

# Drinking Water Operator Certification Training



## Module #24 Gas Chlorination Revised February 2022

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**Topical Outline**

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- I. General Description
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- II. Properties of Chlorine
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- III. Chemistry of Chlorine
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**Unit 4 – Math Principles and Process Control Calculations**

- I. Describe principles and rules for solving equations
  
- II. Perform calculations for the following types of situations:
  - A. Dosage/Feed Rate
  - B. Chlorine Demand or Dose
  - C. CT

**APPENDIX – Sample SDS Sheet**

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# Unit 1 – General Chemistry and Characteristics

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## 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.

- 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.

## 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.
- Chlorine gas can be compressed to a point where it liquifies. Cylinders contain both liquid chlorine (about 85%) and gas chlorine (about 15%).
- In its gaseous form, it is 2.5 times heavier than 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<sup>-</sup>
- The hypochlorite ion (OCl<sup>-</sup>) 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.

Later, we'll discuss how these forms of chlorine are formed and at what pH levels.

### 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 but it is **not impacted by volume**. For example, 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:

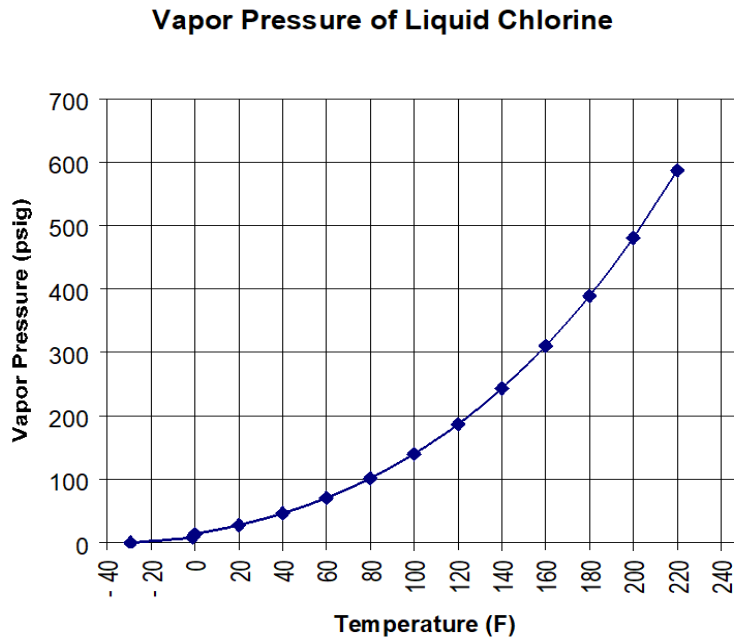


Figure 1.1 Vapor Pressure of Liquid Chlorine

### Gaseous Chlorine

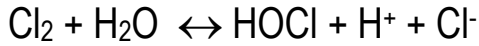
- Gaseous chlorine is a greenish, yellow toxic gas that is about 2.5 times **heavier** than air.
- Common properties of gaseous chlorine are listed in the following table:

Table 1.2 Properties of Gaseous Chlorine

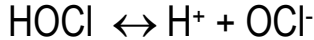
Density (at 32°F & 1 atm)	0.2006 lbs/ cu ft
Specific Gravity (at 32°F & 1 atm)	2.482 (air = 1)
Liquefying Point (at 1 atm)	-30.1 °F
Viscosity (at 68°F)	0.01325 centipoise
Solubility in Water	60.84 lbs/1000 gal

Reactions in Aqueous Solution

- Chlorine added to chemically pure water forms a mixture of hypochlorous (HOCl) and hydrochloric (HCl) acids. At ordinary temperatures, the reaction is essentially complete within a few seconds.



- Hypochlorous acid dissociates into hydrogen and hypochlorite ions almost instantaneously:



- The degree of dissociation is dependent on both pH and temperature.
- The two curves below represent the distribution of hypochlorous acid (HOCl) and hypochlorite ion OCl<sup>-</sup> in water at 20 ° C and 0° C.
- The normal pH of water supplies is within range where chlorine may exist as both (HOCl) and (OCl<sup>-</sup>). This is indicated in the following figure.

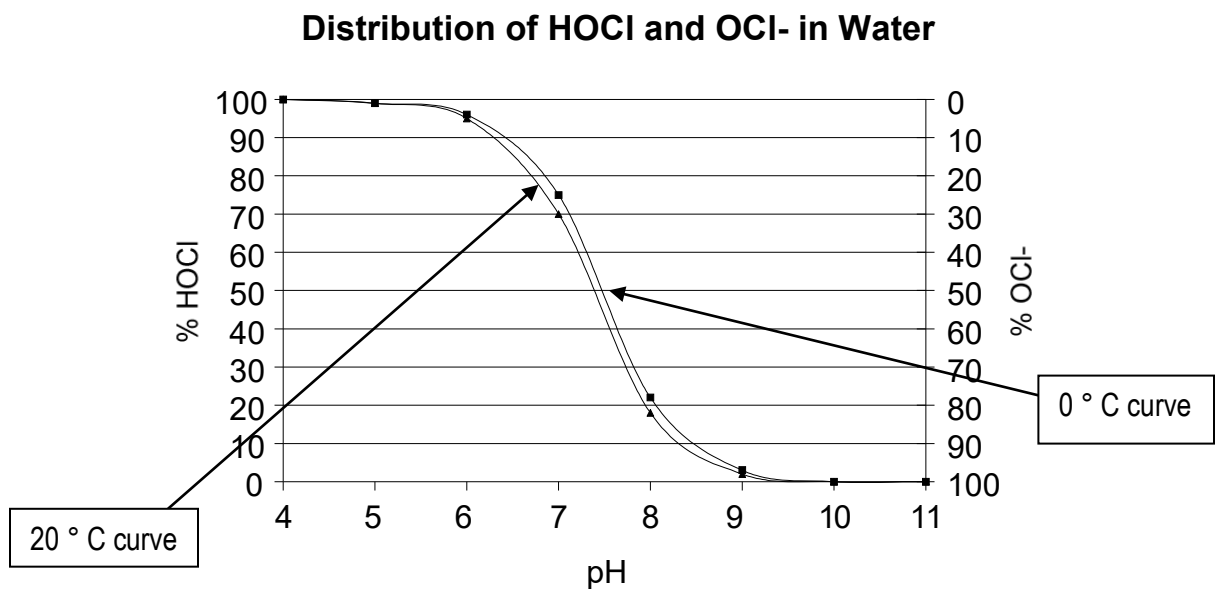


Figure 24.2 Distribution of HOCl and OCl<sup>-</sup> in water

- HOCl dissociates poorly at pH levels below 6; therefore, predominately HOCl exists at relatively low pH levels.
- At a pH level of 7.5, approximately 50% of the chlorine present will be in the form of hypochlorous acid (HOCL) and 50% in the form of the hypochlorite ion (OCl<sup>-</sup>).
- OCl<sup>-</sup> exists almost exclusively above pH 9.5.
- HOCl is a stronger oxidant and disinfectant than OCL<sup>-</sup>, which is why **disinfection is more effective at a lower pH.**

Here's another visual that relates the effectiveness of chlorine to the pH value.

Figure 24.3 shows how the **effectiveness of chlorine decreases as the pH increases**.

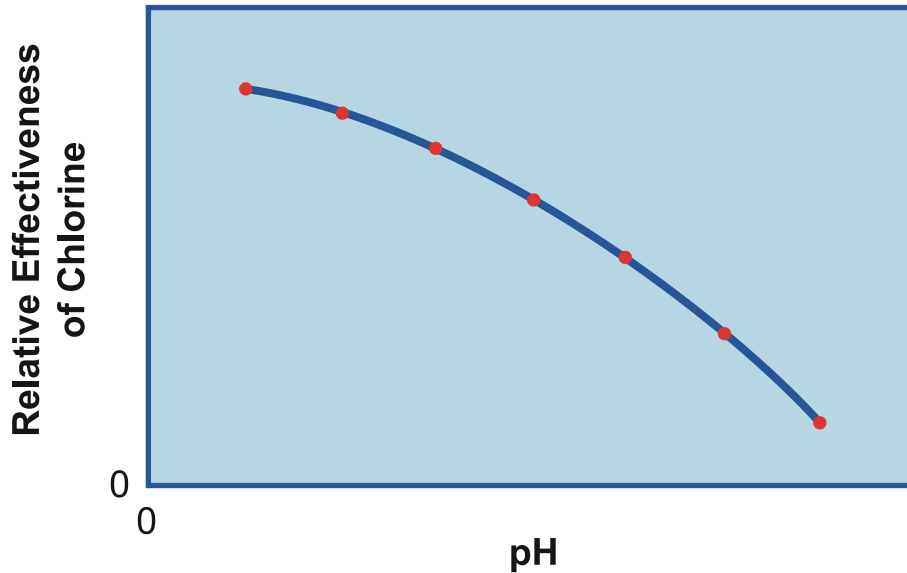


Figure 24.3 The Relationship Between pH and Disinfection When Using Chlorine.

