do not contain iodine reducing substances. The basic method can be modified to measure monochloramine, dichloramine, and free chlorine. The modified method is described below:

- Diethyl-p-phenylene (DPD) is used as an indicator in this method, and it reacts instantly with free available chlorine, in the absence of iodine, to produce a red color. Titration is performed with ferrous ammonium sulfate (FAS) which reacts with the free chlorine to immediately decolorize the solution upon removal of free chlorine. Upon addition of a small amount of potassium iodide, monochloramine reacts with the iodine to produce an immediate color. Titration with FAS to decolorize the solution identifies the concentration of monochloramine. Further addition of potassium iodide to excess causes a rapid reaction with dichloramine to cause a color. Further titration with FAS to decolorize the solution identifies the concentration of dichloramine.

Amperometric Titration: This method uses a bi-metallic cell immersed in a solution containing the chlorine to be measured. The chlorine (an oxidizing agent) causes a current to flow, which is measured by a micro-ammeter. The titration is performed by adding a reducing agent (which reacts with the chlorine) to the solution and measuring the reduction in the current. The end point is reached when no further reduction in the current can be measured. A plate showing the sample flow through an automatic residual analyzer is shown in Figure 2.6.

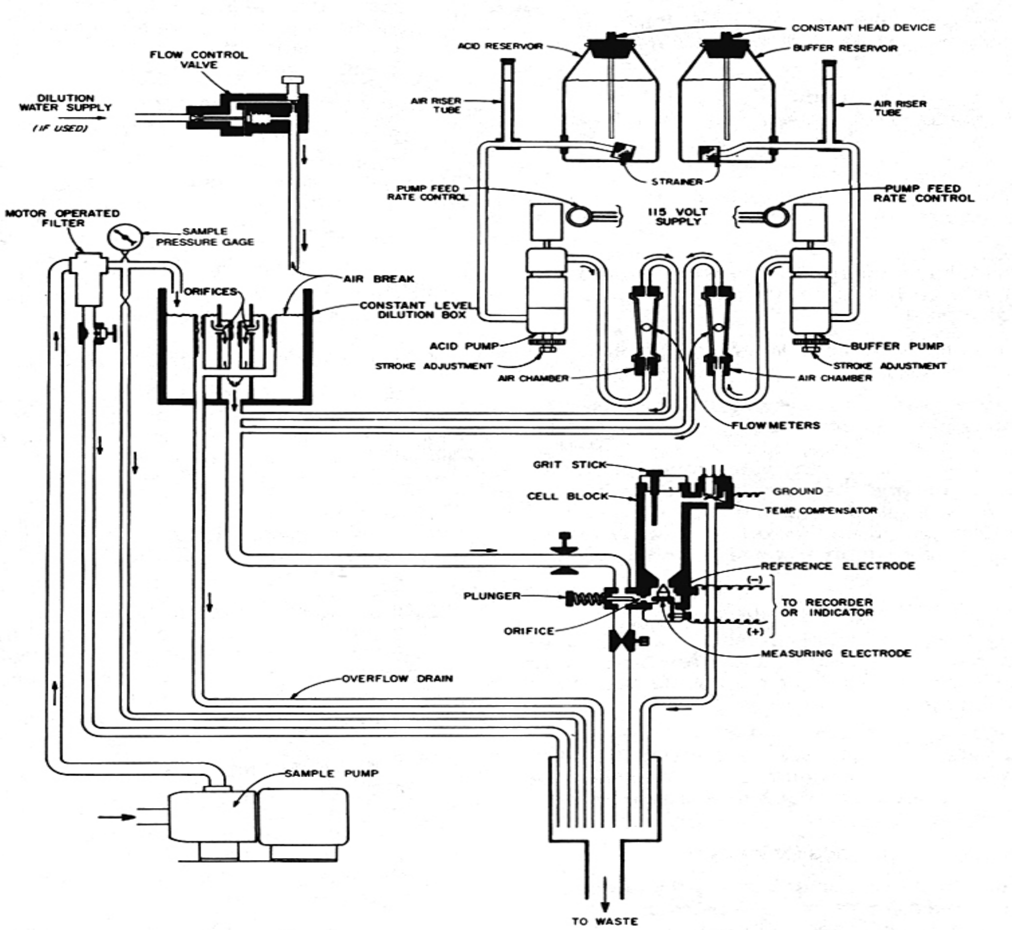


Figure 2.6 Chlorine residual analyzer[1]

Oxidation-Reduction Potential meter (ORP): Another means of monitoring chlorine is ORP. The ORP instrument monitors water for its oxidation potential. Since chlorine is an oxidant, the measurement of the oxidation potential is therefore related to the chlorine residual in the water.

Chlorination Control Nomograph

Laboratory testing of a sample has established the chlorine demand and chlorine residual for a sample in mg/l. With this knowledge, the chlorine dosage can be calculated in mg/l using the following formula:

Chlorine Dosage in mg/l = Chlorine Demand in mg/l + Chlorine Residual in mg/l

With this knowledge and a known flow through the wastewater plant, an operator can determine the setting of the chlorinator in lbs/day using the Chlorination Control Nomograph.

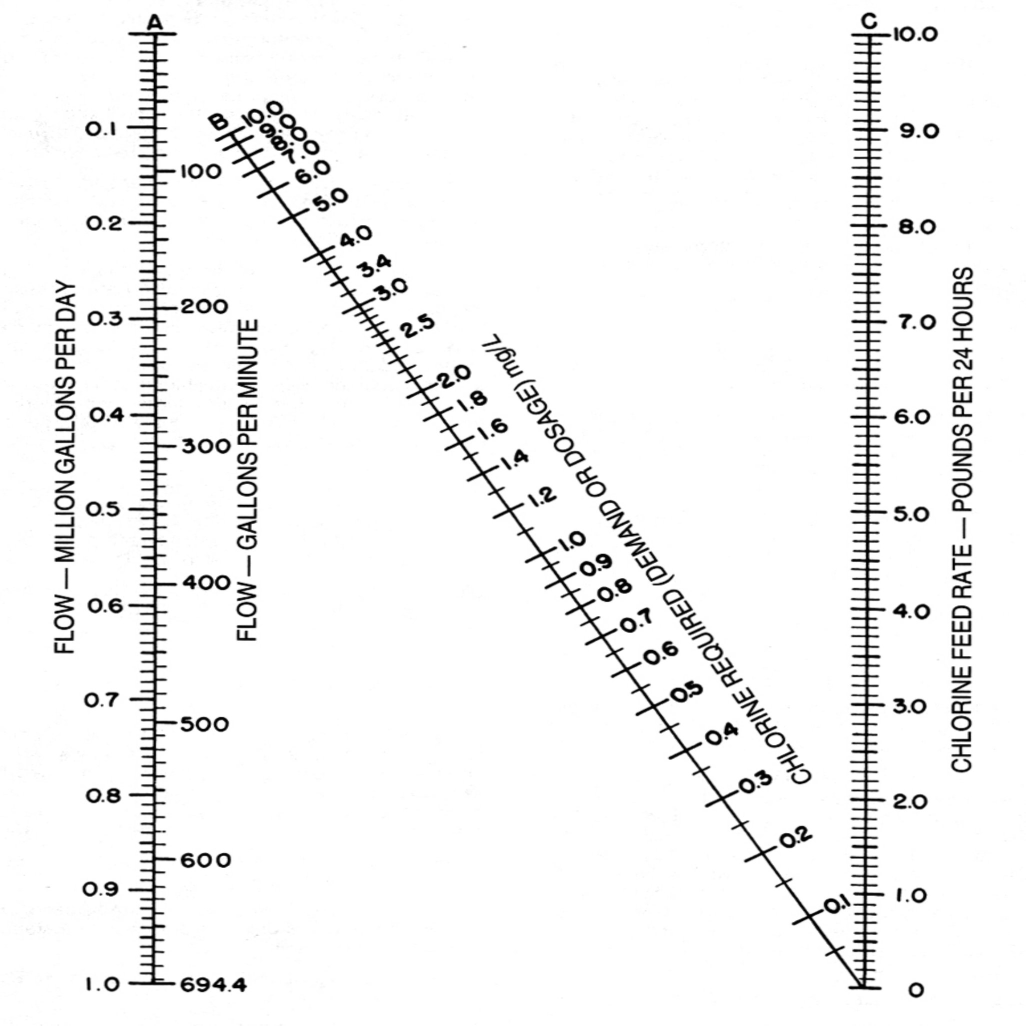


Figure 2.7 Chlorination control nomograph[2]

The nomograph consists of three lines representing Flow (Line A in gallons per minute, or million gallons per day of wastewater), Chlorine Dosage (Line B in mg/L), and Chlorine Feed Rate (Line C pounds per day). A straight edge is required to determine the proper chlorine feed rate. Use of this nomograph is as follows:

- Place a straight edge on line A at the known point through the wastewater plant, and on the point on line B representing dosage in mg/l. The intersection of the straight edge with line C represents the chlorine feed rate, or chlorinator setting in pounds per day (lbs/d).
- Since the scale spans from 0 to 1.0 mgd, an adjustment must be made if flows are above this value. By multiplying both the flow scale and the chlorine feed rate scale by 10, the nomograph can again be used for a plant operating at these higher flow rates.
- The nomograph can also be used to compute the dosage if both the chlorine feed rate, and flow are known by placing the straight edge at the feed rate on line C, and the flow rate on line A, and reading the dosage at the intersection with line B.

