Drinking Water Operator Certification Training

Module #24
Gas Chlorination

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

The Pennsylvania State Association of Township Supervisors (PSATS)
Gannett Fleming, Inc.
Dering Consulting Group
Penn State Harrisburg Environmental Training Center

Topical Outline

Unit 1 – General Chemistry and Characteristics

I. General Description
   - A. Purpose of Chlorination
   - B. Forms of Chlorine

II. Properties of Chlorine
   - A. Liquid Chlorine
   - B. Gaseous Chlorine

III. Chemistry of Chlorine
   - A. Reactions in Aqueous Solution

Unit 2 – Chlorine Handling and Safety

I. Safety Considerations and Programs
   - A. Material Safety Data Sheet (MSDS)
   - B. Chlorine Hazards
   - C. Personnel Safety Protection
   - D. First Aid
   - E. Chlorine Leaks and Response
   - F. Risk Management Plan

II. Chlorine Handling and Storage
   - A. Quantities
   - B. Types of Storage Containers
   - C. Storage Facilities

Unit 1 – General Chemistry and Characteristics

Learning Objectives

- Explain the purpose of chlorination.
- Describe the two forms of chlorine.
- Describe the properties of liquid chlorine and gaseous chlorine.
- Explain how chlorine reacts in aqueous solutions.
- Read and explain chlorine reaction equations.

Purpose of Chlorination

Chlorination is primarily used for disinfection and oxidation in water treatment.

Disinfection

- Disinfection is the most common use of chlorine in water treatment.
- The disinfection of water has probably been practiced for millennia, with no understanding of the principles involved.
- As early as 500 B.C., the boiling of water was recommended.
- The earliest uses of chlorine were experimental:
  - In 1896, filtration studies were conducted in Louisville, KY.
  - In 1897, chlorine was used in England to sterilize water distribution mains following a typhoid epidemic
- The first continuous use of chlorine was in Belgium in 1902, when it was used to aid in coagulation and to make water biologically "safe."
- The first continuous use in North America occurred in 1908 in Jersey City, NJ, where chlorine was used to disinfect a 40 million gallon reservoir supply.

Oxidation

- Chlorine is commonly used to oxidize compounds in water, such as Iron, Manganese, Organic Matter, Cyanide, and Sulfide**.** This allows the oxidized compounds to be removed by subsequent processes such as clarification and filtration.

Forms of Chlorine

Elemental Chlorine

- Elemental chlorine is either liquid or gaseous in form.
- In its liquid form, it must be under extreme pressure.
- In its gaseous form, it is 2.5 times as heavy as air.
  - Liquid chlorine rapidly vaporizes to gas when unpressurized.
  - One volume of liquid yields about 450 volumes of gas.

Forms of Chlorine in Solution

There are two forms of chlorine in solution:

- Hypochlorous Acid
  - The chemical symbol for hypochlorous acid is HOCl
  - HOCl retains the oxidizing and disinfecting property of chlorine. Based on this principle, the disinfecting action of aqueous chlorine solution occurs.
- Hypochlorite Ion
  - The chemical symbol for hypochlorite is OCl^-
  - The hypochlorite ion (OCl^-) is not the same as the salts calcium hypochlorite and sodium hypochlorite although the term is commonly used for both the ion and the salts. Hypochlorites are discussed further in Module 25.

Liquid Chlorine

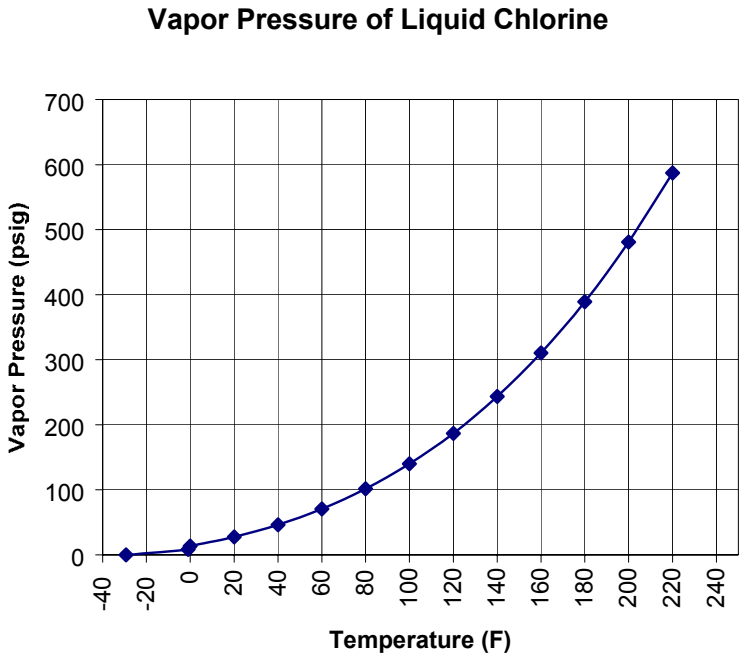
- Liquid chlorine is a clear, amber colored liquid.
- Common properties of chlorine are listed in the following table:

Table 1.1 Properties of Liquid Chlorine

Critical Temperature	144°C; 291.2°F
Critical Pressure	1118.4 psia
Critical Density	38.77 lbs/ cu ft
Density (at 32°F & 1 atm)	91.67 lbs/cu ft
Specific Gravity (at 68°F)	1.41 (water = 1)
Boiling Point	-34.5°C; -30.1°F
Freezing Point	-100.98°C: -149.76°F
Viscosity (at 68°F)	0.342 centipoise (approx 0.35 x water)
1 pound liquid (at 32°F & 1 atm)	4.98 cu ft gas

Vapor Pressure

- Vapor pressure is a function of temperature and is independent of volume. The gage pressure of a container with 1 pound of chlorine will be essentially the same as if it contained 100 pounds, at the same temperature conditions.
- Vapor pressure increases as the temperature increases, as demonstrated in the following figure:



Curve Data	
Temp. (°F)	Press. (psig)
-29.29	
-10	8.29
	13.81
20	27.84
40	46.58
60	70.91
80	
100	
120	
140	243.33
160	310.35
180	389.17
	480.97
220	587.13

Figure 1.1 Vapor Pressure of Liquid Chlorine

Exercise: Using the graph in Figure 1.1, fill in the data points that are missing in the above table.

Gaseous Chlorine

- Gaseous chlorine is a greenish, yellow gas.
- Common properties of gaseous chlorine are listed in the following table:

Table 1.2 Properties of Gaseous Chlorine

Density (at 32°F & 1 atm)	0.2006 lbs/ cu ft
Specific Gravity (at 32°F & 1 atm)	2.482 (air = 1)
Liquefying Point (at 1 atm)	-30.1 °F
Viscosity (at 68°F)	0.01325 centipoise
Solubility in Water	60.84 lbs/1000 gal

Reactions in Aqueous Solution

- Chlorine added to chemically pure water forms a mixture of hypochlorous (HOCl) and hydrochloric (HCl) acids, as indicated in the following chemical equation:

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

- At ordinary temperatures, the reaction is essentially complete within a few seconds.
- Hypochlorous acid dissociates into hydrogen and hypochlorite ions almost instantaneously:

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

- The degree of dissociation is dependent on both pH and temperature.
  - HOCl dissociates poorly at pH levels below 6; therefore, predominately HOCl exists at relatively low pH levels.
  - At pH levels between 6 and 8.5, there is a sharp change from undissociated HOCl to almost complete dissociation. At 20°C above pH 7.5 and at 0°C above pH 7.8, hypochlorite ions (OCl^-) predominate.
  - OCl^- exists almost exclusively above pH 9.5.
- The normal pH of water supplies is within range where chlorine may exist as both hypochlorous acid and hypochlorite ion. This is indicated in the following figure. HOCl is a stronger oxidant and disinfectant than OCL^-, which is why disinfection is more effective at lower pHs.