There is a direct relationship between the effectiveness of chlorine and temperature.

Figure 24.4 shows how the **effectiveness of chlorine increases as temperature increases**.

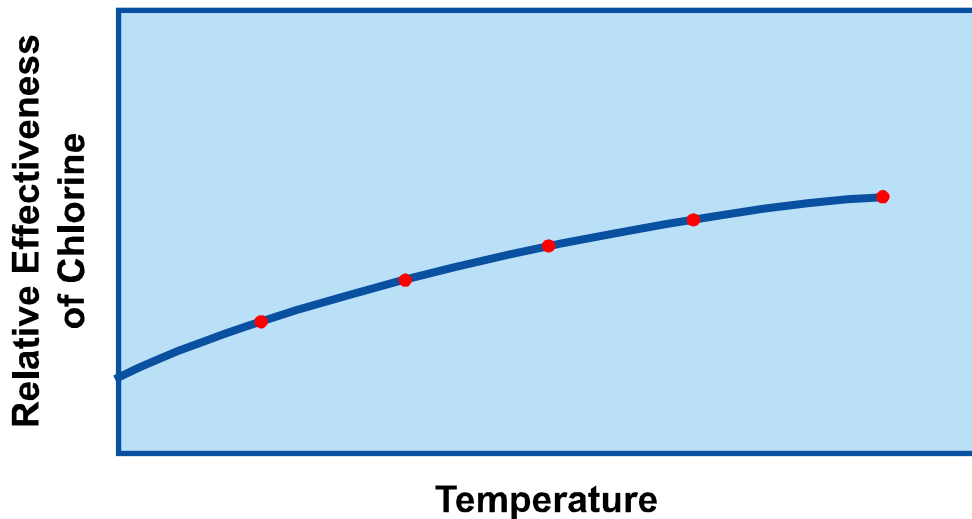


Figure 24.4 The Relationship Between Temperature and Disinfection When Using Chlorine.

- Longer contact times are required to disinfect water at lower temperatures.

### Key Points for Unit 1 – Chemistry of Chlorine

- ✚ Chlorine is widely used to disinfect drinking water.
- ✚ Chlorine can be used as a gas or as a liquid. Calcium hypochlorite is the dry form of chlorine which can be mixed to prepare a liquid chlorine solution.
- ✚ The gas form of chlorine is 2.5 times heavier than air.
- ✚ Vapor pressure increases with temperature; however, it is not impacted by volume. In other words, the 1 pound of chlorine and 100 pounds of chlorine have the same vapor pressure.
- ✚ When added to pure water, chlorine forms hypochlorous (HOCL) and hydrochloric (HCL) acids. HOCl is a stronger oxidant and disinfectant than OCl<sup>-</sup>, which is why **disinfection is more effective at a lower pH**.
- ✚ The effectiveness of chlorine increases as temperature increases. Conversely, longer contact times are required to disinfect water at lower temperatures.
- ✚ In addition to disinfecting water, chlorine can also be used to oxidize materials such as iron, manganese, cyanide, sulfide, and organic matter.

**Unit 1 Exercise**

1. Chlorine gas is heavier/lighter than air. (Underline the correct answer)
  
2. Vapor pressure is independent of volume.  
a. True\_\_\_\_\_ b. False\_\_\_\_\_
  
3. Vapor pressure decreases with increasing temperature.  
a. True\_\_\_\_\_ b. False\_\_\_\_\_
  
4. HOCL/OCl- is the stronger disinfectant. (Underline the correct answer)
  
5. The effectiveness of chlorine increases/decreases with decreasing temperature. (Underline the correct answer)
  
6. Cylinders contain both liquid and gas chlorine.  
a. True\_\_\_\_\_ b. False\_\_\_\_\_

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# Unit 2 – Chlorine Handling, Safety and Storage

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## Learning Objectives

- Identify an SDS 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.

### Safety Data Sheets

A Safety Data Sheet, or SDS, is available from the chemical manufacturer/supplier for every chemical. For years, these sheets were commonly known as MSDS for Material Safety Data Sheet. However, the Occupational Safety and Health Administration (OSHA) Hazard Communication Standard of 2012 (HazCom 2012) mandates the use of a single format for safety data sheets featuring **16 sections**.

You should read and understand the SDS for each chemical used in the plant. You should also maintain a personal copy for all hazardous chemicals that are used.

An SDS contains detailed assessments of chemical characteristics, hazards and other information relative to health, safety and the environment. The SDS includes:

- **Section 1, Identification**
- **Section 2, Hazard(s) identification**
- **Section 3, Composition/information on ingredients**
- **Section 4, First-aid measures**
- **Section 5, Fire-fighting measures**
- **Section 6, Accidental release measures**
- **Section 7, Handling and storage**
- **Section 8, Exposure controls/personal protection**
- **Section 9, Physical and chemical properties**
- **Section 10, Stability and reactivity**
- **Section 11, Toxicological information**
- **Section 12, Ecological information**
- **Section 13, Disposal considerations**
- **Section 14, Transport information**
- **Section 15, Regulatory information**
- **Section 16, Other information**, includes the date of preparation or last revision.



An example of an SDS is included in the Appendix.



## **Chlorine Hazards**

### **Health Hazards**



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

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

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

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### **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.
  - Exhaust fan 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 (SCBA) is available for longer exposures and higher chlorine concentrations. It is the preferred means of respiratory protection. The SCBA should be located near the door outside of the chlorinator room for easy access.
  
-  Protective clothing including safety eyewear and chemical-resistant, impervious gloves.
  
-  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 OSHA 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.
- ✚ Warm milk, cream or coffee will relieve throat irritation.
- ✚ 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 15 minutes.
- ✚ Call for medical assistance.
- ✚ Keep affected area cool.

#### Eye Contact

- ✚ Immediately shower with large quantities of water while holding eyes open. Flush the eyes with water for at least 15 minutes.
- ✚ Call a physician immediately.
- ✚ Transfer promptly to 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 0.3 parts per million (ppm).
- Portable and permanent automatic chlorine detection devices can detect at concentrations of 1 ppm or less.
- A bottle of concentrated ammonia solution (ammonium hydroxide) should be available for leak detection. Ammonia vapors react with gaseous chlorine to produce a visible white cloud or fume. When checking for leaks, only vapors should be dispensed not solution.

#### 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 and the local emergency management agency. 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.
  - 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, to 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 of that which escapes as liquid through the same size hole.
- 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.
- 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 hydrochloric acid formed will increase corrosion at the leak location and make the 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 firefighting 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.

### Chlorine Storage Quantity

- Storage for a 30-day supply should be available.

### Types of Storage Containers and Features

#### 100 and 150 lb. Cylinders

- Position and store vertically (with valve protection cap in place when moving the cylinder).
- Always secure cylinders with restraint chains to protect them from falling, rolling or being dropped.



Figure 2.1 A 150 lb Chlorine Cylinder in Feed Position

- A fusible plug is placed in the valve below the valve seat. The metal softens or melts at 158 to 165 °F to prevent buildup of excessive pressures and the possibility of rupture due to a fire or high surrounding temperatures.

#### Ton Containers

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

- ✚ Secure ton tanks with locking devices to prevent them from rolling while connected.
- ✚ There are 6 to 8 fusible plugs, 3 or 4 on each end that soften or melt at 158 to 165 °F to prevent buildup of excessive pressures and the possibility of rupture due to a fire or high surrounding temperatures.



Figure 2.2 Ton Cylinders in Feed Position

### Tank Cars

- ✚ Tank cars are generally provided only 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 50° F.
- ✚ The chlorine feed room should be kept between 60 ° F and 120 ° F to vaporize liquid chlorine. Below 60 ° F, chlorine gas forms chlorine hydrate, also known as “green ice,” when it comes in contact with water. This green ice can clog the ejector (injector) and gas piping, creating a serious maintenance problem.
- ✚ The temperature in the storage/supply room should be 5 to 10 ° F cooler.