Example Problem

Problem 2.1: If the flow rate through a wastewater plant is 0.6 mgd and the chlorine dosage is 1.0 mg/l, determine the chlorinator setting in lbs/d.

- Place the straight edge on 0.6 mgd on line A, and extend it through the point on line B representing a dosage of 1.0 mg/l. Extend this line until it intersects line C whose reading represents the chlorine feed rate setting. For this example it should read 5 lbs/d.
- Confirmation of this value could be performed by using the equation

  Chlorine Feed Rate in lbs/d = Flow in mgd x 8.34 lbs/gal x(mg/L)x(L/1,000,000 mg)

Or

Chlorine Feed Rate in lbs/d = 0.6mgd x 8.34lbs/gal x 1.0 mg/1,000,000 mg

= 5.0 lbs/d

Key Points for Unit 2 – Chlorination Process Control

- A chlorine feed system has various modes of control including flow proportional, start-stop, step-rate, time-program, chlorine residual control, compound loop control and, most common, manual control.

- Measurement of chlorine residual is accomplished at wastewater treatment plants by one of four methods: Iodometric, DPD Titrimetric, Amperometric Titration, or the ORP method.

- Through the use of a Chlorination Control Nomograph, Which consists of three (3) lines – Flow, Chlorine Dosage and Chlorine Feed Rate, an operator can determine the setting of a chlorinator in lbs/day.

☑ Exercise for Unit 2 – Chlorination Process Control

1. The most commonly used mode of control in a chlorine feed system is the:
    a. Flow proportional
    b. Step-rate
    c. Time-program
    d. Manual control
    e. Chlorine residual control

2. By using a Chlorination Control Nomograph like the one in this workbook, an operator can determine the setting of a chlorinator in units of
    a. Kg/gallon
    b. Mg/ft
    c. Lbs/day
    d. Lbs/metric tonne

3. Measurement of chlorine residual at a wastewater plant can be determined by the use of which of the following methods:
    a. ORP
    b. Amperometric Titration
    c. DPD Titrimetric
    d. Iodometric
    e. All of the above

4. If the flow thru the wastewater plant is 4.5 mgd and the chlorine dosage is 2.5 mg/l, determine the chlorinator setting in lbs/d. Review of the nomograph scale indicates that it only spans from a flow of 0 to 1.0 mgd. To allow for a flow greater than this multiply both the flow and chlorine feed rate scales by a factor of 10. These two scales now represent a flow of 0 to 10 mgd, and a chlorine feed rate of 0 to 100 lbs/d. Following the same procedures as outlined earlier in this unit, find the chlorine federate in lbs/day.

5. If the chlorine feed rate is 3.5 lbs/d, and the flow through the wastewater plant is 700,000 gallons per day, determine the dosage by using the nomograph.

[1] John Brady, William Garber and James F. Stahl, "Chapter 10: Disinfection and Chlorination," in *Operation of Wastewater Treatment Plants, Volume I*, (Sacramento, CA: California State University, Sacramento Foundation, 2001), p. 363.

[2] Brady, p. 359.

Unit 3 – Chlorine Safety and Handling

Learning Objectives

- Describe an effective chlorine safety program.
- Describe the chlorine handling procedure for each chlorine container: cylinders, ton containers, tank cars, and some of the related safety devices provided.
- Describe what measures to take in the event of a chlorine leak.

Chlorine Hazards

Chlorine is a highly toxic chemical that must be handled with care to minimize exposure to personnel. Concentrations of 0.1% (1000 ppm) in the air may be fatal after only a few breaths. The Immediately Dangerous to Life and Health concentration (IDLH) is 10 ppm. OSHA regulations limit human exposure to no more than 1 part per million 0.0001%. It is 2.5 times heavier than air, and any leak in a quiescent room will stay close to the ground where it can be inhaled by an operator.

PHYSIOLOGICAL RESPONSE TO CONCENTRATIONS OF CHLORINE GAS

Effect	Parts of Chlorine Gas Per Million Parts of Air By Volume (ppm)
Slight symptoms after several hours' exposure	1[a]
Detectable odor	0.08 – 0.4
60-minute inhalation without serious effects	4
Noxiousness	5
Throat irritation	15
Coughing	30
Dangerous from one-half to one hour	40
Death after a few deep breaths	1,000

[a] OSHA regulations specify that exposure to chlorine shall at *NO* time exceed 1 ppm.

Figure 3.1 Physiological response to concentrations of chlorine gas[1]

- Chlorine is hazardous and when combined with moisture (including body moisture) becomes extremely acidic and therefore corrosive.

Personnel Safety and Protection

Any facility that utilizes chlorine should have a written safety program that is well documented and distributed to operators. All personnel involved in the handling of chlorine should become knowledgeable in this program. The program should include:

- Rules and specific safety procedures.
- A documented response to accidental releases including the names and telephone numbers of:
  - Fire Department
  - Police
  - County Emergency Management Administration
  - Chlorine Supplier
  - Company Management
- A regularly scheduled program of hands-on training in the use of safety equipment including:
  - Leak detectors
  - Respirators
  - Protective Clothing
  - Atmospheric monitoring instrumentation
  - Repair Kits
  - Eyewash, shower and related alarms
- Practice drills to simulate an emergency scenario.
- Systems that store more than 2,500 pounds must also have a Risk Management Plan on hand.
- A documented maintenance program for all chlorine feed and emergency response equipment.

First Aid

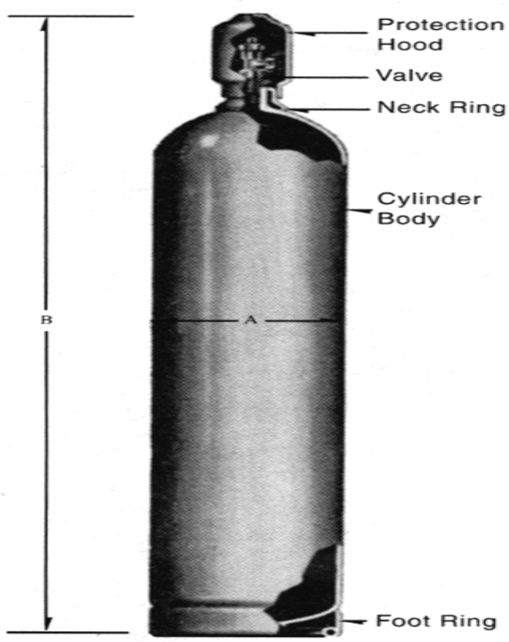
In general, the aid given is dependent upon the exposure of the victim. In all cases, the victim should be taken away from the site of exposure.

- If the exposure is mild, the area of exposure should be thoroughly flushed with water.
- If eyes have been exposed to chlorine, thoroughly flush them for 15 minutes.
- If the victim has an irritated throat, provide a glass of milk.
- If the victim is coughing, a drink of tea or coffee may control the cough.
- If the victim's clothing contains chlorine, remove and thoroughly wash exposed body area.
- If the victim has more severe exposure,
  - Keep patient warm and cover with blanket and in comfortable position.
  - Provide oxygen if breathing is difficult and trained personnel are available.
  - If breathing stops administer cardiopulmonary resuscitation.
- In all cases notify others of your/their exposure, and the problem.

Chlorine Containers

Cylinders are vertical seamless steel tanks available in capacities of 100 or 150 pounds. The cylinders are provided with a shut off valve, fusible plug and protective cap. The fusible plug is designed to fail should temperatures rise to a range of 158 to 165 degrees Fahrenheit.

Chlorine Cylinder



Net Cylinder Contents	Approx. Tare, Lbs.*	Dimensions, Inches	
		A	B
100 Lbs.	73	$8\frac{1}{4}$	$54\frac{1}{2}$
150 Lbs.	92	$10\frac{1}{4}$	$54\frac{1}{2}$

* Stamped tare weight on cylinder shoulder does not include valve protection hood.

Figure 3.2 Cylinder[2]

- These are generally delivered to the site with a stake bodied, or covered truck.
- When delivered to the site, they should be secured to, and moved with a hand truck to its point of storage; however, they may also be rolled in the vertical position to this location.