Distribution of HOCl and OCl- in Water

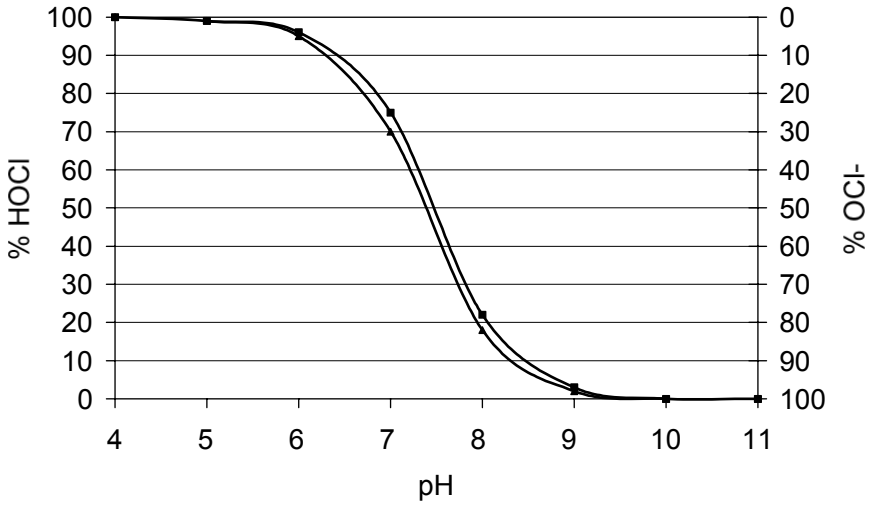


Figure 24.2 Distribution of HOCl and OCl^- in water

Key Points for Unit 1 – Chemistry of Chlorine

Chlorine is widely used to disinfect drinking water.

Chlorine has been used to treat drinking water for over 100 years.

Chlorine can be used as a gas or as a liquid.

The gas form of Chlorine is 2.5 times as heavy as air.

When added to pure water, Chlorine forms hypochlorous (HOCL) and hydrochloric (HCL) acids.

In addition to disinfecting water, Chlorine can also be used to oxidize materials such as Iron, Manganese, Cyanide, Sulfide, and Organic Matter.

Exercise

1. What is the purpose of chlorination?

2. What are the two different forms of chlorine?

3. What are four properties of liquid chlorine?

4. What are the specific gravity and solubility in water of gaseous chlorine?

Unit 2 – Chlorine Handling and Safety

Learning Objectives

- Identify a MSDS and explain its significance.
- Explain the health and environmental hazards of chlorine.
- Identify the basic personnel safety protection equipment and explain its importance.
- List and explain the appropriate first aid procedures for chlorine handling and safety.
- Explain where chlorine leaks can occur, how to detect them, and how to repair and respond to them.
- Explain the importance of a risk management plan and identify its basic components.
- Explain how the quantity of chlorine impacts the storage of it.
- List the common types of chlorine storage containers.
- List and describe the basics of a chlorine storage facility.

Material Safety Data Sheet (MSDS)

- MSDS sheets are available from the chemical manufacturer/supplier for every chemical.
- The Treatment Plant Operator (TPO) should read and understand the MSDS for each chemical used in the plant. Additionally, the TPO should maintain a personal copy for all hazardous chemicals used.
- The MSDS contains a detailed assessment of chemical characteristics, hazards and other information relative to health, safety and the environment.
- Typical information included in an MSDS includes:

  - Product name and synonyms.
  - CAS number.
  - Manufacturer's address and telephone number.
  - Components and contaminants.
  - Physical data.
  - Fire and Explosion hazard data.
  - Toxicity data.
  - Health hazard data, including exposure limits, effects of exposure and emergency and first aid procedures.
  - Reactivity data, including storage and disposal recommendations and conditions to avoid.
  - Spill or leak procedures.
  - Protective equipment.
  - First aid procedures.

☑ An example of a MSDS is included in the Appendix.

Chlorine Hazards

Health Hazards

Using the sample MSDS in the appendix, answer the following questions about chlorine hazards:

1. What effect does liquid chlorine have on the skin and eyes?

2. What effect does gaseous chlorine have on the nose, throat and lungs?

3. What effect does exposure to gaseous chlorine have on heartbeat and pulse?

Environmental

- Since chlorine is heavier than air, it remains in low spots and is therefore difficult to dissipate.
- The health effects to animals are similar to those of humans. Chlorine is toxic to aquatic life.

Personnel Safety Protection

Basic Equipment

- Forced air ventilation is required for all chlorine storage and feed rooms.
  - Exhausts should be located near the floor since chlorine is heavier than air.
  - Equipment should have capacity to replace all air in the room within 3 minutes.
  - The switch should be located outside of the chlorine area.
- There are two types of gas masks – a canister type with a full face piece and a self contained breathing apparatus.
  - The canister-type should be used only for short exposures and for chlorine concentrations of less than 1%. It requires sufficient oxygen (more than 16%).
  - The self contained breathing apparatus is available for longer exposures and higher chlorine concentrations. It is the preferred means of respiratory protection.
- Protective clothing.
- Emergency showers and eye-wash stations.
- Automatic leak detection.

Equipment must be used and maintained in strict accordance with manufacturer's recommendations and instructions. Appropriate OHSA requirements must also be followed.

First Aid

The following guidelines should be adhered to in the event of exposure to chlorine.

Inhalation

- Remove the injured party to an uncontaminated outdoor area. Use appropriate respiratory equipment during rescue—do not become another victim.
- Check for breathing and pulse. If not breathing, give artificial respiration. If breathing is difficult, have trained personnel administer oxygen as soon as possible. If no pulse, perform CPR.
- Call for medical assistance as soon as possible.
- Check for other injuries.
- Keep the injured party warm and at rest.

Skin Contact

- Immediately shower with large quantities of water.
- Remove protective clothing and equipment while in shower.
- Flush skin with water for at least 5 minutes.
- Call for medical assistance.
- Keep affected area cool.

Eye Contact

- Immediately shower with large quantities of water while holding eyes open.
- Call a physician immediately.
- Transfer promptly to medical facility.

Ingestion

- Do not induce vomiting.
- Give large quantities of water.
- Call physician immediately.
- Transfer promptly to a medical facility.

Chlorine Leaks and Response

Potential Points of Chlorine Leaks

- Leaks can occur anywhere in the pressurized supply, including connections and piping joints, cylinders or containers and feed equipment.

Leak Detection

- The sense of smell can detect chlorine concentrations as low as 4 parts per million (ppm).
- Portable and permanent automatic chlorine detection devices can detect at concentrations of 1 ppm or less.
- A rag saturated with strong ammonia solution will indicate leaks by the presence of white fumes.

Leak Repair

In the event of a chlorine leak, the following guidelines should be followed.

- Activate the chlorine leak absorption system, if available.
  - The system uses alkaline solution to react with and absorb chlorine.
- Repair leaks immediately or they will become worse.
  - Repair work should be performed by properly trained operators wearing proper safety equipment.
  - Always work in pairs during chlorine leak detection and repair.
  - All other persons should leave the danger area until conditions are safe again.
  - If the leak is large, evacuate the area and obtain help from the local fire company. They have self-contained breathing equipment and can assist with evacuation efforts. The local police can also assist in the event there are curious sightseers. Keep in mind that emergency vehicles and vehicle engines may quit operating due to a lack of oxygen
- If the leak is in the chlorine supply piping:
  - Close the container valve to isolate the leak.
  - Repair as required by tightening the packing gland nut for leaks around valve stems, replacing the gasket for leaks at the discharge valve outlet and/or using emergency repair kits for leaks at fusible plugs and cylinder valves.
  - Clean, dry and test repair for leak prior to returning the system to service.