### ***Ventilation***

- ✚ Forced air ventilation should be provided. Mechanical exhaust systems must draw air from the room at a point no higher than 12 inches above the floor in the storage area.
- ✚ 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:



- ✚ 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. Specifically, it is severely corrosive to the skin, eyes and mucous membranes. First-aid measures to remove chlorine from skin or eyes include showering with large quantities of water for at least 15 minutes.
- ✚ A Safety Data Sheet (SDS) contains an assessment of chemical characteristics, hazard, personal protection equipment and other information relative to health, safety and the environment.
- ✚ The self-contained breathing apparatus (SCBA) is required when entering a room with chlorine concentrations great than 1% or when a longer exposure time is required. The SCBA should be located near the door outside of the chlorinator room for easy access. If a chlorine leak is large, contact the local fire company and local emergency management agency for assistance.
- ✚ Forced air ventilation (or exhaust fans) are required in chlorine storage and feed rooms. Fans should be located near the floor, since chlorine is 2.5 times 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 leaks may occur around valve stems, leaded gaskets at the discharge valve outlet, cylinder valves or fusible plugs. Repairs may be as simple as tightening the packing gland nut, replacing the leaded gasket or more complex repairs that require emergency repair kits for leaks at fusible plugs and cylinder valves.
- ✚ The quantity of chlorine that escapes from a leak is significantly less as a gas than as a liquid. Consequently, if a leak occurs in a cylinder, you should turn it so that the leaking side is on top, if possible, so that gas escapes rather than liquid.
- ✚ Do not immerse a leaking container in water because the hydrochloric acid formed will increase corrosion at the leak location and make the leak worse and gas will be released at the water surface.
- ✚ Position and store 100 and 150 lb cylinders vertically and secure them with chains. When using ton containers of chlorine, align the valves vertically to feed chlorine gas and install locking devices to prevent containers from rolling.
- ✚ A fusible plug is designed to soften or melt at 158° F to 165° F to prevent buildup of excessive pressures and the possibility of rupture due to a fire or high surrounding temperatures. Cylinders and ton container are equipped with fusible plugs.
- ✚ The chlorine feed room temperature should be kept between 60° F and 120° F to vaporize liquid chlorine. Below 60° F, chlorine gas forms chlorine hydrate, also known as “green ice,” when it comes in contact with water. This green ice can clog the ejector (injector) and gas piping, creating a serious maintenance problem.

**Exercise for Unit 2 – Chlorine Handling and Storage.**

1. The quantity of chlorine that escapes from a leak is significantly less as a gas/liquid. (Underline the correct answer)
2. Chlorine feed room exhaust fans or a forced-air ventilation inlet must be near the floor.  
a. True\_\_\_\_\_ b. False\_\_\_\_\_
3. The chlorine feed room should be at least 60°F to facilitate chlorine discharge.  
a. True\_\_\_\_\_ b. False\_\_\_\_\_
4. The fusible plug on a 100 pound cylinder will melt at 120°F.  
a. True\_\_\_\_\_ b. False\_\_\_\_\_
5. Where should the self-contained breathing apparatus be located?
  - a. Inside the chlorine feed room
  - b. Near the door outside of the chlorine feed room
  - c. In the manager's office
  - d. In the first-aid room
6. Repairing chlorine leaks in cylinders may include:
  - a. Replacing the lead gasket at the discharge valve outlet
  - b. Using the emergency repair "A" kit for cylinders
  - c. Tightening the packing gland nut
  - d. All of the above
7. When chlorine comes in contact with moisture, it turns into hydrochloric acid.  
a. True\_\_\_\_\_ b. False\_\_\_\_\_
8. To detect a chlorine leak, a bottle of which type of solution is used to produce white fumes?
  - a. Sodium thiosulfate
  - b. Caustic soda
  - c. Ammonia
  - d. Saline solution

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# Unit 3 – Application of Gas Chlorine

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## Learning Objectives

- Discuss chlorination definitions and disinfection regulatory requirements
- List and explain the components of each of the following pieces of equipment:
  - Gas feed system
  - Liquid vaporizers
  - Monitoring equipment
  - Chemical feed control

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## Chlorination Definitions



An **enteric virus** is 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 (dose) and the amount remaining (residual) after a given contact time.



**Chlorine residual** is the total of all compounds with disinfecting properties and any remaining free chlorine. The presence of measurable chlorine residual indicates that all chemical reactions have been satisfied and that sufficient chlorine is present to kill microorganisms.

**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.



**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)



**CT** – CT is equal to the **residual disinfectant concentration (C)** measured in mg/L in a representative sample of water prior to the first customer **multiplied** by the disinfection **contact time (T)** in minutes; that is “**C**” x “**T**”. The time **T** is measured between the point of application of the disinfectant and the measurement of the residual.



**Breakpoint chlorination** is the addition of chlorine until all chlorine demand has been satisfied (i.e., no organic matter to react with the chlorine). At this point, further additions of chlorine will result in a **free** chlorine residual that is directly proportional to the amount of chlorine added beyond the breakpoint. It is used to determine how much chlorine is required for disinfection.

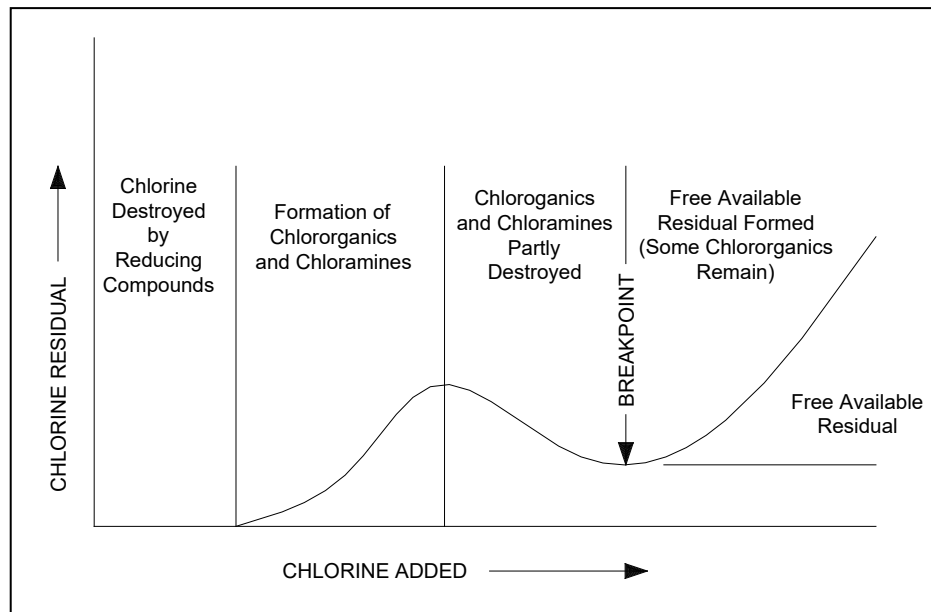


Figure 3.1 Breakpoint Chlorination Curve

- Chlorine added to water containing organic and inorganic chemicals reacts with these materials to form chlorine compounds.



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



**Sodium Thiosulfate** – A chemical used to neutralize all of the chlorine residual when collecting a bacteriological sample for coliforms.

## Regulatory Requirements

All community water systems (CWSs) are required to provide continuous disinfection. Also, CWSs must meet the disinfection byproducts MCLs. The following regulatory requirements address both disinfection and their associated byproducts with treatment technique requirements, MCLs, and MRDLs.

Chlorine added to water containing organic and inorganic chemicals reacts with these materials to form chlorine compounds. Maximum Contaminant Levels (MCLs) have been established for these disinfection byproduct compounds.

### Maximum Contaminant Levels










Maximum contaminant levels (MCLs) regulations are issued by the USEPA and in Pennsylvania by the DEP. The MCLs list a variety of organic and inorganic chemicals, disinfection by products (DPBs), radionuclides, microbiological contaminants, and turbidity levels that pertain to drinking water. Some example MCLs are listed below.

### Maximum Residual Disinfectant Level



The maximum residual disinfectant level (MRDL) is the maximum permissible level of a disinfectant added for water treatment that may not be exceeded at the consumer's tap without an unacceptable possibility of adverse health effects.

<u>Contaminant</u>	<u>MCL or MRDL</u>
 Total Trihalomethanes (TTHMs), a DBP	0.080 mg/L
 Haloacetic Acids (HAA5), a DBP	0.060 mg/ L
 Bromate, a DBP	0.010 mg/ L
 Chlorite, a DBP	1.0 mg/L
 Benzene	0.005 mg/ L
 Diquat	0.02 mg/ L
 Chlorine (as Cl <sub>2</sub> )	4.0 mg/ L as maximum residual disinfectant level (MRDL)



**Log inactivation** is defined as follows:

- **1 log inactivation = 90%**
- **2 log inactivation = 99%**
- **3 log inactivation = 99.9%**
- **4 log inactivation = 99.99%**



### Surface Water Supplies

- The **disinfection process (alone)** must achieve 90% (1.0 log) inactivation of *Giardia* cysts and 99.9% (3.0 log) inactivation of enteric viruses.
- *Giardia* log inactivation must be calculated at least once per day during expected peak hourly flow.
  - ▶
- This must be determined by 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*.