- If required to be lifted, use a clamp, cradle or carrier. Never use chains, rope slings or magnetic hoists.
- Cylinders should be stored in the upright position and secured to prevent toppling. The protective hood should remain in place until the cylinder is placed into service.
- Storage should be in a secure area, away from an excessive heat source, and free from combustible materials that could react in the presence of chlorine.

Ton Containers are horizontal welded steel tanks with a nominal capacity of 2,000 pounds (one ton container). The total weight of the container and contents may be as much as 3,700 pounds. The cylinders are provided with two shut off valves that are 180 degrees apart, and six fusible plugs. Three plugs are located at each end of the container. The plugs are designed to fail should the temperature rise to a range of 158 to 165 degrees Fahrenheit. The end with the valves is provided with a valve protection hood.

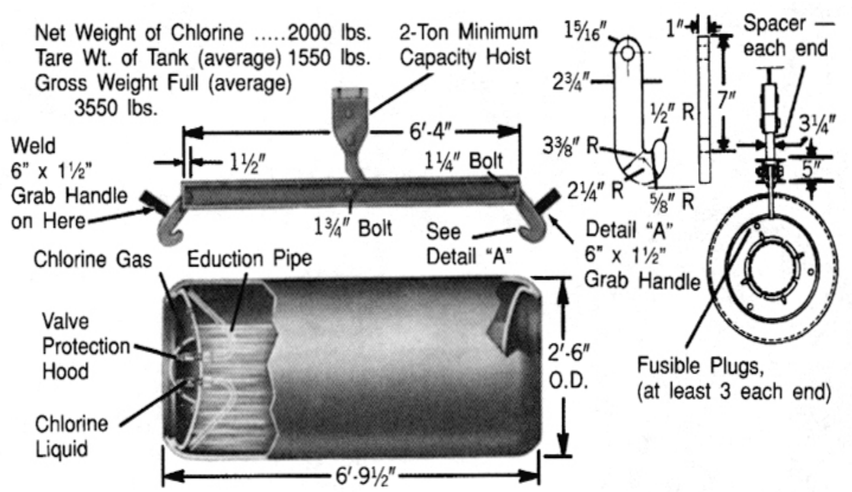


Figure 3.3 Ton container[3]

- These are delivered to the site by truck or rail.
- The ends are concave to allow for moving with a spreader bar and grab handles.
- A hoist is utilized to remove the containers from the delivery vehicle and transporting it to its point of storage. This should have a minimum capacity of 2 tons.
- Containers should not be stacked on top of one another.

- Containers should be stored on their side, with the two valves in the twelve and six o'clock position. This assures that one valve will release gas, and the other liquid chlorine, respectively. This also reduces the risk of having a liquid leak in the event of a valve failure since only one valve is connected to the liquid phase.

- Containers should be secured with chocks to preclude their movement after being set in place. An alternative would be to place them on trunnions, which would also allow them to be rotated more readily and set in their proper position.

- Storage should be in a secure area, away from an excessive heat source, and free from combustible materials that could react in the presence of chlorine.

Tank Cars are railroad tank cars that have a capacity of 16, 30, 55, 85, or 90 tons. The tank cars are provided with a valve cluster consisting of four angle valves and a safety relief valve. Two of the angle valves allow for liquid chlorine withdrawal (front and rear valves) and two allow for gas withdrawal (side valves). A pressure relief valve is provided to relieve pressures above either 225 or 375 psi, dependent upon the pressure rating of the tank car. Excess flow control valves are also provided on the lines entering the tank to prevent an uncontrolled release in the event of an angle valve or downstream piping system failure.

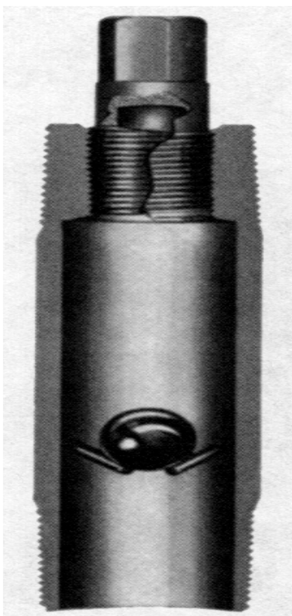


Figure 3.4 Excess flow valve[4]

- Tank cars are delivered to a railroad siding. The siding is provided with wheel chocks, tank car stops, and derail facilities to prevent a car from drifting away from the delivery area.

Chlorine Leaks

Chlorine leaks may be detected by several means:

- The pungent smell of chlorine is readily detectable at concentrations as low as 0.010 mg/l.
- Testing joints or potential points of leakage with an ammonia solution. Reaction with chlorine will produce smoke as a visible indicator of the presence of chlorine.
- Utilizing an on-line chlorine gas detector in an area that may contain chlorine under pressure.

A leak protocol should be developed that addresses an operator's response to a leak.

- Only trained personnel should respond to a leak.
- All others should leave the area until conditions are safe again.
- For a larger leak, the area should be secured, and assistance from emergency response agencies requested.

Respondents should use personal safety protection equipment prior to entering any area where gas has been detected.

Response

In the event of a manageable leak a response decision must be made:

- In the event of equipment leakage, such as a faulty evaporator, relief valve or line valve, the response may be as simple as closing an upstream guardian valve or closing the cylinder or container valve.
- In the event the leak is from a cylinder or container, repair kits should be available to allow personnel to address the leak. The contents of a chlorine repair kit for cylinders or containers are shown in Figure 3.5.

Figure 3.5 Chlorine repair kit[5]

In the event of a leak, it is important to mitigate its uncontrolled release.

- Since many areas that use chlorine are in populated areas, an uncontrolled release can have catastrophic effects.
- In the event of a leak, it should be isolated, and contained within the room.

A shut down of the ventilation system would minimize release into the atmosphere.

Isolate the leak to retain it in a controlled area. It may also be dealt with by a slow controlled release over time into the atmosphere if no better alternative is available for dealing with the gas.

Scrubbing equipment could be provided to neutralize the gas and convert it into a form that could be disposed of safely. Figure 3.6 presents a photo of a typical chlorine scrubber with a dry media such as caustic soda as the scrubbing medium.

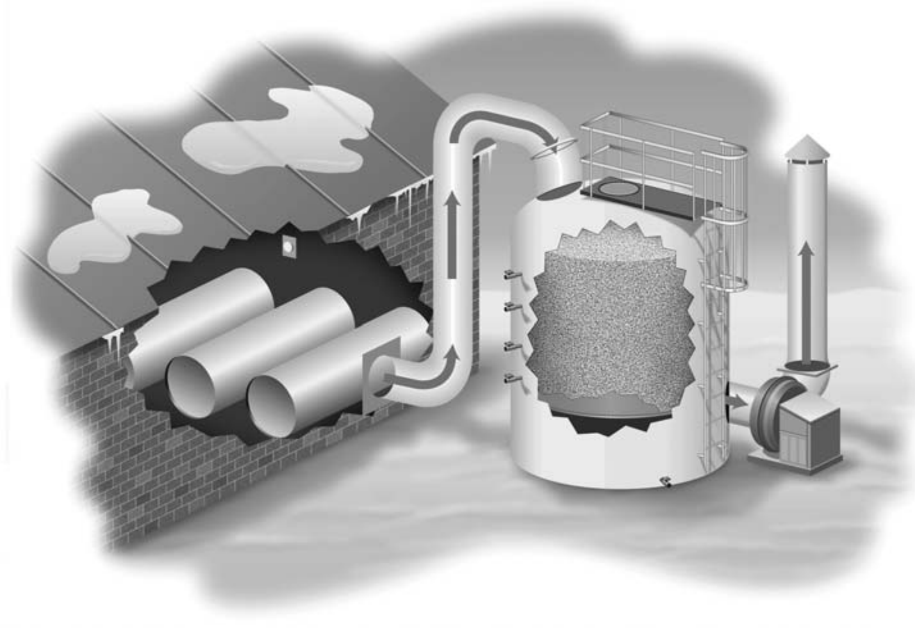


Figure 3.6 Chlorine scrubber[6]

Key Points for Unit 3 - Chlorine Safety and Handling

- Chlorine is a highly toxic chemical with concentrations as low as 1 ppm in air having consequences to human health.

- All facilities that utilize chlorine should have a safety program consisting of rules and safety procedures, an emergency response plan, hands on training in the use of safety equipment, practice drills, a risk management plan and a well documented maintenance program.

- All operators should be trained in first aid for chlorine exposure.

- Chlorine comes in 3 types of containers 100 to 150 lb cylinders, one ton or 2,000 lb containers and tank cars.

- If a chlorine leak is detected only trained personnel should respond to immediately rectify the situation.

Exercise for Unit 3 – Chlorine Safety and Handling

1. Chlorine is hazardous and when combined with moisture (including body moisture) it becomes extremely acidic and corrosive.
    a. True
    b. False

2. Any facility that uses chlorine should have a written ____________ program that is well documented and distributed to all operators.

3. Facilities that store more than 2,500 pounds of chlorine must also have a __________ ____________________ Plan on hand.