- If the leak is in the equipment:
  - Close the container valve to the equipment.
  - Continue to operate the equipment (without chlorine feed supply) until all chlorine has been displaced.
  - Repair as required.
  - Clean, dry and test repair prior to returning system to service.
- If the leak is in a cylinder or container:
  - Increase the feed rate if possible, and cool the tank to reduce leak rate.
  - Turn, if possible, so that gas escapes rather than liquid. The quantity of chlorine that escapes as gas is 1/15 that which escapes as liquid through the same size hole.
  - Use the emergency repair kit appropriate to the container size:

    Kit A – for 100 and 150 pound cylinders
    Kit B – for 1 ton containers
    Kit C – for tank cars and tank trucks
  - Do not immerse a leaking container in water because the acid formed will increase corrosion at the leak location and make leak worse and gas will be released at water surface.
  - Call the supplier for instructions for returning leaking containers or containers with leaking valves. DO NOT SHIP leaking cylinders.

Other Chlorine Emergency Measures

Fire

- Chlorine will not burn in air. It is a strong oxidizer and contact with combustible materials may cause fire. When heated, chlorine is dangerous and emits highly toxic fumes.
- In the event of a fire caused by chlorine, the following fire fighting measures should be adhered to:
  - Use appropriate extinguishing media for combustibles in the area.
  - Move chlorine containers away from the fire source if possible.
  - Cool the container with water spray; however, do not apply water to a leak.
  - Be sure to wear full protective equipment, including self-contained breathing equipment.

Risk Management Plan

An emergency plan for chlorine is essential and should include the following:

- Training of personnel.
- Periodic training drills.
- A list of assistance available in the event of an emergency. The supplier's name, address and emergency telephone number should be posted.

Quantities

Storage Requirements

- Separate rooms for storage and feed facilities should be provided.
- Storage and feed rooms need to be separate from other operating areas.
- Rooms should have an inspection window to permit equipment to be viewed without entering the room.
- All openings between rooms and the remainder of the plant need to be sealed.
- Storage for a 30 day supply should be available.

Types of Storage Containers

100 and 150 lb. Cylinders

- Position and store vertically.
- Restraint chains are necessary to prevent accidents.

Figure 2.1 A 150 lb Chlorine Cylinder in Feed Position

Ton Containers

- Provide storage area with 2 ton capacity monorail or crane for cylinder movement and placement.
- Roller trunions are necessary to properly position cylinders.
- Cylinder valves must be positioned vertically. Gas flows from the top valve and liquid flows from the bottom valve.

Figure 2.2 Ton Cylinders in Feed Position

Tank Cars

- Tank cars are generally only provided for the largest plants.
- Rail siding is required.

Storage Facilities

Basic Facilities and Housing

- Storage should be in a clean, cool, well ventilated area.
- Interior rooms should be of fire-resistant construction and isolated from other areas of the plant. Storage facilities should be away from heat sources, flammable substances and other compressed gasses.
- Exterior storage is not recommended since containment of emergency spills is not available. A spill would result in the free release of chlorine gas.

- If exterior storage has been provided, the areas should be shielded from direct sunlight and protected from rain, ice and snow.

- In service containers (both "on-line" and "in-reserve") should be located inside where temperature can be controlled.

- Cylinders should be moved inside sufficiently in advance of use to allow temperature to stabilize. Cylinder withdrawal rate must be considered if exterior storage is used. Decreased temperatures will decrease available withdrawal rate.

- Cylinder storage and the chemical feed area should be in separate rooms. A window should be available to permit operator to view the storage and feed rooms without entering.

Entry (Ingress) and Exit (Egress) Requirements

- Access should be from the exterior only. It should be designed such that personnel can exit quickly under emergency conditions.

- Doors should open outward, be provided with panic hardware and lead to an unobstructed outside area.

Heating

- Storage and feed rooms should be heated when the outside temperature falls below 50º F.

- The recommended comfortable working temperature for chlorine feed room is 65 to 70º F.

- The temperature in the storage/supply room should be 5 to 10 º F cooler.

Ventilation

- Forced air ventilation should be provided.

- Exterior switch or door interlock should be provided so that the ventilation system can be started prior to entering area

Lighting

- Storage and feed rooms should be well lit.

Chlorine Scrubbers

Description of Equipment

- A chlorine scrubber is a type of equipment that is available to neutralize liquid and gas chlorine spills.
- In the event of a chlorine release, fresh air from outside is introduced at the top of the storage room and chlorine is pulled from the floor level through the unit. The chlorine scrubber maintains negative pressure in the storage room during the entire chlorine release event and exchanges chlorine in the atmosphere with fresh air.
- The chlorine scrubbing process neutralizes chlorine and vents the inert gases into the atmosphere.
- The size of the equipment is dependent on the size of the chlorine containers used at the facility. The equipment size is based on the release of the entire contents of one container within 30 minutes and on Uniform Fire Code Guidelines.

Description of Process

Two chlorine scrubbing processes are available: one uses a caustic solution and the other uses solid media.

Caustic Solution Type

- A caustic soda is used to neutralize the chlorine:

$$Cl_2 + 2\ NaOH \rightarrow NaOCl + NaCl + H_2O$$

- This process produces sodium hypochlorite (NaOCl) and salt (NaCl). It requires 1.13 pounds of NaOH to react with 1 pound Cl and produces 1.05 pounds NaOCl.
- This process requires the removal of hypochlorite and replacement with fresh caustic after use.

Solid Media Type

- Uses a resin to absorb chlorine.
- Chlorine remains on the media and air is discharged to the atmosphere.
- The media must be replaced after use.
- Solid media is somewhat safer than the caustic solution system, since the storage of caustic solution is not necessary.

Key Points for Unit 2 – Chlorine Handling and Storage.

- Chlorine has health and environmental hazards.
- Material Safety Data Sheets (MSDS) are available for every chemical.
- The MSDS contains detailed information about chemical characteristics, hazards, and information relative to health, safety and the environment.
- Exhaust fans are required in Chlorine storage and feed rooms. Fans should be located near the floor, since Chorine is heavier than air.
- First aid, Chlorine leak response, emergency measures, and risk management plans should be reviewed with all employees.
- Rooms for Chlorine storage and feed should be separate from other operating areas.
- Chlorine scrubbers are specialized equipment to neutralize liquid and gas Chlorine spills.

Exercise for Unit 2 – Chorine Handling and Storage.

Figure 3. Explain the meaning of a MSDS.

_____
_____
_____
_____
_____

2. List two undesirable health effects from Chlorine exposure.

_____
_____
_____
_____

3. List two ways of detecting Chlorine leaks.

_____
_____
_____
_____

4. What are three types of storage containers for Chlorine?

_____
_____
_____

5. List at least three characteristics of an appropriate storage facility for Chlorine.

_____
_____
_____
_____

6. What are the two basic types of Chorine Scrubbers?

_____
_____
_____

Unit 3 – Application of Gas Chlorine

Learning Objectives

- List and explain the components of each of the following pieces of equipment:
    - Gas feed system
    - Liquid vaporizers
    - Monitoring equipment
    - Chemical feed control
- Perform chlorine feed computations.

Chlorination Mechanics and Terminology

An **enteric virus** in one that lives in the intestines.

Chlorine demand is the amount of chlorine required to react with all the organic and inorganic material. In practice, the chlorine demand is the difference between the amount of chlorine added and the amount remaining after a given contact time.

Some reactive compounds have disinfecting properties and others do not.

Chlorine residual is the total of all compounds with disinfecting properties and any remaining free chlorine.