### Groundwater Supplies

- Community groundwater systems are required to provide continuous disinfection and at least 4-log treatment of viruses (99.99% removal and/or inactivation).
- Community groundwater systems are required to maintain at each groundwater entry point a minimum residual disinfection concentration approved by DEP to provide 4-log treatment of viruses.
- This applies to groundwater supplies **not** under the influence of surface water intrusion.
- A minimum of 20 minutes of contact time must be provided.

### Chlorine Residual Requirements for Entry Point and Distribution Samples

- **For surface water systems:**
  - ▶ **Entry Point (EP):** May not be less than **0.20 mg/L** for more than 4 hours.
    - If the EP residual drops below 0.20 mg/L, *Giardia* log inactivation shall be calculated every 4 hours until the residual disinfectant concentration at the EP is at or above the minimum value.
  - ▶ **Distribution:** May not be less than **0.2 mg/L** measured as free or total chlorine, for any distribution sampling point.
    - Samples are taken at the same locations at representative points within the distribution system and at the same time as the total coliform samples.
    - Disinfectant residual measurements must also be conducted at least once/week. Water systems that do not collect at least 1 coliform sample each week will need to conduct additional disinfectant residual measurements each week that a coliform sample is not collected
    - Any location that has a disinfectant residual less than 0.2 mg/L in a month must also be sampled the following month.

■ **For groundwater systems:**

- ▶ **Entry Point:** May not be less than **0.40 mg/L measured as free chlorine** or its equivalent as approved by DEP or other minimum residual approved by DEP to provide 4-log treatment of viruses for more than 4 hours.
- ▶ **Distribution:** May not be less than **0.2 mg/L** measured as free or total chlorine, for any distribution sampling point.
  - Samples are taken at the same locations at representative points within the distribution system and at the same time as the total coliform samples.
  - Disinfectant residual measurements must also be conducted at least once/week. Water systems that do not collect at least 1 coliform sample each week will need to conduct additional disinfectant residual measurements each week that a coliform sample is not collected
  - Any location that has a disinfectant residual less than 0.2 mg/L in a month must also be sampled the following month.

**Unit 3 Exercise Part 1**

1. The amount of chlorine required to react with all the organic and inorganic material is known as the chlorine \_\_\_\_\_.
2. Breakpoint chlorination:
  - a. Is the addition of chlorine until all chlorine demand has been satisfied.
  - b. Occurs when no organic matter is available to react with the chlorine.
  - c. Is used to determine how much chlorine is required for disinfection.
  - d. Is the point at which further addition of chlorine will result in a free chlorine residual that is directly proportional to the amount of chlorine added beyond the breakpoint.
  - e. All of the above
3. Name the chemical used to neutralize all of the chlorine residual when collecting a bacteriological sample for coliforms. \_\_\_\_\_.
4. The \_\_\_\_\_ is the maximum permissible level of a disinfectant added for water treatment that may not be exceeded at the consumer's tap without an unacceptable possibility of adverse health effects.
5. Chlorine residual samples are taken at representative points within the distribution system. These samples are taken at the same time and at the same location as the coliform samples are taken.
  - a. True \_\_\_\_\_
  - b. False \_\_\_\_\_
6. All water systems must maintain a **minimum** detectable disinfectant residual throughout their entire **distribution system**. What is the value of this minimum distribution disinfectant residual?
  - a. 0.2 mg/L
  - b. 0.02 mg/L
  - c. 0.4 mg/L
  - d. 4.0 mg/L

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.