4. Chlorine cylinders come in sizes to hold 100 and 150 pounds of chlorine. The cylinders have a shut off valve, a protective cap, and a fusible plug that is designed to fail and leak chlorine to the atmosphere if the temperature rises to a range of _______ to _______ degrees Fahrenheit.

5. Ton containers of chlorine should be stored on their sides with the two valves in the _____ and the ______ o'clock position to assure that one valve will release chlorine gas and the other valve will release liquid chlorine.

6. Only trained personnel should respond to a chlorine leak. All others should leave the area until conditions are once again safe.
    a. True
    b. False

7. The largest container that is used to transport chlorine is a _______________ _______ car.

[1] John Brady, William Garber and James F. Stahl, "Chapter 10: Disinfection and Chlorination," in *Operation of Wastewater Treatment Plants, Volume I*, (Sacramento, CA: California State University, Sacramento Foundation, 2001), p. 377.

[2] Brady, p. 380.

[3] Brady, p. 382.

[4] Brady, p. 388.

[5] Brady, p. 389.

[6] Permission of Purafil.

Unit 4 – Chlorination Equipment and Maintenance

Learning Objectives

- Identify equipment related to a gas feed system.
- Identify equipment related to a hypochlorite feed system.
- Identify equipment related to a chlorine dioxide feed system, and how it differs from the gas and hypochlorite feed systems.

Equipment

Chlorination equipment consists of various components. The gas system consists of equipment that allows for the safe removal of chlorine from a vessel, and transmission through a series of valves, piping and control devices, under vacuum to a point of application. A schematic of a typical gas feed system is shown in Figure 4.1.

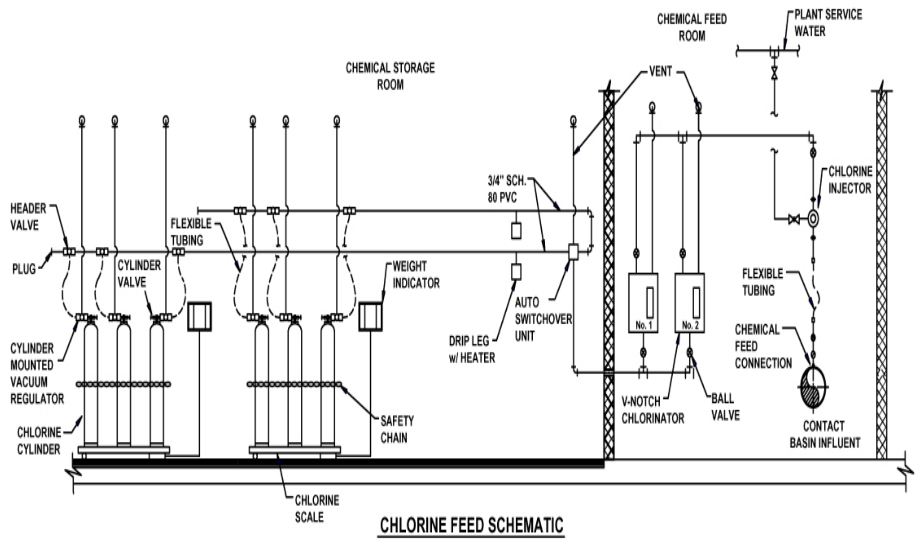


Figure 4.1 Gas feed system

The major components of the feed system include:

Cylinders or containers that supply the chlorine. Cylinders contain 100 or 150 pounds of chlorine and individually are limited to providing up to 70 pounds per day of gas. This can be increased by manifolding more than one cylinder into a header system. Containers store 2,000 pounds, one ton, of chlorine and are limited to providing approximately 400 pounds per day of gas. They also contain a connection that allows for liquid withdrawal that is capable of being depleted well within one day. Containers can be manifolded to provide greater quantities of chlorine.

Manual isolation valves consist of three types:

- **Auxiliary cylinder/container valves** that isolate a cylinder/container from the rest of the feed system. They connect to the cylinder or container valves and minimize the release of gas when changing units. These units require that a new lead gasket be provided when making any new connections to the cylinder or container.
- **Header valves** allow for the connection of the cylinder to a header system and isolate the header from the container and rest of the feed system. These are generally connected to a section of flexible tubing that connects to the auxiliary cylinder/container valve.
- **Line valves** which allow for the isolation of portions of the feed system for purposes of shut down and maintenance.

Regulating valves are of various types and purposes. In general, each uses a configuration of diaphragms, springs and orifices to perform its function.

- **Vacuum regulator** reduces tank pressure to a vacuum. These are now commonly located on ton container and cylinder valves to minimize downstream piping being exposed to positive pressure. Systems using liquid to gas phase evaporators have these located downstream of the evaporator. Piping downstream from a regulator is considered safe from leakage since any break in the line would be exposed to a vacuum, which would pull air into the system rather than release gas. In the past these valves were located downstream of the header valves and on the piping system upstream of the chlorinator.
- **Vacuum relief valve** is placed on a vacuum portion of the line to prevent excessive vacuum within the equipment.
- **Pressure relief valve** is placed on lines subject to positive pressure such as piping upstream of a vacuum regulator on an evaporator system. In the event of high pressure, it allows chlorine to be discharged to the atmosphere.

Automatic switchover system allows for two chlorine supplies to be piped to one common valve. The valve only allows one supply to be in use at a given time with the other as a hot standby. These consist of two types:

- **Gas phase system** where the valve monitors vacuum pressure on the supply side to the switchover system. When the vacuum gets too high, due to the container/cylinder being empty, a shuttle valve inside the device switches over and places the second system into service.
- **Liquid phase systems** use switches to monitor the pressure leaving a container. When the pressure gets too low, a signal to the switchover system control panel initiates closure of a ball valve that isolates this system, and the opening of a second ball valve that places the hot standby system into service.

Drip leg and heater is provided to collect any condensate that may form after the expansion of gas downstream of the pressure regulator. The heater is provided to regasify the liquid after it is collected in the drip leg.

Pressure gauges consist of two types:

- One measures the vacuum gas pressure downstream of a regulator, or on the supply side to a chlorine injector.
- The other measures the positive gas pressure on the discharge side of an evaporator.

A **Chlorinator** is used to establish a feed rate in pounds per day. It consists of several components including:

- A **differential regulating valve** that maintains a fixed pressure across a V-Notch orifice to assure repeatability of flow control regardless of variations in upstream or downstream vacuum pressures. This too is a form of regulating valve.
- A **V-Notch orifice with plug positioner.** The positioning of the plug allows for the increasing or decreasing of the gas flow area and thereby a regulation of the gas flow. The positioner can be set manually by turning a dial, or automatically, with a motor operated linkage that moves the plug up or down.
- A **rotameter** measures the flow rate of gases and liquids. The gas or liquid being measured flows vertically up a calibrated tube. Inside the tube is a small ball or bullet-shaped float (it may rotate) that rises or falls depending on the flow rate. The flow rate may be read on a scale behind the middle of the ball or the top of the float. In simple terms it allows for the visual view of the gas feed rate through the V-Notch.

Expansion tanks are provided in liquid chlorine supply systems between isolation valves. This provides a point of relief in the event the valves are closed, and liquid pressures rise due to an increase in temperature.

Injector is a venturi type device that allows for the absorption of chlorine gas into water prior to being introduced to the flow stream being treated. High-pressure water enters the venturi, and as it passes through the throat, its velocity is increased converting pressure energy into velocity energy. The pressure remaining has decreased to a point where it is now negative. This negative pressure (vacuum) pulls in the chlorine gas causing it to be absorbed by the water.

Solution tube is the final device that introduces the chlorinated water into the flow stream. Depending upon the type of distribution required into the flow stream, it may be a simple open ended pipe, or a more detailed distribution manifold with orifices designed to distribute the flow across a wide path.

Piping systems for chlorine are generally of two types:

- Seamless steel pipe rated at 3000 psi is used where chlorine is in the liquid phase or gas phase and upstream of the regulating valve. Joints are threaded. Where necessary, unions of the flanged ammonia type are provided. Schedule 80 PVC is used once the chlorine has been converted to the gas phase, although seamless steel pipe may also be utilized.

Evaporator is a piece of equipment that allows for the withdrawal of liquid chlorine from ton containers at higher rates than could be achieved in the gas phase. In general the limitation of the gas phase is approximately 400 pounds per day and is dependent upon temperature of the cylinder. An evaporator allows for the addition of heat to the liquid chlorine so that it will boil and evaporate.