Chlorine Residual (mg/l) = **Combined Chlorine Forms** (mg/l) + **Free Chlorine** (mg/l)

The residual should contain free chlorine since it has the highest disinfecting ability.

The presence of measurable chlorine residual indicates that all chemical reactions have been satisfied and that sufficient chlorine is present to kill microorganisms.

Chlorine dose is the amount of chlorine needed to satisfy the chlorine demand plus the amount of chlorine residual needed for disinfection.

Chlorine Dose (mg/l) = **Chlorine Demand** (mg/l) + **Chlorine Residual** (mg/l)

Breakpoint chlorination is the addition of chlorine until all chlorine demand has been satisfied. It is used to determine how much chlorine is required for disinfection.

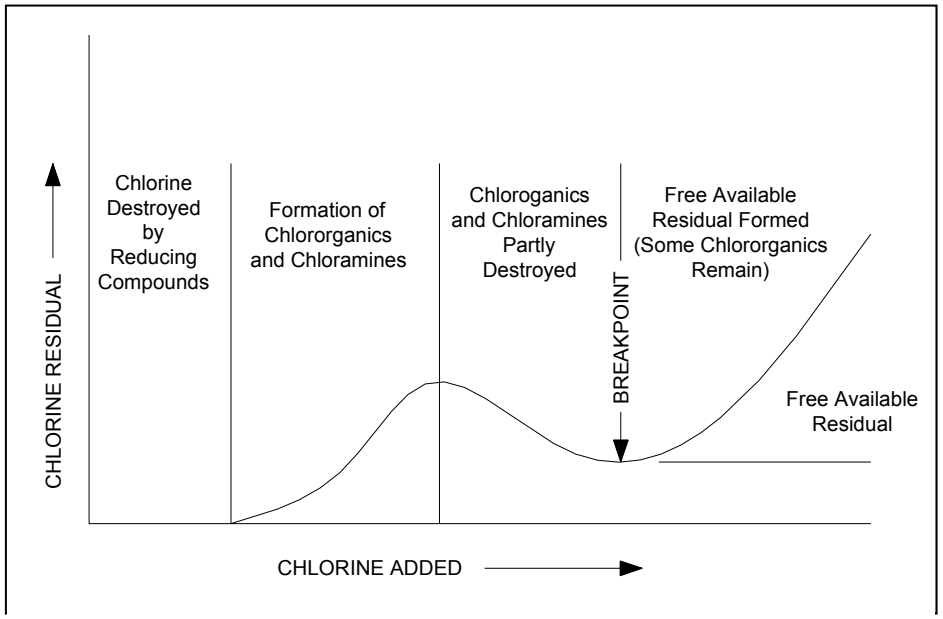


Figure 3.1 Breakpoint Chlorination Curve

Regulatory Requirements

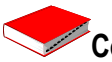
Continuous disinfection is required of all public water systems.

For surface water supplies:

- The disinfection process must achieve 99.9% (3 log) inactivation of Giardia cysts and 99.99% (4 log) inactivation of enteric viruses.

Log inactivation is defined as follows:

- **1 log inactivation = 90 %**
- **2 log inactivation = 99%**
- **3 log inactivation = 99.9%**
- **4 log inactivation = 99.99%**
    - Chlorination equipment must be capable of maintaining a chlorine residual which achieves a minimum of 1 log Giardia cyst inactivation following filtration.



Contact time can be thought of as a residual disinfectant concentration **C** in mg/L which is multiplied by a time **T** in minutes. The time **T** is measured between the point of application of the disinfectant and the measurement of the residual.

- For groundwater supplies not under the influence of surface water intrusion:
  - Minimum of 20 minutes of contact time must be provided
- For chlorine residual requirements:
  - Minimum free, combined, or chlorine dioxide residual entering the distribution system must exceed 0.2 mg/l, and be maintained 0.02 mg/l at the most distant points in the system
  - Must be determined by Contact Time (CT) factors and measurement methods established by EPA. Refer to EPA's "Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources," which establishes procedures and guidance for complying with the EPA Surface Water Treatment Rule (SWTR).
- The exact mechanism of chlorine disinfection is not fully known.
  - One theory is that chlorine directly destroys the bacterial cell.
  - Another theory is that chlorine inactivates the enzymes which enable the cells to use food, thus starving the organisms.
- Chlorine added to water containing organic and inorganic chemicals reacts with these materials to form chlorine compounds.

Example:

Calculate the CT product, or Contact Time, for a ground water supply not under the influence of surface water intrusion. Assume that the concentration **C** is 0.25 mg/L and that the time **T** is 25 minutes.

Process Calculations

There are two basic chlorination process calculations: chlorine dosage and chlorine demand.

Chlorine Dosage Calculation

- To perform the calculation, you will need to know the amount of chlorine being added and the amount of water being treated.

$$\text{Chlorine Dosage (mg/l)} = \frac{\text{Chlorine Feed (lb/day)}}{\text{[Flow (mgd) x 8.34 (lb/gal)]}}$$

Chlorine Demand Calculation

- A sufficient amount of chlorine must be added so that the chlorine demand is met and the desired chlorine residual is provided.

$$\text{Chlorine Demand (mg/l)} = \text{Chlorine Dose (mg/l)} - \text{Chlorine Residual (mg/l)}$$

Sample Calculations

Example 1.

The chlorinator at a water treatment plant operating at a flowrate of 1.0 million gallons per day is set to feed 20 pounds in a 24 hour period. The chlorine residual in the finished water leaving the plant after a 20 minute contact period is 0.5 mg/l. Calculate the chlorine demand of the water.

Known: Flow, (mgd) = 1.0 MGD
Chlorinator setting = 20 pounds/day
Finished water chlorine residual = 0.5 mg/l

Find: Chlorine Dosage (mg/l) and Chlorine Demand (mg/l)

Step 1: Calculate chlorine dosage in mg/l

$$\text{Chlorine Dose (mg/l)} = \frac{\text{Chlorine Feed (lb/day)}}{[\text{Flow (mgd)} \times 8.34\ \text{(lb/gal)}]}$$

$$\text{Chlorine Dose (mg/l)} = \frac{[20\ \text{lb Cl/day}]}{[1.0\ \text{(mgd)} \times 8.34\ \text{(lb/gal)}]}$$

$$= \frac{20\ \text{lb Cl/day}}{8.34\ \text{(million lb water /day)}}$$

= 2.4 lb Cl/million lb water

= 2.4 Parts Per Million (ppm)

= 2.4 mg/l

Step 2: Calculate Chlorine Demand in mg/l

Chlorine Demand (mg/l) = Chlorine Dose (mg/l) - Chlorine Residual (mg/l)

Chlorine Demand (mg/l) = 2.4 (mg/l) – 0.5 (mg/l)

= 1.9 mg/l

Example 2.

A water system is known to have a Chlorine Demand of 1.8 mg/l. Past experience indicates that a Chlorine Residual of 0.6 mg/l is a good setting for this system. Calculate the required Chlorine Dose in mg/l.

Solution: Use the formula Chlorine Dose (mg/l) = Chlorine Demand (mg/l) + Chlorine Residual (mg/l)

Chlorine Dose (mg/l) = 1.8 mg/l + 0.6 mg/l

Chlorine Dose (mg/l) = 2.4 mg/l

Exercise

1. What is produced when chlorine reacts with organic matter in the water?

2. Explain what breakpoint chlorination is.

3. A water treatment plant operating at 750,000 gallons per day adds 3.0 mg/l of chlorine for disinfection. After a 30 minute contact period, the chlorine residual is measured at 1.35 mg/l. Compute the chlorine demand of this water.

4. What is the definition of chlorine residual?

Gas Feed System

A typical vacuum controlled gas chlorine feed system using 150 pound chlorine cylinders as the supply source is shown in the figure below.