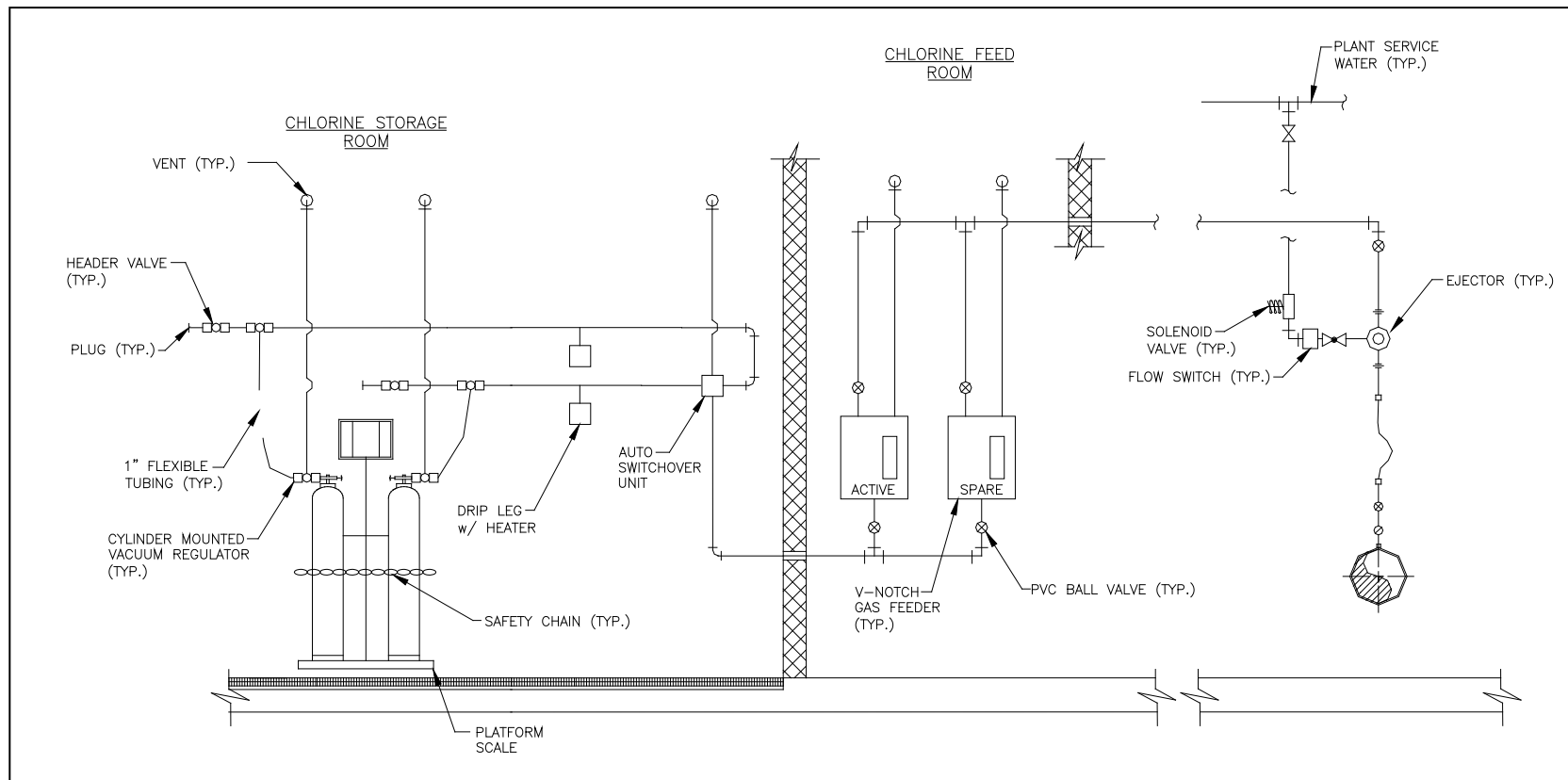


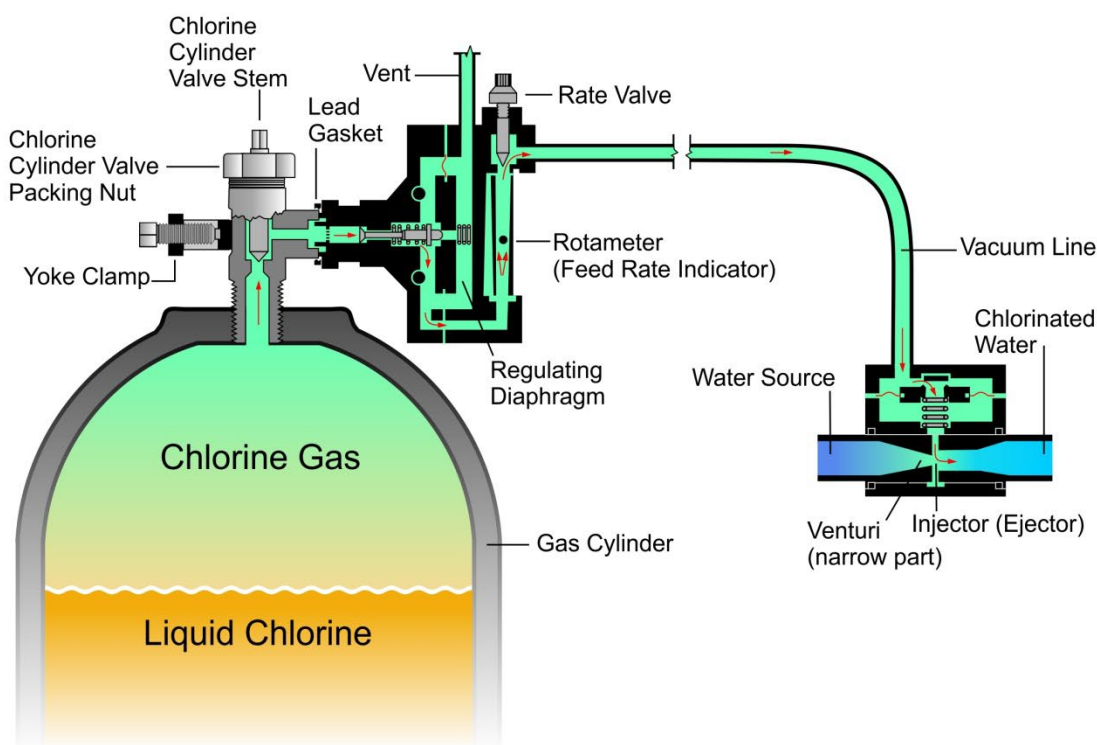
Fig 3.1 Typical Small Gas Chlorination System Schematic

### 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 ejector, or injector, mixes the chlorine gas into the water supply.

Here's a close-up diagram of a direct cylinder mounted vacuum regulator.

### Direct Cylinder Mounted Vacuum Regulator




#### Specific Features:

- **Chlorine Cylinder Valve Packing Nut:** Chlorine leaks could occur at the valve stem so an operator may need to tighten the chlorine cylinder valve packing nut to repair this type of leak.
- **Lead Gasket:** A vacuum regulator inlet valve is attached directly to the chlorine container valve by means of a positive yoke connection which is sealed by a single leaded gasket. A soft, lead gasket is used to seal the connection and should be changed every time the connection is broken.
- **Rotameter:** The rotameter serves as a chlorine feed rate indicator. The small ball rises or falls depending on the flow rate. The flow rate may be read on a scale behind or on the tube by looking at the middle of the ball or at the widest part or top of the float.
- **Ejector:** The ejector contains a Venturi nozzle that creates the pressure differential to establish a vacuum which is used to pull chlorine gas into the water supply.

### Maximum Feed Rates

- It is not advisable to draw more than 1.6 pounds/hr (or 40 pounds in a 24-hr period) from any one 100 to 150 pound cylinder. At higher chlorine withdrawal rates, “freezing” can occur because the chlorine gas is removed from the cylinder faster than the liquid chlorine is being converted to chlorine gas. When this happens, the actual flow of chlorine gas will be reduced and become less than the desired rate.
- Ton containers are limited to approximately 16 pounds per hour (or 400 pounds in a 24-hr period).
- 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.

### Chlorine Evaporator

- 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.
- 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 Ejectors***

- Daily
  - Check ejector water supply pressure. Pressures will range from 40 to 90 psi depending on the system. A significant decrease in water pressure may cause chlorine ejection failure.
  - Check chlorinator vacuum. A vacuum is required to move the gas in the ejector.
  - 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 sight 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 online and allow chlorinator to operate to empty chlorine gas from system.
  - Repair leak or replace chlorinator.
    - Leak Repair Suggestions**
      - ✚ Valve stem leaks – Close the valve or tighten the packing gland nut.
      - ✚ Valve discharge outlet leaks – Replace the lead gasket or adapter connection.
      - ✚ Cylinder valves or fusible plug leaks – Call your chlorine supplier immediately and obtain an emergency repair kit for this purpose if you do not have a kit readily available.
      - ✚ Pin hole leaks in the walls of cylinder and ton tanks – Use a clamping pressure saddle with a turn-buckle available in repair kits.
- 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 online if demand is higher than can be provided by a single unit).

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

- ✚ Community water suppliers have both **minimum and maximum chlorine residual requirements** to meet according to their source water classification. The minimum and maximum levels are listed here:
  - **Minimum entry point and distribution system requirements for surface water systems:** Surface water suppliers are required to have a minimum free, combined or chlorine dioxide residual entering the distribution system (i.e., **entry point**) that may not be less than 0.20 mg/L for more than 4 hours.
  - **Minimum entry point and distribution system requirements for groundwater systems:** Groundwater suppliers are required to have a minimum free chlorine residual entering the distribution system (i.e., **entry point**) no less than 0.40 mg/L or its equivalent as approved by DEP or other minimum residual approved by DEP to provide 4-log treatment of viruses.
  - Additionally, all water supplies are required to maintain a disinfectant residual concentration in the **distribution** of at least 0.2 mg/L.
  - **Maximum residual disinfectant level (MRDL) requirements within the distribution system for all system types:** Surface water and groundwater suppliers are required comply with a maximum residual disinfectant level no greater than 4.0 mg/L as chlorine. Compliance is based on a running annual average, computed quarterly, of monthly averages of all samples collected within the distribution system.
- ✚ Chlorine residual samples are taken at representative points within the distribution system. These samples are taken at the **same time** and at the **same location** as the coliform samples are taken. Disinfectant residual measurements are to be conducted at least once a week.
- ✚ Breakpoint chlorination is the addition of chlorine until all chlorine demand has been satisfied (i.e., no organic matter to react with the chlorine). At this point, further additions of chlorine will result in a **free chlorine** residual that is directly proportional to the amount of chlorine added beyond the breakpoint.
- ✚ Sodium thiosulfate is used to neutralize all of the chlorine residual when collecting a bacteriological sample for coliforms.
- ✚ A vacuum regulator inlet valve is attached directly to the chlorine container valve by means of a positive yoke connection which is sealed by a single leaded gasket. A soft, lead gasket is used to seal the connection and should be changed every time the connection is broken.
- ✚ 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 is not advisable to draw more than 1.6 pounds/hr (or 40 pounds in a 24-hr period) from any one 100 to 150 pound cylinder. At higher chlorine withdrawal rates, “freezing” can occur because the chlorine gas is removed from the cylinder faster than the liquid chlorine is being converted to chlorine gas. When this happens, the actual flow of chlorine gas will be reduced and become less than the desired rate.

- ✚ Chlorine evaporators are used to convert liquid chlorine into gas when higher chlorine withdrawal rates are necessary.
- ✚ Chlorine storage areas should be inspected at least once each day.

**Unit 3 Exercise Part 2.**

1. A leaded gasket is used to seal the connection between chlorine cylinder yoke and the vacuum regulator inlet valve. Every time the connection is broken, the leaded gasket should be replaced..  
a. True \_\_\_\_\_ b. False \_\_\_\_\_
2. A \_\_\_\_\_ is a device used to measure the flow rate of gases and liquids.
3. A gas chlorine system problem may be due to:
  - a. No ejector vacuum.
  - b. Significant decrease in water pressure.
  - c. Both a and b.
  - d. None of the above
4. A 150 pound cylinder can provide chlorine at a maximum rate of about \_\_\_\_\_ pounds per hour.
5. Frost forms on a gas chlorine when the feed rate is too low.  
a. True \_\_\_\_\_ b. False \_\_\_\_\_
6. Daily activities for chlorinators and ejectors include:
  - a. Check ejector water supply pressure
  - b. Check chlorinator vacuum
  - c. Read and record chlorine feed rate
  - d. Measure chlorine residual
  - e. All of the above

### References

Information on leak repair suggestions taken from Water Treatment Plant Operation, Volume 1, Third Edition, 1994, California State University, Chapter 7, Disinfection, page 311.

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

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# Unit 4 – Math Principles and Process Control Calculations

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## Learning Objectives

- Describe principles and rules for solving equations.
- Perform calculations for the following types of situations
  - Dosage/Feed Rate.
  - Chlorine Demand or Dose.
  - CT.