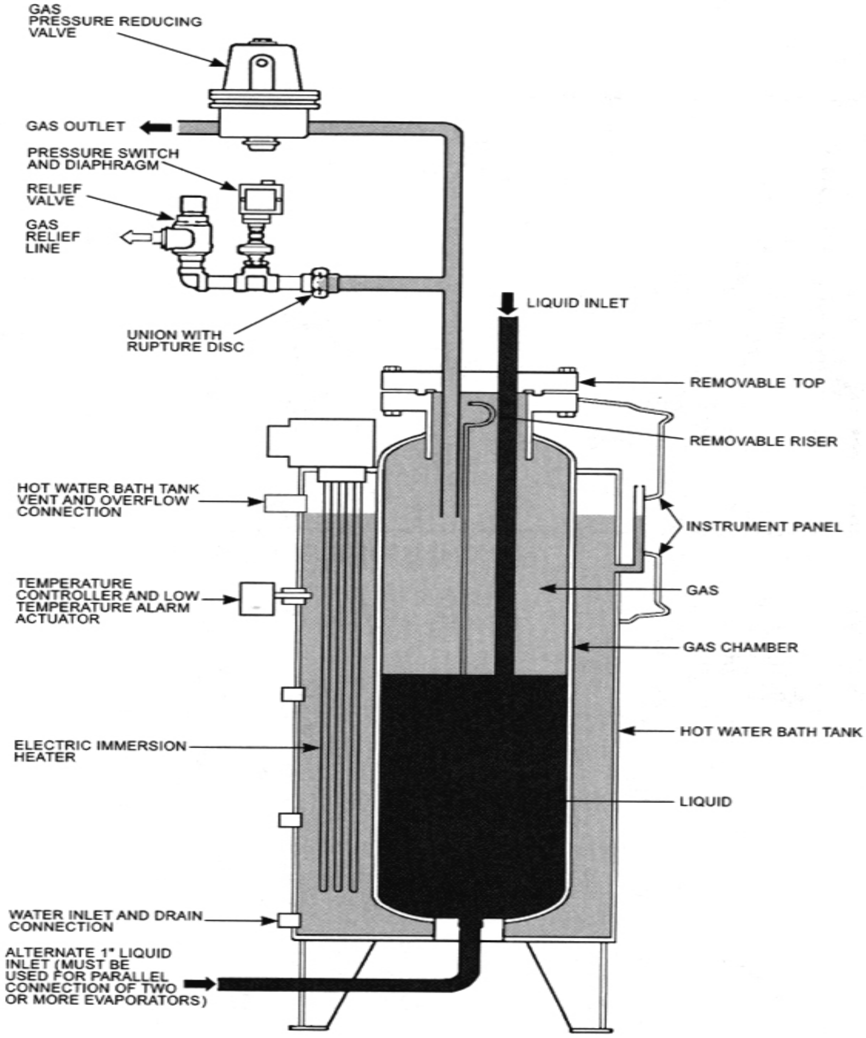


Figure 4.2 Evaporator[1]

Operation

- Start-up of the system should only be initiated after becoming familiar with the system. Once familiar, a procedure should be documented for the site-specific installation. In general this should include:
  - A check that all valves are in their proper start up position and tagged.
  - A check that all piping has been inspected and found to be in operating condition.
  - A check that all feed and safety equipment are found to be in operating condition.
  - A program to sequentially open valves, and start equipment.
- A similar procedure should be developed that documents the shut-down of the system.

Maintenance

- A detailed maintenance program should be developed, and performed on a routine basis. This should include verification that:
  - Equipment is operating without leaks
  - Scales are functioning properly
  - Adequate chlorine supply is available
  - Valves operate properly
  - Pressures are within proper range upstream and downstream of regulators
  - Pressures are within proper range at injector
- For system with evaporators this shall also include verification that:
  - Water levels are within range
  - Water temperatures are within range
  - Chlorine inlet and outlet pressures are within range
  - Chlorine inlet and outlet temperatures are within range
  - Equipment is operating without leaks
- Related Equipment:
  - Inspect and test gas detector to assure that it is operating properly
  - Inspect heating and ventilation system to assure that it is operating properly
  - Inspect hoisting equipment and scrubber system
- For all equipment perform maintenance as required and recommended by the manufacturer including lubrication, valve packing replacement, cleaning, painting and replacement.

Equipment

A sodium hypochlorite feed system consists of various components. Equipment allows for the safe removal of sodium hypochlorite from a storage system, and transmission through a series of pumps and valves to a point of application. A schematic of a typical system is shown in Figure 4.3.

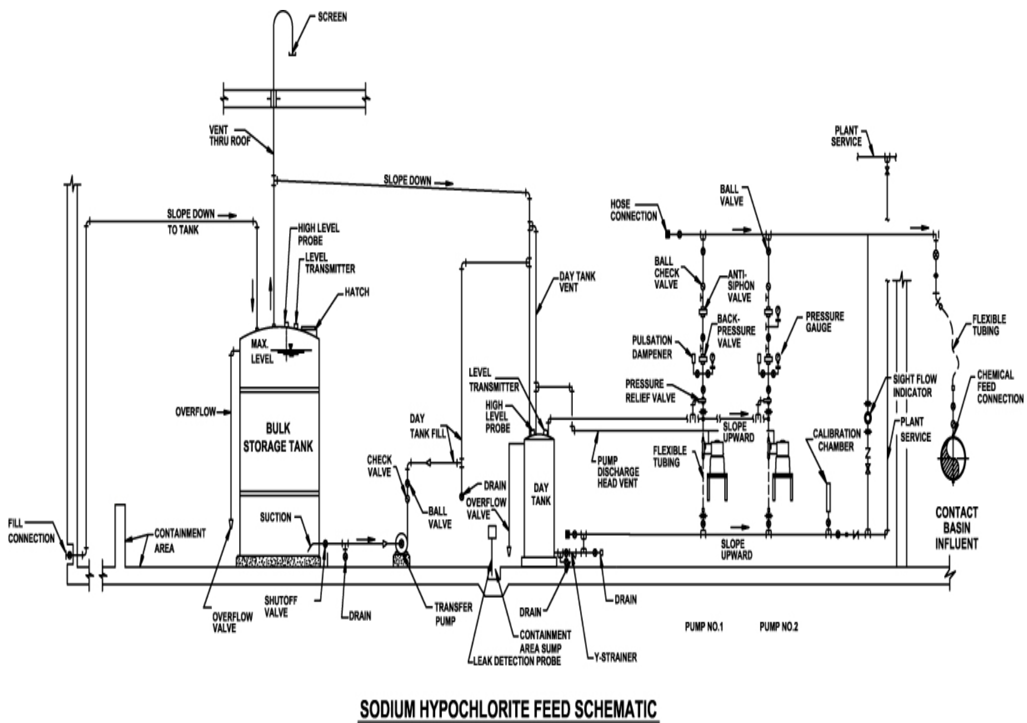


Figure 4.3 Sodium hypochlorite feed system

The major components of the feed system include:

- Storage tanks are provided to accept bulk deliveries of chemical. These are generally sized to store one month's supply of chemical, or one tank truck delivery, plus operating storage to allow for flexibility in delivery schedule. However, since the chemical has a limited shelf life, it may not be practical to store it in bulk form, and small containers may be utilized for storage. If received and stored in bulk, sampling and analysis for available chlorine is recommended upon receipt and periodically thereafter.

- Day tanks are provided to store up to one day's chemical so that a shift operator is only required to fill this tank once a day. The day tank also allows for daily monitoring of chemical since daily usage can be easily measured. For systems that use alternate forms of bulk storage, the storage container itself, such as carboys, may be suitable for day tank use.

- Transfer pumps are used to fill day tanks from bulk storage facilities.

- Chemical feed pumps may be provided in a variety of designs. Selection of type in part is dependent upon capacity requirements, and preference. Typical pump designs for this application include:
  - Solenoid actuated pumps
  - Mechanical diaphragm actuated pumps
  - Hydraulic actuated pumps

- Isolation valves are provided to shut down a portion of the system, primarily for maintenance purposes.

- Check valves are provided to eliminate flow reversal from the point of application to the chemical storage facility.

- Backpressure anti-siphon valves are provided to assure that chemical is not siphoned from the storage facility to the point of application or a break in the line if the height of the storage facility is higher than the point of application.

- Pressure relief valves are provided on pump discharge lines to relieve excess pressures that may build up due to pumping against a closed valve or other obstruction.

- Vent valves may be manual or automatic and serve to eliminate an off gassing of the chemical in the piping system, or pump discharge head.

- Solution tube is the device that finally is used to discharge the chemical into the point of application.

Drive water may be used to provide a higher flow at the point of entry, and thereby provide better mixing of the hypochlorite with the flow stream.

Hypochlorite Generator

Recently, hypochlorite generators have come into more common use at wastewater plants. These eliminate the need to store large quantities of an unstable and hazardous chemical by providing for the use of on site generation of hypochlorite. This is accomplished through the electrolytic processing of salt and storing the end product in smaller day tanks, or other conveniently sized vessel. Feeding of the chemical is the same as that for conventional sodium hypochlorite.