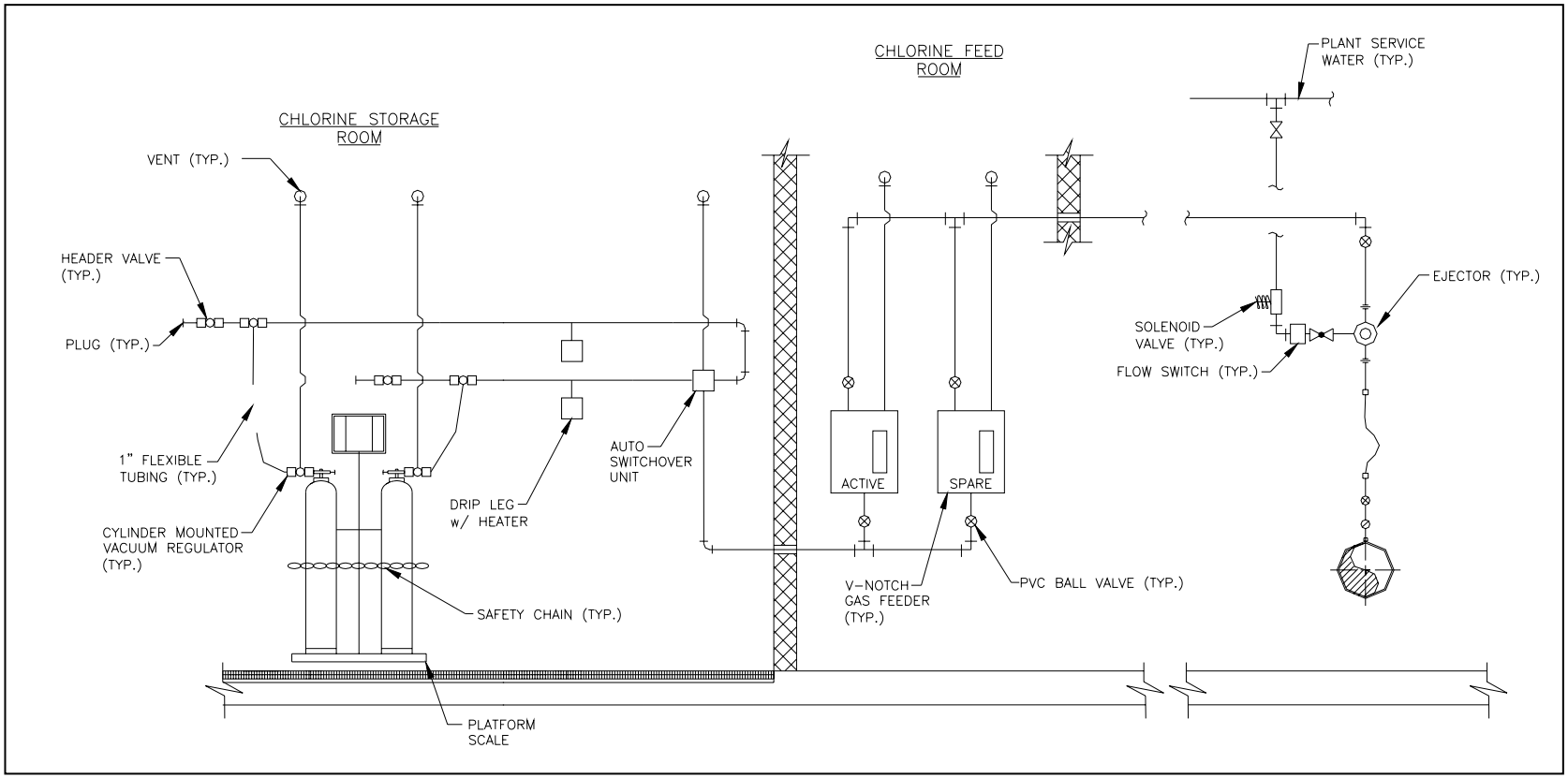


Fig 3.1 Typical Small Gas Chlorination System Schematic

Major Components

- The gas supply provides a source of chlorine gas from the container. In this figure, that is 150 pound cylinders.
- The cylinder scale measures the amount of chlorine in the container.
- The vacuum regulator/check unit maintains a constant vacuum on the chlorinator. It should be located as close as possible to the chlorine supply container to minimize the length of pressurized chlorine piping. In this schematic, it is mounted on the cylinder.
- The header valve permits the changing of an empty cylinder while maintaining continuous chlorine feed.
- The automatic switchover unit automatically switches to the standby chlorine container when the on-line container is empty.
- The chlorinator, or gas feeder, controls the chlorine feed rate by regulating the flow of chlorine gas and indicates the chlorine feed rate with the rotameter position. It also includes provision for manual and automatic feed rate adjustment.
- The ejector water supply provides the source of water for the chlorine feed solution.
- The ejector, or injector, mixes the chlorine gas into the water supply. It also creates the required vacuum to operate the system.

Chlorine Evaporator

Major Components

- The maximum sustained withdrawal rate at which chlorine can be taken from a 100 or 150 pound cylinder is 1 pound/day/degree F. The corresponding rate for a ton container is 8 pounds/day/degree F.
  - 100 and 150 pound cylinders are limited to approximately 1.5 pound per hour.
  - Ton containers are limited to approximately 15 pounds per hour.
- If required rates exceed these values, several containers may be connected together through a manifold so that the withdrawal rate from an individual container remains within this limit.
  - To assure equal withdrawal from all containers, all containers connected by a manifold should be at the same temperature.
- If more than several ton containers are required to provide the necessary gas feed, an evaporator can be used with liquid withdrawal.
  - Liquid chlorine is delivered from the bottom valve of a ton container.
  - The maximum liquid withdrawal rate is 400 pounds per hour (9600 pounds/day).
- Chlorine evaporators are used to convert liquid chlorine to gas.
  - This works similar to a water heater. Liquid chlorine is introduced into the bottom of a heated pressure cylinder where the liquid "vaporizes" to chlorine gas. Gas is removed from the top of the unit.

Monitoring Equipment

- The gas detector detects chlorine leaks at chlorine levels of 1 mg/l or less and should be provided in both the storage and feed rooms.
- The scale is used to monitor chlorine usage and indicates when the container is empty.
- The residual monitor is used to measure the chlorine residual in the treated water flow. It provides a control signal for compound loop control systems.

Chemical Feed Control

Manual

- The operator manually adjusts the chlorine feed rate at the chlorinator.

Start-Stop

- The chlorinator is activated in response to a flow signal. Usually the feed rate is adjusted manually. Control is based on time, pump or other mechanical equipment operation.
- Typical for chlorination of well supplies where a well pump does not operate continuously.

Flow Proportional

- The chlorinator feed rate is automatically adjusted proportional to a water flow signal. This maintains a constant chlorine feed rate proportional to the metered flow.

Chlorine Residual

- The chlorinator feed rate is automatically adjusted proportional to a measured chlorine residual signal. By varying the chlorine feed rate, a constant chlorine residual is maintained.

Compound Loop

- This combines flow proportional and chlorine residual control. The chlorinator is automatically adjusted based on the flow signal and the feed rate automatically trimmed in accordance with the measured chlorine residual

System Operation

Normal Operation

Normal operation of the chlorine feed system requires regular observation of the facilities and equipment and a regular preventative maintenance program. Exact operating procedures will depend on the equipment installed, but the general procedure is as follows.

Container Storage Area

- Daily
  - Visually inspect the storage area.
  - Verify operation of the ventilation equipment.
  - Read scales, charts or meters at the same time each day to determine chlorine use.
  - Replace empty containers as required.
  - Check for leaks at least once per shift.
- Weekly
  - Clean the building or storage area.
  - Check the operation of the chlorine leak detection equipment.
- Monthly
  - Exercise all valves.
  - Inspect flexible connectors and replace as necessary.
  - Inspect hoisting equipment if provided.
  - Examine ventilation equipment, clean and adjust if necessary.
  - Perform scheduled preventative maintenance.