## Basic Math Principles for Solving Dosage Calculations

Here are some basic math terms and principles.

**Fraction:** A numerical expression containing a numerator and denominator that represents portions of a whole object. Fractions are used to represent ratios and represent division. For example, the fraction  $\frac{1}{4}$  is used to represent the ratio 1:4 and  $1 \div 4$ .

### Parts of a Fraction

1. **Numerator:** The **top** number of a fraction that indicates how many parts are being considered.
2. **Division Line:** The line between the numerator and denominator that indicates that the numerator value is divided by the denominator value to convert a fraction into a decimal.  
Example:  $\frac{1}{4} = 0.25$  (as a decimal)
3. **Denominator:** The **bottom** number of a fraction that tells us how many equal parts into which the whole has been divided.

### Fraction Written in Vertical Format:

$\frac{1}{4}$  (numerator)  
4 (denominator)

Let's begin this unit with a review of a basic math rule about solving for an unknown variable.

### Rules for Solving for an Unknown Variable (such as X)

When solving for the unknown variable (**X**), there are 2 basic objectives:

1. **X** must be in the numerator, **AND**
2. **X** must be by itself (on one side of the equation).

To accomplish these objectives, **only diagonal movement of terms across the equal sign is permissible in multiplication and division problems.**

$$\begin{array}{ccc} (5) & \leftarrow = & (3) \\ (3) & \leftarrow & (5) \end{array}$$

**Explanation of diagonal movement and an example.**

An equation is a mathematical statement in which the terms or calculation on one side = the terms or calculation on the other side. To keep both sides equal, any multiplication or division done to one side, must be done to the other. This keeps the equation balanced.

**Example:**

$$5X = 20$$

Question #1 regarding Example #1: Is the **X** in the numerator? \_\_\_\_\_

Question #2 regarding Example #1: Is the **X** alone on one side of the equation? \_\_\_\_\_

How do we use diagonal movement to place **X** alone on one side of the equation?

Answer:

- Divide both sides by “5” to get **X** alone and **treat both sides of the equation equally**. Notice that the 5 was moved from the top of the left side to the bottom of the right side of the equation – a **diagonal move**.

$$\frac{5X}{5} = \frac{20}{5}$$

**FINAL ANSWER:** \_\_\_\_\_

There are a few rules for doing the various mathematical functions like multiplication, division, addition and subtraction.

<b>Order of Operation for Multiplication, Division, Addition and Subtraction</b>
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To solve for <b>X</b> when multiplication and division as well as addition and subtraction of terms is indicated, use the following steps:
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- |   |
|---|
| <ol style="list-style-type: none"><li>1. Simplify as many terms as possible, using the order of operation:<ul style="list-style-type: none"><li>• If <b>brackets or parentheses</b> contain any arithmetic, <b>simplify within these groups first</b> by:<ul style="list-style-type: none"><li>○ Completing the multiplication or division, <b>THEN</b></li><li>○ Complete the addition or subtraction.</li></ul></li><li>• Complete all <b>multiplication and division</b> from left to right, <b>THEN</b></li><li>• Complete all <b>addition and subtraction</b> from left to right.</li></ul></li><li>2. Verify that the <b>X</b> term is in the numerator. If it is not, move the <b>X</b> term to the numerator, using a diagonal move.</li><li>3. Verify that <b>X</b> is by itself, on one side of the equation.</li></ol> |
|---|

We practice step 1 (simplifying terms) in dosage equations later in this section. We practice steps 2 and 3 when we create a ratio of a known feed rate and flow to unknown feed rate and a reduced flow in the last equation in this section.

Let's apply these math rules to operator process calculations.

## Process Calculations

There are three basic chlorination process calculations:

1. chlorine dosage or feed rate
2. chlorine demand
3. CT calculation

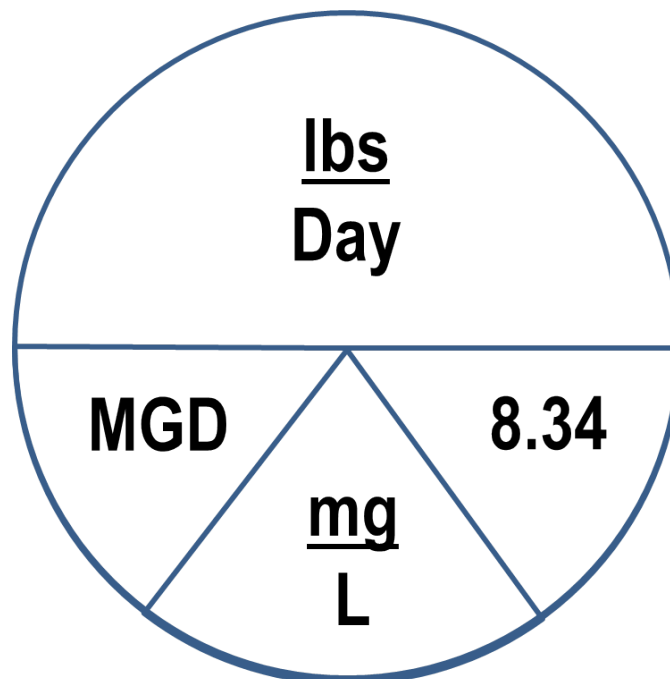
### Chlorine Dosage/Feed Rate Calculation

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

Feed Rate, lbs/day = Flow (MGD) x Dosage (mg/L) x 8.34 lbs/gal

This formula is represented in the following diagram called the Davidson Pie which was created by Gerald Davidson, Manager, Clear Lake Oaks Water District, Clear Lake Oaks, CA.

### Davidson Pie



**Key Acronyms:**

MG = million gallons

MGD = million gallons per day

**Davidson Pie Diagram Interpretation and Formulas**

This diagram can be used to solve for 3 different results: dosage, feed rate, and flow (or volume).

As long as you have 2 of those 3 variables, you can solve for the missing variable.

**Davidson Pie Interpretation**Middle line = divided by ( $\div$ )Bottom diagonal lines = multiply by ( $\times$ )

In other words, here are the 3 equations that can be used with these variables:

1. **Feed Rate, lbs/day = Flow (MGD) or Volume (MG)  $\times$  Dosage (mg/L)  $\times$  8.34** (which is the density of water)
2. Flow (MGD) = lbs/day  $\div$  (Dosage, mg/L  $\times$  8.34)

$$\text{Vertical Format: Flow(MGD)} = \frac{\text{Feed Rate (lbs/day)}}{[\text{Dosage (mg/L)} \times 8.34]}$$

3. Dosage (mg/L) = lbs/day  $\div$  (Flow, MGD  $\times$  8.34)

$$\text{Vertical Format: Dosage (mg/L)} = \frac{\text{Feed Rate (lbs/day)}}{[\text{Flow(MGD)} \times 8.34]}$$

We are only going to review equation # 1 and equation #3 in this course.

We'll begin with the first equation.

**Equation # 1: Feed Rate Calculation Using Flow**

**Feed Rate, Pounds per day = Flow(MGD) x Dose(mg/L) x (8.34)**

This equation alone (without extra steps) can be used to solve for feed rates of 100% strength chemicals, such as chlorine gas.

A water treatment plant produces 3 million gallons per day, and uses chlorine gas, dosed at 7 mg/L, how many pounds per day will the plant will use?

Feed Rate, Pounds per day =  $3 \times 7 \times 8.34 = 175$  pounds per day

**Practice Problem:** If a water treatment plant has a flow rate of 0.55 MGD and a chlorine dosage of 3.9 mg/L, what is the feed rate in pounds/day?

Feed Rate, lbs/day = Flow (MGD) X Dose (mg/L) X 8.34

? lbs/day = \_\_\_\_\_ X \_\_\_\_\_ X 8.34 = \_\_\_\_\_ lbs/day

**Solving for the lbs/hour:**

What if you need to calculate the feed rate in lbs/hour?

**Step 1:** Solve for feed rate for one day.

Lbs/day = Flow (MGD) X Dose (mg/L) X 8.34  
? lbs/day =  $0.55 \times 3.9 \times 8.34 = 17.88$  lbs/day

**Step 2:** Divide feed rate for one day by 24 hours

$17.88 \div 24 =$  \_\_\_\_\_ lbs/hour

**Solving for the Quantity of Chlorine Used in 30 Days**

What if you needed to calculate how much chlorine was used in 30 days?

**Step 1:** Solve for feed rate for one day.

Lbs/day = Flow (MGD) X Dose (mg/L) X 8.34  
? lbs/day =  $0.55 \times 3.9 \times 8.34 = 17.88$  lbs/day

**Step 2:** Multiply feed rate for one day X 30 days

$17.88 \times 30 =$  \_\_\_\_\_ lbs/30 days

If your flow is less than a million gallons/day, here's the conversion you need to use.