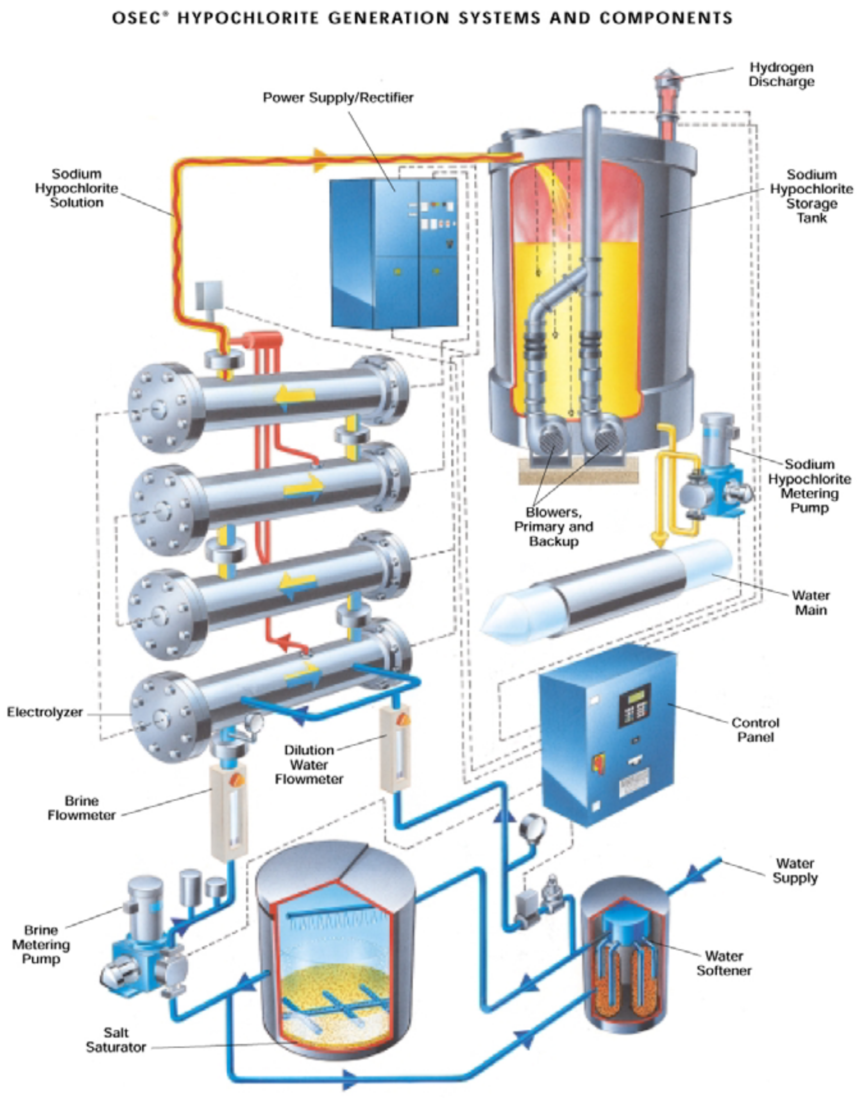


Figure 4.4 Hypochlorite generator[2]

Chlorine Dioxide Generators

Due to its instability, chlorine dioxide is generated on site and used within a short period of time after generation. Two systems are used to generate the chemical. In each, the process blends chlorinated water or hydrochloric acid with sodium chlorite in a mixing chamber to produce chlorine dioxide. The reactions are as follows:

$Cl_2 + 2NaClO_2 \Rightarrow 2NaCl + 2\ ClO_2$

$4HCl + 5NaClO_2 \Rightarrow 4ClO_2 + 5NaCl + H_2O$

- The first system uses an in-stream blending system containing Raschig rings that incorporates a large surface area for the mixing. Since the reaction takes place in a flow stream, it may be discharged directly to the point of use. A schematic of the process is presented in Figure 4.5.

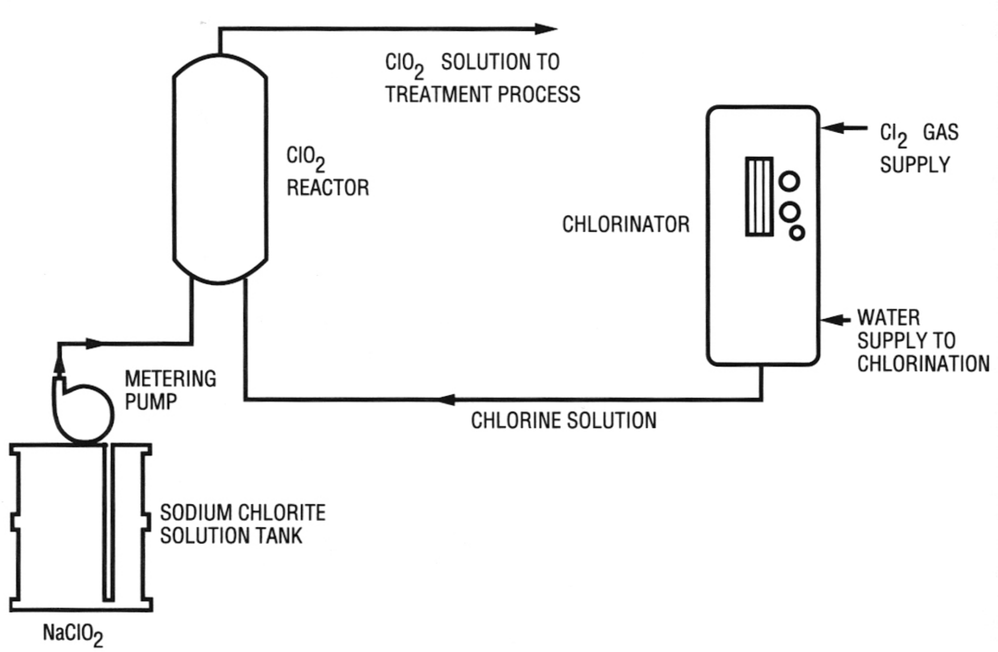


Figure 4.5 Chlorine dioxide facility[3]

- In this case:
  - Chlorine gas is fed from a typical feed system using a chlorinator.
  - Sodium chlorite or hydrochloric acid is fed from a storage/day tank facility much like sodium hypochlorite.
  - The feed rates of these chemicals are set to maintain a fixed percentage of each chemical to optimize the reaction, however there is no other control over this process.

- Chlorine dioxide can also be generated on site using package systems with control instrumentation that maximizes the reaction of the sodium chlorite. This results in chlorine dioxide solutions with strengths as high as 4%. The chemical is stored in a batch tank prior to being pumped to the point of application. The basic chemicals are fed in a similar manner as with the in-stream system.

Although chlorine dioxide is an effective chemical, it is not commonly used in wastewater applications due to safety issues related to the handling and storage of sodium chlorite which is combustible in the presence of organic compounds.

Key Points for Unit 4 – Chlorination Equipment and Maintenance

- Gas chlorination equipment allows for the safe removal of chlorine from a vessel and transmission through a series of valves, piping and control devices under vacuum to a point of application.

- Sodium hypochlorite system equipment allows for the safe removal of sodium hypochlorite from a storage vessel and transmission through a series of pumps and valves to a point of application.

- A hypochlorite generator is device which produces hypochlorite on-site through the electrolytic processing of salt.

- Chlorine dioxide generator is a device which generates chlorine dioxide on-site by blending chlorinated water or hydrochloric acid with sodium chlorite in a mixing chamber but is little used in the wastewater industry due to safety issues.

☑ Exercise for Unit 4 – Chlorination Equipment and Maintenance

1. The chlorine residual is too high in the plant effluent. The probable causes may include:
   a. The organic strength of the wastewater influent has decreased.
   b. The flow through the treatment plant has changed.
   c. The test equipment used to check chlorine residual needs to be calibrated.
   d. All of the above.

2. Low chlorine gas pressure at the chlorinator is suspected to be due to a depleted chlorine container. The best course of action would be to:
   a. Clean the filter.
   b. Switch to a full chlorine container.
   c. Add baffles to the chamber.
   d. Increase the influent flow.

3. A safety concern with the use of sodium chlorite in a wastewater facility is that it is combustible in the presence of organic compounds.
   a. True __________
   b. False __________

4. Day tanks are designed to hold what amount of a chemical compound?
   a. One day.
   b. One week.
   c. One month
   d. Five days.

5. List five major components of a chlorine feed system.

   a. ____________________
   b. ____________________
   c. ____________________
   d. ____________________
   e. ____________________

6. It is very important to have a detailed maintenance program that is performed on a routine basis. List five items that should be part of a gas feed chlorination maintenance plan.

   a. ____________________
   b. ____________________
   c. ____________________
   d. ____________________
   e. ____________________

[1] John Brady, William Garber and James F. Stahl, “Chapter 10: Disinfection and Chlorination,” in *Operation of Wastewater Treatment Plants, Volume I*, (Sacramento, CA: California State University, Sacramento Foundation, 2001), p. 395.