Chlorinators and Injectors

- Daily
  - Check injector water supply pressure.
  - Check chlorinator vacuum.
  - Read and record chlorine feed rate.
  - Examine and record mode of control.
  - Measure chlorine residual.
  - Inspect the system auxiliary components.
  - Check and verify chlorinator controls and recorders.
- Weekly
  - Operate the chlorinator on manual through full range and verify proper operation.
  - Clean the residual analyzers as required.
- Monthly
  - Exercise all valves.
  - Inspect heaters and ventilation equipment.
  - Check vent line(s).
  - Inspect for vacuum leaks.
  - Clean rotameter sigh glass.
  - Inspect all hoses and drain lines.
  - Perform routine maintenance: chlorinator and chlorine analyzer maintenance in accordance with manufacturer's recommendations and inspect the control system and safety equipment (including self-contained breathing equipment and container repair kits).

Evaporators

- Daily
  - Check water bath level and temperature.
  - Check chlorine inlet pressure.
  - Measure chlorine outlet temperature.
  - Verify proper operation of the pressure reducing valve.
  - Look for leaks and check as discovered.

Abnormal Operation

The following are some abnormal operating conditions which may be encountered.

- Chlorine leak in the chlorinator
  - Shut off gas flow.
  - Leave ejector on line and allow chlorinator to operate to empty chlorine gas from system.
  - Repair leak or replace chlorinator.
- Low gas pressure
  - Check chlorine supply. Replace empty chlorine containers and switch to standby units.
  - Verify proper evaporator operation.
- Low vacuum
  - Inspect the injector water supply system and verify proper operation of all components.
  - Inspect solution discharge line downstream of ejector. Also check for plugged diffuser, closed valve, broken pipe, etc.
- Low chlorine residual
  - Determine actual chlorine residual in lab. Compare with residual analyzer reading. Recalibrate the analyzer.
  - If the analyzer is properly calibrated, check the sample pump operation, control system if on automatic control (operate in manual control mode if necessary) and water chlorine demand (add additional chlorinators on line if demand is higher than can be provided by a single unit).

Key points for Unit 3 – Chlorine Feed Equipment, Operation and Maintenance.

- All public water systems are required to use a continuous disinfection process.
- Chlorine is usually used to disinfect drinking water.
- A Breakpoint Chlorination Curve can be used to determine how much Chlorine must be added to result in a Chlorine Residual.
- Chlorine Dose (mg/l) = Chlorine Demand (mg/l) + Chlorine Residual (mg/l).
- Chlororganics and chloramines are produced when chlorine reacts with organic matter in water.
- Chlorine can be stored in 100 to 150 pound cylinders or ton containers.
- Chlorine evaporators are used to convert liquid chlorine into gas.
- Chlorine storage areas should be inspected at least once each day.
- A chemical feed control is used to adjust the chlorine feed rate at the chlorinator.

Exercise for Unit 3.

1. What is the percentage of inactivation for a 2 log and a 4 log process?
   _____
   _____

2. Explain the meaning of chlorine demand.
   _____
   _____
   _____

3. Chlorine can be provided in 150 pound _____.

4. A 150 pound cylinder can provide chlorine at a maximum rate of about _____ pounds per hour.

5. Gas detectors can find chlorine leaks of _____ mg/l or less and should be used in storage and feed rooms.

6. A start-stop operation of a chlorinator is typical for chlorination of _____ _____ where a _____ pump does not operate continuously.

7. Low chlorine residual would be considered to be an example of _____ operation.

8. A chlorine residual of _____ mg/l must be maintained at the most distant points of a distribution system.

References

Water Quality and Treatment, Fifth Edition, 1999, McGraw-Hill, Section 14, page 4.

Unit 4 – Formation of Alternate Chlorine Compounds and Dechlorination

Learning Objectives

- List two alternate chlorine chemical compounds.
- For chloramines:
    - Explain their purpose.
    - Identify the reactants.
    - Explain the three types.
    - List and explain the monitoring equipment.
    - List and explain the chemical feed control equipment.
    - Perform chloramine feed computations.
- For chlorine dioxide:
    - Explain their purpose.
    - Identify the reactants.
    - Explain the basics of its chemistry.
    - Explain the basics of sodium chlorite handling and safety.
    - List and explain the chemical feed control equipment.
    - Perform chlorine dioxide feed computations.
    - List Disinfection monitoring requirements.
- For dechlorination:
    - Explain the basic principles.
    - Identify the reactants.
    - Explain the basics of its chemistry.
    - Explain the safety procedures and list the emergency equipment.
    - List and explain the chemical feed equipment.
    - Explain chemical feed control.

Chloramines

Types

- Hypochlorous acid will react with ammonia to form a series of compounds referred to as "chloramines" dependent on water chemistry (temperature, pH, and ammonia concentration) and selected ammonia chemical used.
- Typical chloramines are: monochloramine, dichloramine, and nitrogen trichloride (trichloramine).
- At conditions usually noted in water treatment, monochloramine is the dominant form.

Purpose

- Chlorine added to water will react with ammonia compounds to form chloramines.
- Chloramines provide chlorine residual. They are slower acting than free chlorine but capable of disinfection.
- The addition of ammonia or ammonia compounds with the chlorine will form chloramines. The reaction of the ammonia with the hypochlorous acid is formed by chlorination.
- The utilization of chloramines minimizes the formation of disinfectant byproducts such as:
  - Trihalomethanes (THM's)
  - Haloacetic acid (HAA's)
  - Other disinfection byproducts (DBP's)
- Chloramines may eliminate taste and odor problems associated with free chlorine disinfection.

Reactants

Reactants include:

Anhydrous Ammonia

- This is ammonia gas. Its chemical formula is NH_3.
- The chemical feed facilities and equipment are similar to those used to feed chlorine gas.

Aqua Ammonia

- This is ammonium hydroxide. Its chemical formula is NH_4OH.

- Ammonium hydroxide is a water white alkaline liquid.
- The chemical feed facilities and equipment are similar to other liquid chemical feed systems.

Chemical Feed Equipment

- The chemical feed and monitoring equipment is similar to other plant equipment used to feed and monitor gas or liquid chemicals.

Chemical Feed Control

- Although the normal chemical feed ratio of 1 part ammonia to 3 to 5 parts chlorine can be used to control the ammonia dosage, such use can lead to incorrect conclusions regarding the finished water quality.
- For example, in systems that feed the chlorine prior to the ammonia, the chlorine demand of the water will reduce the amount of chlorine available to form chloramines. In this type application, the applied ammonia/chlorine ratio will be greater than the actual ratio. Therefore, the combined chlorine residual (chloramines) should be monitored.
- When measuring the combined chlorine residual in the field, free chlorine should be analyzed. No free chlorine should be present.

Chlorine Dioxide

Purpose

- Used to a limited extent in water treatment for control of tastes and odors.
- Does not form carcinogenic compounds that may occur with other chlorine chemicals.
- Not affected by ammonia, and is a very effective disinfectant at higher pH levels.

Reactants

- Reactants are generated on site from the reaction of chlorine with sodium chlorite.

Sodium Chlorite Handling and Safety

Special precautions must be taken when handling sodium chlorite.

- It is usually supplied as a salt which is very combustible in presence of organic compounds and should be stored in its original shipping container away from all organic material.

- Spills must be neutralized with anhydrous sodium sulfite.
- Clothing which contacts sodium chlorite should be removed immediately and soaked in water to remove all traces of the chemical or they should be burned.
- Since it is a corrosive chemical, appropriate protective clothing should be worn and an emergency shower and eye wash station should be provided.