### **Converting from GPD to MGD before solving with the formula**

**Problem:** If a water treatment plant is making water at the rate of 150,000 gallons per day, and the chlorine dose is 0.8 mg/L, how many pounds of chlorine will they use daily (assume 100% strength)?

**Step 1: Convert gallons per day into million gallons per day (MGD) using unit cancellation.**

$$\frac{? \text{ MG}}{\text{day}} = 1 \frac{\text{MG}}{1,000,000 \text{ gallons}} \times \frac{150,000 \text{ gallons}}{\text{day}} = 0.15 \text{ MGD}$$

**Step 2: Use MGD in feed rate formula to solve for lbs/day**

$$\text{Feed Rate, Pounds per day} = \text{Flow(MGD)} \times \text{Dose(mg/L)} \times 8.34$$

$$0.15 \times 0.8 \times 8.34 = 1 \text{ lb/day}$$

Sometimes we need to calculate the dose, based on the chlorine demand and residual.

### Chlorine Demand or Dose Calculation

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

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

OR

$$\text{Chlorine Dose (mg/L)} = \text{Chlorine Demand (mg/L)} + \text{Chlorine Residual}$$

**Example #1:** The chlorine demand of water is 2.1 mg/L. If a chlorine residual of 0.6 mg/L is desired, what is the required chlorine dosage in mg/L?

$$\text{Chlorine Dose (mg/L)} = \text{Chlorine Demand (mg/L)} + \text{Chlorine Residual (mg/L)}$$

$$\begin{aligned} ? \text{ Dose} &= 2.1 + 0.6 \\ &= 2.7 \text{ mg/L} \end{aligned}$$

**Example #2:** The chlorine dosage is 2.9 mg/L. If the chlorine residual is 0.6 mg/L, what is the chlorine demand in mg/L?

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

$$\begin{aligned} ? \text{ Chlorine Demand} &= 2.9 - 0.6 \\ &= 2.3 \text{ mg/L} \end{aligned}$$

**Practice Problem:** You must maintain 0.5 mg/L chlorine residual in the finished water with a chlorine demand of 1.5 mg/L. What should the chlorine dose be?

$$\begin{aligned} ? \text{ Dose} &= \text{Chlorine Demand} + \text{Chlorine Residual} \\ ? \text{ Dose} &= \underline{\quad\quad} + \underline{\quad\quad} \\ ? \text{ Dose} &= \underline{\quad\quad\quad} \text{ mg/L} \end{aligned}$$



**Calculating Dose (from Cl<sub>2</sub> demand and residual) to Solve Feed Rate Calculation**

**Example:** How many pounds of chlorine gas will be required to treat 116,000 gpd with a desired residual of 0.5 mg/L and a chlorine demand of 2.0 mg/L?

**Step 1: Calculate the dose using the formula**

Chlorine Dose (mg/L) = Chlorine Demand (mg/L) + Chlorine Residual (mg/L)

$$\begin{aligned} \text{Dose} &= 2.0 + 0.5 \\ &= \underline{\hspace{2cm}} \text{ mg/L} \end{aligned}$$

**Step 2: Convert gpd to MGD**

$$\frac{116,000}{1,000,000} = \underline{\hspace{2cm}} \text{ MGD}$$

**Step 3: Use Feed Rate calculation to solve for lbs/day**

$$? \text{ lbs/day} = \text{flow} \times \text{dose} \times 8.34 = (0.116)(2.5)(8.34) = \underline{\hspace{2cm}} \text{ pounds of chlorine is required.}$$

**Practice Problem:** How many lbs of chlorine gas will be required to treat 400,000 gallons per day with a desired residual of 0.6 mg/L and a chlorine demand of 2.2 mg/L?

**Step 1: Calculate the dose using the formula**

Chlorine Dose (mg/L) = Chlorine Demand (mg/L) + Chlorine Residual (mg/L)

$$\begin{aligned} \text{Dose} &= 2.2 + 0.6 \\ &= \underline{\hspace{2cm}} \text{ mg/L} \end{aligned}$$

**Step 2: Convert gpd to MGD**

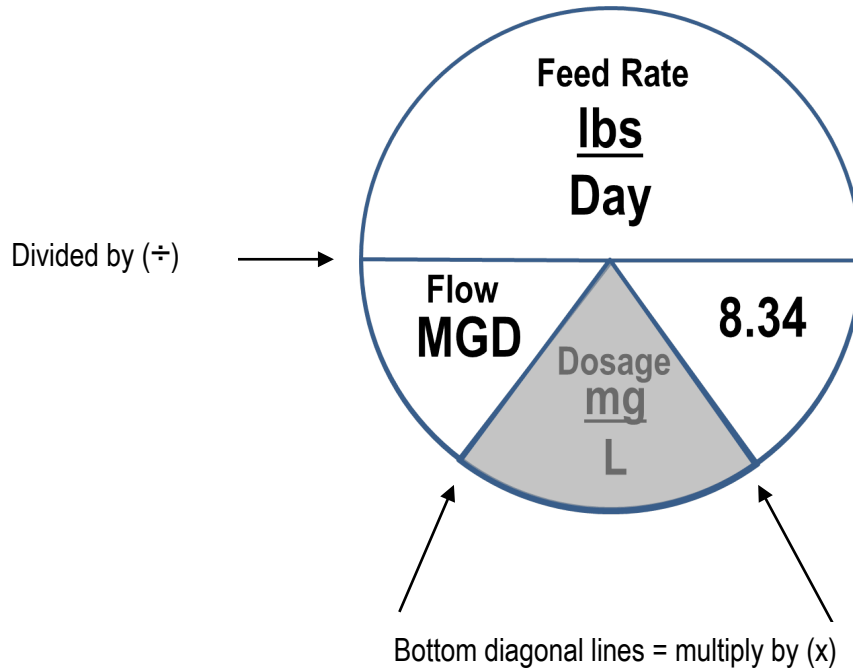
$$\frac{400,000}{1,000,000} = \underline{\hspace{2cm}} \text{ MGD}$$

**Step 3: Use Feed Rate calculation to solve for lbs/day**

$$? \text{ lbs/day} = \text{flow} \times \text{dose} \times 8.34 = \underline{(0.4)(2.8)(8.34)} = \underline{\hspace{2cm}} \text{ pounds of chlorine is required.}$$

We will not be reviewing Equation #2: Solving for Flow Using the Feed Rate Formula. Let's look at the final equation.

**Equation #3: Solving for Dose Using the Feed Rate Formula**



Vertical Format:  $\text{Dose, mg/L} = \frac{\text{Feed Rate, lbs/per day}}{(\text{Flow, MGD})(8.34)}$

Example: A water treatment plant is producing 1.5 million gallons per day of potable water, and uses 38 pounds of chlorine each day. What is the chlorine dose at that plant?

**Step 1:** Set up the variables in vertical format and insert known values

$$? \text{ Dose (mg/L)} = \frac{\text{Feed Rate, lbs/day}}{(\text{Flow, MGD})(8.34)} = \frac{38 \text{ lbs/day}}{(1.5)(8.34)}$$

← Known feed rate  
↑  
**Known Flow (MGD)**

**Step 2:** Multiply 1.5 x 8.34 in the denominator = 12.51 (basic math rule)

**Step 3:** Perform the **DOSE** division: 38 (numerator) ÷ 12.51 (denominator) = 3.03 mg/L

**Practice Problem:** A water treatment plant produces 11,000,000 gallons of water every day. It uses 200 lbs/day of chlorine. What is the dose (mg/L) of chlorine?

**Step 1:** Set up the variables in vertical format.

$$? \text{ Dose (mg/L)} = \frac{\text{Feed Rate, lbs/day}}{(\text{Flow, MGD})(8.34)}$$

**Step 2:** Insert known values into equation.

$$? \text{ Dose (mg/L)} = \frac{\text{Feed Rate, lbs/day}}{(\text{Flow, MGD})(8.34)} = \frac{(200) \text{ lbs/day}}{(11)(8.34)}$$

**Step 3:** Multiply 11 x 8.34 in the denominator = \_\_\_\_\_ (basic math rule)

**Step 4:** Perform the **DOSE** division: 200 (numerator) ÷ 91.74 (denominator) = \_\_\_\_\_  $\frac{\text{mg}}{\text{L}}$

There are 2 variations to this basic dosage problem. They include:

1. Solving for a dosage reduction value when the feed rate is decreasing.
2. Solving for a reduced feed rate when the flow decreases.