[2] Permission of Wallace & Tiernan Division, Penwalt Corporation.

[3] Brady, p. 396.

Unit 5 – Dechlorination

Learning Objectives

- Describe the need for dechlorination and how it is usually accomplished.
- State the differences between the sulfur compounds used for dechlorination.

Dechlorination is the removal of chlorine from treatment plant effluents. It is important to remove chlorine because wastewater effluent is discharged into streams, rivers, and lakes, which provide habitat for wildlife and plant life. Without dechlorination, excess chlorine may kill the wildlife and plant life.

Dechlorination of plant effluent flow may be accomplished by various processes. These include:

- Detention Ponds: Ponds may be designed to detain wastewater for an adequate amount of time to allow chlorine to naturally dissipate prior to discharging to a receiving stream.

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

- Sunlight: The chorine residual may be decomposed by exposure to sunlight. Thin layers of flow, when exposed to sunlight react with the light to form hydrochloric acid.

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

- Sulfur Compounds: Sulfur compounds are commonly used in the dechlorination process due to its rapid reaction, ease of use, and relatively inexpensive cost. Typical compounds used are as follows:
  - Sulfur Dioxide (SO_2)
  - Sodium Sulfite (Na_2SO_3)
  - Sodium Bisulfite ($NaHSO_3$)
  - Sodium Metabisulfite ($Na_2S_2O_5$)
  - Sodium Thiosulfate ($Na_2S_2O_3$)

Of these, sulfur dioxide is the most common form of dechlorination agent in use. It utilizes equipment that is similar to chlorination facilities and therefore its operation is understood readily by operators.

Sulfur Compounds

Sulfur dioxide

- Sulfur dioxide is a colorless, toxic gas provided in liquid form in cylinders or containers much like chlorine.
- Sulfur dioxide is not flammable, explosive, or corrosive to most metals when dry. When in the presence of moisture, the gas forms sulfuric acid which is highly corrosive.
- Sulfonators are similar in design and operation as a chlorinator, but are manufactured with special materials suitable for sulfur dioxide.
- Approximately one pound of sulfur dioxide will react and neutralize one pound of chlorine. Care must be taken not to add excessive amounts of sulfur dioxide as to reduce the DO lenels as is seen in the following formulas.
- $SO_2 + H_2O \Rightarrow HSO_3^- + H^+$

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

  $SO_2 + HOCl + H_2O \Rightarrow Cl^- + SO_4^{-2} + 3H^+$
- For combined forms of chlorine, such as chloramines the reaction is still one to one and as follows:

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

Sodium sulfite

1. Sodium sulfite may be provided in either a liquid or tablet form. Approximately 2.4 pounds of sodium sulfite are required to react with one pound of chlorine.

   $Na_2SO_3 + HOCl \Rightarrow SO_4^{-2} + Cl^{-1} + H^{-1} + 2\ Na^{+1}$

Dechlorination Control

Control may either be manual, or automatic. Since it is important to maintain a chlorine residual as low as possible, automatic control is generally used to assure minimal chlorine residual without the need to wastefully overdose with chemical. Compound loop control, as described for the chlorination system, is the preferred method of control. The manual control should only be used when there is a failure of the automatic control system. By maintaining a residual of 0.5 mg/l of sulfur dioxide, an operator can be assured that residual chlorine has fully reacted.

Example 5.1: How many pounds per day of SO_2 must be fed if the plant is operating at a flow rate of 3.0 MGD, and has a chlorine residual of 5.0mg/l and the desired SO_2 residual is 0.5mg/l?

Feed Rate in lbs/day = (Flow in MGD) x (Dose in mg/l) x (8.34 lbs/gal)

Feed Rate in lbs/day = (3 MGD) x (5.0 mg/l + 0.5 mg/l) x (8.34 lbs/gal)

Feed Rate in lbs/day = (3 MGD) x (5.5 mg/l) x (8.34 lbs/gal)

Feed Rate in lbs/day = (3,000,000 gal/day) x (5.5 mg/l) x (8.34 lbs/gal)

Now, the dosage can be expressed as

5.5 mg/l = (5.5 mg/l) x (1l/1,000,000 mg) = (5.5)/(1,000,000)

Then, we can write

Feed Rate in lbs/day = (3,000,000 gal/day) x (5.5)/(1,000,000) x (8.34 lbs/gal)

Feed Rate in lbs/day = (3 gal/day) x (5.5) x (8.34 lbs/gal) = 137.61 lbs/day

Rounding off gives us

Feed Rate in lbs/day = 138 lbs/day

Safety (Sulfur Dioxide)

- Sulfur dioxide is a highly toxic chemical that must be handled with care to minimize exposure to personnel. It is more than 2.3 times heavier than air, and any leak in a quiescent room will stay close to the ground where it can be inhaled by an operator.

- Concentrations of 0.04% (400 ppm) in the air may be fatal after only a few breaths. The Immediate Dangerous to Life of Heath (IDLH) concentration is 100 ppm according to National Institute for Occupational Safety and Health. The OSHA regulations limit short term exposure to no more than 5 parts per million over a 15-minute period.

- Sulfur dioxide is hazardous and when combined with moisture (including body moisture) becomes extremely corrosive.

Safety Procedures and Response

Safety procedures and response to leaks are similar to those presented for use with chlorine gas (see unit 3).

Emergency Safety Equipment

Emergency safety equipment is similar to that used for response to chlorine leaks including respiratory (see unit 3).

Equipment

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

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

Key Points for Unit 5 - Dechlorination

- Dechlorination is the removal of chlorine form treatment plant effluents after disinfection due to increasing concerns of the affects of residual chlorine on fish, wildlife and even human health.

- Dechlorination can be accomplished through detention ponds, aeration, sunlight, activated carbon and the addition of sulfur compounds.

- Approximately one pound of sulfur dioxide will neutralize one pound of chlorine.

- By maintaining a residual of 0.5 mg/l of sulfur dioxide, an operator can be assured that all the residual chlorine has reacted.

Exercise for Unit 6 - Dechlorination

1. The effluent from a wastewater treatment plant may need to be dechlorinated after disinfection because of harmful affects the chlorine residual may have on fish, wildlife, and even human health.
   a. True
   b. False

2. Common methods of dechlorination include:
   a. ____________________
   b. ____________________
   c. ____________________
   d. ____________________

3. One pound of sulfur dioxide will neutralize how many pounds of chlorine?
   a. 4 pounds
   b. 2.5 pounds
   c. 1 pound
   d. Neutralization of chlorine is not possible by using sulfur dioxide.

4. Sulfur dioxide is often used to dechlorinate wastewater effluent, however, like chlorine it is very toxic and must be handled with great care.
   a. True
   b. False

5. A wastewater treatment plant operates with a flow of 2.0 MGD. The Chlorine residual is 3.5 mg/l. How much sulfur dioxide should be used to assure that the chlorine residual has fully reacted in the dechlorination process?

Unit 6 – Ultraviolet Radiation

Learning Objectives

- Describe why ultraviolet (UV) radiation is an effective means of disinfection.
- State the differences between the three types of UV systems.
- Describe the UV radiation process.

- Ultraviolet light, or UV, is an effective means to disinfect, or deactivate pathogens. This is accomplished by exposing waterborne microorganisms to ultraviolet light, having a wavelength of 254 nanometers (nm), at a specified intensity for a specified period of time. The UV light damages the genetic materials (DNA) within the organism so that it is incapable of continued growth or reproduction.

- UV is a safe form of disinfection that does not rely on either chlorine related feed systems or sulfur based dechlorination agents to be applied to the plant effluent flow.

- UV is effective when effluent turbidities remain low.

- Unlike chlorine where a residual measurement assumes a level of disinfection, routine bacteriological testing of plant effluent must be performed to assure that the system is operating satisfactorily. Also, UV leaves no residual so there is no protection from recontamination.

- UV disinfection has become an attractive alternative to chlorination because of its effectiveness, simplicity of operation, ease of installation, and low operating and capital costs.

- Typical UV lamp configurations are shown in Figure 6.1.