Chemical Feed Equipment

- Chlorine dioxide is generated on-site by combining chlorine solution with sodium chlorite solution.
- Chemical feed control and monitoring requirements are the same as the other forms of disinfection already discussed.

Dechlorination

Basic Principles

Dechlorination is the removal of all or a portion of the residual chlorine by any chemical or physical treatment.

- Required chlorine residuals, both free and combined, may be high enough that the water will be esthetically or otherwise objectionable. The discharge of chlorinated water in the plant waste stream may have regulatory concerns, particularly about the toxic effects of chlorine, especially in the form of chloramines, on fish and other aquatic life.
- Dechlorination at a water treatment facility is accomplished by the addition of sulfur dioxide or its derivatives. This results in feasible, rapid and precise dechlorination.

Reactants and Chemistry

The reactants are chlorine and sulfur compounds.

The following are typical sulfur compounds:

- Sulfur dioxide (SO_2)
- Sodium bisulfite ($NaHSO_3$)
- Sodium sulfite (Na_2SO_3)
- Sodium thiosulfate ($Na_2S_2O_3$)

Chemical Feed Equipment, Control and Safety

- The feed systems, including controls, are similar to other chemical feed systems in the facility.

Key points for Unit 4.

- Chloramines are formed when chlorine is added to water with ammonia compounds present.
- Chloramines can provide part of the chlorine residual and may eliminate some taste and odor problems.
- Monochloramine is usually the most prevalent chloramines, but dichloramine and trichloramine may also be present.
- Chlorine dioxide can be used to control taste and odor problems.
- Chlorine dioxide is not affected by ammonia and does not form carcinogenic compounds.
- Chlorine and sodium chlorite are used to generate chlorine dioxide on site. Special precautions must be taken when handling these chemicals.
- Dechlorination may be needed if too much residual chlorine is present in the effluent. Sulfur dioxide is often used to dechlorinate.

Exercise

1. List two alternate chlorine chemical compounds and explain the purpose of each.

2. List three types of chloramines.

3. What are two advantages of using chlorine dioxide?

4. List the dechlorination reactants.

Appendix

A Typical Chlorine MSDS Sheet

The MSDS format adheres to the standards and regulatory requirements of the United States and may not meet regulatory requirements in other countries.

DuPont Page 1

Material Safety Data Sheet

Chlorine

7410CR Revised 6-APR-1998

CHEMICAL PRODUCT/COMPANY IDENTIFICATION

Material Identification

Corporate MSDS Number: DU000003

CAS Number: 7782-50-5

Formula: Cl2

CAS Name: CHLORINE

Tradenames and Synonyms

CL 2

Company Identification

MANUFACTURER/DISTRIBUTOR

DuPont Chemical Solutions Enterprise

1007 Market Street

Wilmington, DE 19898

PHONE NUMBERS

Product Information: 1-800-441-7515 (outside the U.S. 302-774-1000)

Transport Emergency: CHEMTREC 1-800-424-9300 (outside U.S. 703-527-3887)

Medical Emergency: 1-800-441-3637 (outside the U.S. 302-774-1000)

COMPOSITION/INFORMATION ON INGREDIENTS

Components

Material CAS Number %

***CHLORINE 7782-50-5 100**

*** Disclosure as a toxic chemical is required under Section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 and 40 CFR part 372.**

HAZARDS IDENTIFICATION

 # Potential Health Effects

Liquid chlorine is corrosive to the skin and eyes. Liquid chlorine may also cause frostbite burns. Eye damage may be permanent and may include blindness. Chlorine gas is extremely irritating to the nose, throat, and lungs. Gross overexposure may cause death.

7410CR DuPont Page 2
Material Safety Data Sheet

(HAZARDS IDENTIFICATION - Continued)

HUMAN HEALTH EFFECTS:
Skin contact may cause skin irritation with discomfort or rash. Eye contact may cause eye irritation with discomfort, tearing, or blurring of vision. Eye damage may be permanent and may include blindness. Liquid chlorine poses cryogenic hazards; skin or eye contact with liquid may cause frostbite burns. Inhalation may cause irritation of upper respiratory passages; nonspecific discomfort such as nausea, headache, or weakness; or corrosion of teeth. Higher exposures may cause skin burns or ulceration; eye corrosion with corneal or conjunctival ulceration; temporary lung irritation with cough, discomfort, difficulty breathing, or shortness of breath; followed in hours by severe shortness of breath, requiring prompt medical attention; asthma-like reactions with shortness of breath, wheezing, or cough, possibly occurring on subsequent reexposure to concentrations below established exposure limits; or temporary alteration of the heart's electrical activity with irregular pulse, palpitations, or inadequate circulation. Death may occur from gross overexposure.
Epidemiologic studies demonstrate no significant risk of human cancer from exposure to this compound.
Individuals with preexisting diseases of the eyes, skin, lungs, central nervous system, or cardiovascular system may have increased susceptibility to the toxicity of excessive exposures.
Carcinogenicity Information
None of the components present in this material at concentrations equal to or greater than 0.1% are listed by IARC, NTP, OSHA or ACGIH as a carcinogen.

FIRST AID MEASURES

First Aid
Contact with moisture in air or tissue may produce hydrochlorous and hydrochloric acids.
INHALATION
If inhaled, remove patient to an uncontaminated atmosphere. Call a physician. Check for breathing and pulse. If not breathing, give artificial respiration. If breathing is difficult, give oxygen as soon as possible (6 liters per minute). Check for other injuries. Keep the patient warm and at rest.

7410CR DuPont Page 3
Material Safety Data Sheet

(FIRST AID MEASURES - Continued)

SKIN CONTACT
Immediately, within seconds of contact or suspected contact, shower with large quantities of water and completely remove all personal protective equipment, clothing, and shoes while in the shower. Flush the skin thoroughly with water for at least 5 minutes. Call for medical help while flushing the skin. Keep the affected area cool. Avoid freezing affected area. Wash clothing before reuse.
EYE CONTACT
Immediately flush eyes with large quantities of water while holding the eyelids apart. Continue flushing for 5 minutes. Do not try to neutralize the acid. Call a physician immediately. Transfer promptly to a medical facility. Apply cool packs on the eyes while transporting patient. Avoid freezing affected area.
INGESTION
Do not induce vomiting. Give large quantities of water. Call a physician immediately and transfer promptly to a medical facility. Never give anything by mouth to an unconscious person.

FIRE FIGHTING MEASURES

Flammable Properties
Will not burn in air.
Strong Oxidizer.
Fire and Explosion Hazards:
Contact with combustible materials may cause fire.
Dangerous when heated; emits highly toxic fumes. Follow appropriate National Fire Protection Association (NFPA) codes.
Extinguishing Media
As appropriate for combustibles in area.
Fire Fighting Instructions
Wear self-contained breathing apparatus. Wear full protective equipment. Shut off source of fuel, if possible and without risk. Keep personnel removed and upwind of fire. Do not apply water directly to leak. Cool tank/container with water spray. Run-off from fire control may cause pollution.

7410CR DuPont Page 4
Material Safety Data Sheet

ACCIDENTAL RELEASE MEASURES

Safeguards (Personnel)
NOTE: Review FIRE FIGHTING MEASURES and HANDLING (PERSONNEL) sections before proceeding with clean-up. Use appropriate PERSONAL PROTECTIVE EQUIPMENT during clean-up. Evacuate personnel, thoroughly ventilate area, use self-contained breathing apparatus. Keep upwind of leak - evacuate until gas has dispersed.
Initial Containment
Dissipate vapor with water spray. Prevent material from entering sewers, waterways, or low areas.
Accidental Release Measures
Specially trained personnel should stop the leak if possible, dike the spill, and neutralize any water that may be used with caustic. Comply with Federal, State, and local regulations on reporting releases. The CERCLA Reportable Quantity for a spill, leak, or release is 10 lbs. DuPont Emergency Exposure Limits (EEL) are established to facilitate site or plant emergency evacuation, and to specify airborne concentrations of brief durations which should not result in permanent adverse health effects or interfere with escape. EEL's are expressed as airborne concentration multiplied by time (CxT) for up to a maximum of 60 minutes and as a ceiling airborne concentration. These limits are used in conjunction with engineering controls/monitoring and as an aid in planning for episodic releases and spills. For more information on the applicability of EEL's, contact DuPont.
The DuPont Emergency Exposure Limit (EEL) for chlorine is 10 ppm for 1 minute, 7 ppm for 1-5 minutes, 5 ppm for 5 to 60 minutes with a not-to-exceed ceiling of 10 ppm.

HANDLING AND STORAGE

Handling (Personnel)
Do not breathe gas. Do not get in eyes, on skin, or on clothing. Wash thoroughly after handling.
Storage
Store in a cool place away from heat, sparks, and flame. Keep containers tightly closed.

7410CR DuPont Page 5
Material Safety Data Sheet

EXPOSURE CONTROLS/PERSONAL PROTECTION

Engineering Controls
Use sufficient ventilation to keep employee exposure below recommended exposure limits.
Personal Protective Equipment
CHLORINE GAS:
Have available and wear as appropriate for exposure conditions: chemical splash goggles; safety glasses, (side shields preferred); full-length face shield; gloves, pants, jacket, apron, and footwear or acid suit made of butyl, Chemfab, Chloropel, Neoprene, nitrile, "Saranex" coated Tyvek, urethane, or Viton and NIOSH approved respiratory protection.
LIQUID CHLORINE:
Under the cryogenic cooling conditions of liquid chlorine, the chemical suits listed above are NOT sufficiently protective. Wear positive pressure, full face-piece self-contained breathing apparatus approved by NIOSH and totally encapsulating chemical protective suit such as Tychem 10,000, with specialized thermal insulation inside the suit, gloves and boots to prevent frostbite burns.
Exposure Guidelines
Exposure Limits
Chlorine
PEL (OSHA): 1 ppm, 3 mg/m3, Ceiling
TLV (ACGIH): 0.5 ppm, 1.5 mg/m3, 8 Hr. TWA, A4
STEL 1 ppm, 2.9 mg/m3, A4
AEL * (DuPont): 0.5 ppm, 8 & 12 Hr. TWA
STEL 1 ppm, 15 minute TWA
* AEL is DuPont's Acceptable Exposure Limit. Where governmentally imposed occupational exposure limits which are lower than the AEL are in effect, such limits shall take precedence.

PHYSICAL AND CHEMICAL PROPERTIES

Physical Data
Boiling Point: -34.6 C (-30.3 F) @ 760 mm Hg
Vapor Pressure: 4,800 mm/Hg @ 20 C (68 F)
Vapor Density: 2.5 (Air = 1)
Melting Point: -101 C (-150 F)
Evaporation Rate: (Butyl Acetate = 1)
Greater than 1
Solubility in Water: 0.57 WT% @ 30 C (86 F)

7410CR DuPont Page 6
Material Safety Data Sheet

(PHYSICAL AND CHEMICAL PROPERTIES - Continued)

Odor: Acrid
Odor Threshold: 0.2-0.4 ppm
Form: Gas at STP/Liquid
Color: Gas: Greenish yellow; Liquid: Amber
Specific Gravity: 1.56 @ -35C (-31F) Liquid

STABILITY AND REACTIVITY

Chemical Stability
Dry chlorine is stable in steel containers at room temperature.
Decomposition
Hydrochloric and hypochlorous acids are formed with water or steam.
Polymerization
Polymerization will not occur.
Other Hazards
Incompatibility:
Incompatible with alkalies, reducing agents and organic materials. Reacts explosively or forms explosive compounds with acetylene, turpentine, fuel gas, hydrogen, ether, ammonia gas, and finely divided metals. Reacts vigorously with titanium, zinc, and tin. Reaction with aluminum may result in generation of flammable hydrogen gas. May also form explosive mixtures with combustible organic vapors and cause runaway reactions with certain polymers if contacted in confined areas. Combines with carbon monoxide and sulfur dioxide to form toxic and corrosive phosgene and sulfuryl chloride.

TOXICOLOGICAL INFORMATION

Animal Data
Inhalation 1-hour LC50: 293 ppm in rats
The compound is corrosive to eyes and skin. Toxic effects described in animals from short exposures by inhalation include upper and lower respiratory, kidney, liver, and lung effects. Long-term inhalation exposures caused eye irritation and nonspecific effects such as weight loss. By ingestion, the effects included irritation and corrosion of mucosal surfaces; kidney, liver, and lung effects; and nonspecific effects such as decreased weight gain.

7410CR DuPont Page 7
Material Safety Data Sheet

(TOXICOLOGICAL INFORMATION - Continued)

No significant adverse effects were observed from long-term dietary administration.
Animal testing indicates that the compound does not have carcinogenic or reproductive effects. Tests for embryotoxic activity in animal species have been inconclusive, with positive results in some studies and negative results in others. Tests in bacterial cell cultures demonstrate mutagenic activity.

ECOLOGICAL INFORMATION

Ecotoxicological Information
Aquatic Toxicity
96-hour LC50, rainbow trout: 0.132 mg/L

DISPOSAL CONSIDERATIONS

Waste Disposal
Treatment, storage, transportation and disposal must be in accordance with applicable Federal, State, and local regulations.

TRANSPORTATION INFORMATION

Shipping Information
DOT/IMO
Proper Shipping Name: CHLORINE
Hazard Class: 2.3
UN No.: 1017
DOT/IMO Label: POISON GAS, CORROSIVE
Special Information: POISON-INHALATION HAZARD, ZONE B; MARINE POLLUTANT
Reportable Quantity: 10 lb
Shipping Containers
Tank Cars.

7410CR DuPont Page 8
Material Safety Data Sheet

REGULATORY INFORMATION

U.S. Federal Regulations
TSCA Inventory Status: Reported/Included.
TITLE III HAZARD CLASSIFICATIONS SECTIONS 311, 312
Acute: Yes
Chronic: Yes
Fire: No
Reactivity: Yes
Pressure: Yes
LISTS:
SARA Extremely Hazardous Substance -Yes
CERCLA Hazardous Material -Yes
SARA Toxic Chemicals -Yes
CHLORINE is specifically listed in Appendix A of 29 CFR 1910.119. Use of chlorine may require compliance with 29 CFR 1910.119, Process Safety Management of Highly Hazardous Chemicals.

OTHER INFORMATION

NFPA, NPCA-HMIS
NFPA Rating
Health: 3
Flammability: 0
Reactivity: 0
Oxidizer.

NPCA-HMIS Rating
Health: 3
Flammability: 0
Reactivity: 1
Personal Protection rating to be supplied by user depending on use conditions.
Additional Information
NSF LIMITS:
NSF Maximum Drinking Water Use Concentration: 30 mg/L as chlorine.

7410CR DuPont Page 9
Material Safety Data Sheet (Continued)

The data in this Material Safety Data Sheet relates only to the specific material designated herein and does not relate to use in combination with any other material or in any process.
Responsible for MSDS: MSDS Coordinator
> : DuPont Chemical Solutions Enterprise
Address: Wilmington, DE 19898
Telephone: (800) 441-7515
 # Indicates updated section.
This information is based upon technical information believed to be reliable. It is subject to revision as additional knowledge and experience is gained.
End of MSDS