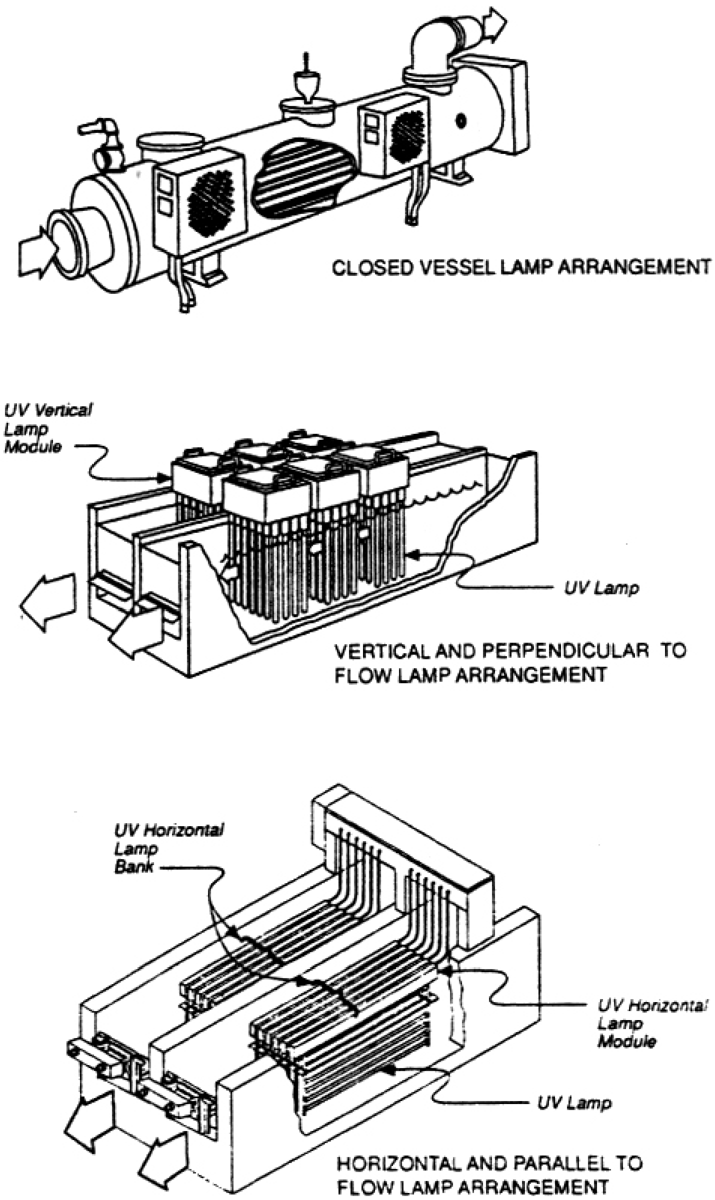


Figure 6.1 Typical UV lamp configurations[1]

Several types of UV systems are now available for treatment of final wastewater effluent. Each is unique and has its own advantages and disadvantages. The following presents three systems, their differences, advantages, and disadvantages.

Low Pressure-Low Intensity

- Utilized for relatively low flow applications, (<0.5 MGD).
- Lamp is monochromatic – Low UV output, (27 – 32 watts @ UVC-254 nm).
- Lamp life is adequate, (8,760 hours) when operated continuously at 100% output.
- Automatic cleaning systems are not available for most low pressure-low intensity systems. Manual cleaning is required.
- Lamp operating temperature is very low, (60^{o} F).
- Lamp efficiency is good, 32 – 34%.
- Variable lamp output feature is not available.
- Mercury content of lamp is in a liquid state.

Low Pressure-High Intensity

- Utilized on small, medium and large-scale systems, (>0.25 MGD).
- Lamp is monochromatic - High UV output, (52 – 139 watts @ UVC-254 nm).
- Lamp life is good, ranging from 8,760 – 12,000 hours when operated continuously at 100% output.
- Automatic cleaning systems are available. Due to low lamp operating temperature, mechanical wiping systems are utilized. No chemicals are required.
- Lamp operating temperature is low, (110^{o} F).
- Lamp efficiency is good, 34 –40%.
- Variable lamp output feature available with some Low Pressure-High Intensity lamp systems.
- Mercury content of the lamp is available in either a solid state (amalgam) or in a liquid state.

Medium Pressure-High Intensity

- Utilized on medium to large-scale applications, (>2 MGD).
- Lamp is polychromatic - High UV output, (280 watts @ UVC-254nm equivalent).
- Polychromatic lamps are more effective for disinfection because they impair the ability of microorganisms to photo-reactivate (repair) themselves after exposure to UV.
- Lamp life is short, (Ave. 3,000 hours @ continuous 100% output). Lamp replacement is required 3 to 4 times more frequently than to most low-pressure lamps.
- Automatic cleaning systems are available. Due to the high operating temperature, a combination of mechanical and chemical cleaning must be utilized.
- Lamp operating temperature is very high, (1,100^{o} F -1,650^{o} F). Fouling of quartz sleeve occurs rapidly.
- Lamp efficiency is low, 10 –12%.
- Power consumption is typically 3 to 4 times greater than low pressure systems for the same flow rate and UVC output.
- Variable lamp output feature available with some systems.
- Mercury content of lamp is in a liquid state.

Factors Influencing Effectiveness of UV

- UV lamps have a limited life and will experience reduced output as time goes on. This in turn will result in a reduction of pathogen inactivation if the system were not properly sized.

- UV sleeves are subject to fouling from materials in the flow stream with accompanying dose (light intensity) reductions.

- UV systems are subject to fouling of the quartz sleeve due to crystallization of dissolved solids on the surface of the sleeve and thereby reducing transmission of light into the flow stream and the effectiveness of the system.

- UV sleeves are subject to discoloration (known as solarization) resulting in reduced capacity of the lamp to transmit light to the flow stream, reducing its effectiveness. UV sleeves are more prone to solarization when used in high intensity-medium pressure systems.

UV Control

- UV may be controlled by turning on or off selected sections of the UV train and thereby increase or decrease the dosage of UV radiation applied to the flow stream.

- UV may be controlled by increasing or decreasing the power to a UV train resulting in increased or decreased levels of radiation emitting from the lamps.

- On/Off or variable lamp output can be controlled using signal from plant flow meter – "Flow Pacing."

- On/Off or variable lamp output can be controlled using signals from UV intensity sensor and plant flow meter – "Dose Pacing."

- Dose pacing accounts for lamp age, condition of quartz sleeve, and water quality, (transmittance). However, the greater the frequency of on/off cycles, the shorter the life of the lamps.

Safety

- Some UV lamps operate at high temperatures and care should be taken not to come in contact with the lamp or related equipment while in operation or during its cool down cycle.
- UV lamps contain mercury either in the solid form or gaseous form and should be handled with care to avoid breakage and exposure to the mercury.
- UV radiation is harmful to eyes and skin and care should be taken to avoid exposure. Never look at operating UV lamps without proper eye protection.
- An acid solution is used to clean the quartz sleeve that surrounds the lamp and care should be taken as acids can burn eyes and skin.

Equipment Maintenance

- Maintenance of the UV equipment is generally limited to replacing lamps as they either weaken, or burn out, cleaning the quartz sleeve that surrounds the lamp with an acid solution, replacement of automatic wiper components, and ballast replacement. Maintenance should also be planned relating to the power supplies to assure that they are also operating satisfactorily. Solid state ballasts have an average life of 8–10 years. Annual failure rate may average between 1–2 %.

Key Points for Unit 6 – Ultraviolet Radiation

- Ultraviolet light or UV is an effective and increasing popular means of disinfection of wastewater by exposing microorganisms to light having a wave length of 254 nm for a specified period of time thereby damaging the DNA of the microorganism rendering them incapable of continued growth or reproduction.

- The major operational problem associated with UV disinfection is high turbidity in the wastewater or fouling of the sleeve or lamp thereby decreasing light intensity and subsequently dosages of the wastewater.

- Types of UV systems include Low Pressure-Low Intensity, Low Pressure-High Intensity and Medium Pressure-High Intensity.

- UV control can be either by Flow or Dose Pacing.

- Safety concerns of UV lamps include high temperatures, possible exposure to mercury and the UV light is harmful to the eyes.

- Maintenance of the UV equipment is generally limited to replacing lamps as they either weaken, or burn out, cleaning the quartz sleeve that surrounds the lamp, replacement of automatic wiper components, and ballast replacement.

Exercise for Unit 6 – Ultraviolet Radiation

1. UV light used to disinfect or inactivate pathogens has a wavelength of:
   a. 580 kHz
   b. 92.7 MHz
   c. 254 nm
   d. 1760 yd

2. Three typical UV lamp configurations are:
   a. ____________________
   b. ____________________
   c. ____________________

3. UV light is harmful to the eyes and skin.
   a. True
   b. False

4. Low pressure-low intensity UV lamps are often used in wastewater systems with a flow of
   a. >0.5 MGD
   b. <0.5 MGD
   c. >2.0 MGD
   d. Are rarely used because they get too hot during operation.

5. In a typical UV disinfection system, replacement of the UV lamps should occur more often than replacement of the lamp ballasts.
   a. True
   b. False

6. Flow or dose pacing are means of
   a. UV control
   b. Maintenance planning
   c. Dechlorination
   d. Residual monitoring

[1] John Brady, William Garber and James F. Stahl, "Chapter 10: Disinfection and Chlorination," in *Operation of Wastewater Treatment Plants, Volume I*, (Sacramento, CA: California State University, Sacramento Foundation, 2001), p. 422.