Let's start with the first variation on the next page.

**Solving for Dosage Reduction Value when Feed Rate is Decreasing**

**Example:** A chlorinator in a water treatment plant that produces 875,000 gallons per day is set to feed 20 lbs/day. If this feed rate is decreased by 5 lbs/day, the dosage will be reduced by how many mg/L?

**Step 1:** Set up the variables in vertical format.

$$? \text{ Dose (mg/L)} = \frac{\text{Feed Rate Difference, lbs/day}}{(\text{Flow, MGD})(8.34)}$$

**Step 2:** Convert gallons per day into MGD and insert known values into equation.

$$? \text{ MG} = \frac{1 \text{ MG}}{1,000,000 \text{ gallons}} \times \frac{875,000 \text{ gallons}}{\text{day}} = \underline{0.875} \text{ MGD}$$

$$? \text{ Dose (mg/L)} = \frac{\text{Feed Rate Difference, (lbs/day)}}{(\text{Flow, MGD})(8.34)} = \frac{(5) \text{ lbs/day}}{(0.875)(8.34)}$$

**Step 3:** Multiply 0.875 x 8.34 in the denominator = 7.29 (basic math rule)

**Step 4:** Perform the **DOSAGE** division of the **feed rate difference**:

$$5 \text{ (numerator)} \div 7.29 \text{ (denominator)} = \underline{0.68} \text{ mg/L}$$

## CALCULATIONS: DOSAGE REDUCTION VALUE

**Practice Problem:** A chlorinator in a water treatment plant that produces 600,000 gallons per day is set to feed 30 lbs/day. If this feed rate is decreased by 10 lbs/day, the dosage will be reduced by how many mg/L?

**Step 1:** Set up the variables in vertical format.

$$? \text{ Dose (mg/L)} = \frac{\text{Feed Rate Difference, lbs/day}}{(\text{Flow, MGD})(8.34)}$$

**Step 2:** Convert gallons per day into MGD and insert known values into equation.

$$? \text{MG} = \frac{1 \text{ MG}}{1,000,000 \text{ gallons}} \times \frac{600,000 \text{ gallons}}{\text{day}} = \text{_____ MGD}$$

$$? \text{ Dose (mg/L)} = \frac{\text{Feed Rate Difference, lbs/day}}{(\text{Flow, MGD})(8.34)} = \frac{(10) \text{ lbs/day}}{(0.6)(8.34)}$$

**Step 3:** Multiply 0.6 x 8.34 in the denominator = \_\_\_\_\_ (basic math rule)

**Step 4:** Perform the **DOSAGE** division of the **feed rate difference**:

$$10 \text{ (numerator)} \div 5 \text{ (denominator)} = \text{_____ mg/L}$$

## CALCULATIONS: REDUCED FEED RATE DUE TO REDUCED FLOW

### Solving for a Reduced Feed Rate when Flow Decreases

Using the basic math rules, we can create a ratio between the **known feed rate and original flow** and the **unknown feed rate and reduced flow**.

**Example:** If a water treatment plant that produces 600,000 gallons per day decreases its flow to 500,000 gallons per day, the amount of chlorine fed will change from 18 lbs/day to how many pounds per day?

**Step 1:** Convert gallons per day into MGD for both the **original flow** and the **reduced flow**.

a) **Original Flow:**

$$\frac{? \text{ MG}}{\text{day}} = \frac{1 \text{ MG}}{1,000,000 \text{ gallons}} \times \frac{600,000 \text{ gallons}}{\text{day}} = \underline{0.6} \text{ MGD}$$

b) **Reduced Flow:**

$$\frac{? \text{ MG}}{\text{day}} = \frac{1 \text{ MG}}{1,000,000 \text{ gallons}} \times \frac{500,000 \text{ gallons}}{\text{day}} = \underline{0.5} \text{ MGD}$$

**Step 2:** Create the ratio of  $\frac{\text{Original Feed Rate}}{\text{Original Flow (MGD)}} = \frac{X \text{ (Unknown Feed Rate)}}{\text{Reduced Flow (MGD)}}$

$$\frac{18}{0.6} = \frac{X}{0.5}$$

**Step 3:** To get "X" alone, multiply  $18 \times 0.5 = \underline{9}$  (in the numerator)

**Step 4:** Then divide numerator (9) by denominator (0.6) = 15 lbs/day

## CALCULATIONS: REDUCED FEED RATE DUE TO REDUCED FLOW

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**Practice Problem:** If a water treatment plant that produces 990,000 decreases its flow to 850,000 gallons per day, the amount of chlorine fed will change from 20 lbs/day to how many pounds per day?

**Step 1:** Convert gallons per day into MGD for both original flow and reduced flow.

a) **Original Flow:**

$$\frac{? \text{MG}}{\text{day}} = \frac{1 \text{ MG}}{1,000,000 \text{ gallons}} \times \frac{990,000 \text{ gallons}}{\text{day}} = \underline{\hspace{2cm}} \text{MGD}$$

b) **Reduced Flow:**

$$\frac{? \text{MG}}{\text{day}} = \frac{1 \text{ MG}}{1,000,000 \text{ gallons}} \times \frac{850,000 \text{ gallons}}{\text{day}} = \underline{\hspace{2cm}} \text{MGD}$$

**Step 2:** Create the ratio of  $\frac{\text{Original Feed Rate}}{\text{Original Flow}} = \frac{X \text{ (Unknown Feed Rate)}}{\text{Reduced Flow}}$

$$\frac{20}{0.99} = \frac{X}{0.85}$$

**Step 3:** To get "X" alone, multiply  $20 \times 0.85 = \underline{\hspace{2cm}}$  (in the numerator)

**Step 4:** Then divide numerator (17) by denominator (0.99) =  $\underline{\hspace{2cm}}$  lbs/day

The next type of calculation involves calculating CT.

CT



CT – The product of residual disinfectant concentration (C) measured in mg/L in a representative sample of water prior to the first customer, and disinfection contact time (T) in minutes; that is “C” x “T.”

$$CT = \text{disinfectant concentration} \times \text{contact time} = C \text{ (mg/L)} \times T \text{ (minutes)}$$

Therefore, the *units of CT are expressed in mg-min/L.*

**Example #1:** If a free chlorine residual of 1.8 mg/L is measured at the entry point of the system, after 120 minutes of detention time in the clearwell, what is the CT value in mg-min/L?

$$CT = \text{disinfectant concentration} \times \text{contact time}$$

$$1.8 \text{ mg/L} \quad \times \quad 120 \text{ minutes} = \underline{216} \text{ mg-min/L}$$

**Example #2:** If a free chlorine residual of 3.0 mg/L is measured at the end of the clearwell after 5 hours of detention time, what is the CT value in mg-min/L?

**Step 1:** Convert 5 hours of detention time to minutes (CT must be in minutes)

$$\text{Min} = \frac{60 \text{ min}}{\text{hr}} \quad \times \quad 5 \text{ hr} \quad = \underline{300} \text{ minutes}$$

**Step 2:** Insert disinfectant residual concentration and contact time (in minutes) into CT equation and multiply the values.

$$CT = \text{disinfectant concentration} \times \text{contact time}$$

$$CT = 3.0 \text{ mg/L} \quad \times \quad 300 \text{ min} = \underline{900} \text{ mg-min/L}$$



**Practice Problem:** If a free chlorine residual of 2.5 mg/L is measured at the end of the clearwell after 4 hours of detention time, what is the CT value in mg-min/L?

**Step 1:** Convert detention time from hours to minutes.

$$? \text{ Min} = 60 \frac{\text{min}}{\text{hr}} \quad \times \quad 4 \text{ hr} \quad = \underline{\hspace{2cm}} \text{ minutes}$$

**Step 2:** Insert disinfectant residual concentration and contact time (in minutes) into CT equation and multiply the values.

$$\text{CT} = \text{disinfectant concentration (mg/L)} \times \text{contact time (mins)}$$

$$\text{CT} = \underline{\hspace{1cm}} \text{ mg/L} \times \underline{\hspace{1cm}} \text{ minutes} = \underline{\hspace{2cm}} \text{ mg-min/L}$$



**Unit 4 Key points for Chemical Feed Dosage, Chlorine Demand and CT Calculations**

- Remember to perform math calculations using the order of operation steps listed in this unit.
- The Davidson Pie diagram can be used to solve for feed rate (lbs or lbs/day), flow (MGD) or dosage (mg/L) by using the following formulas:
  1. Feed Rate, lbs/day = Flow (MGD) or Volume (MG) x Dosage (mg/L) x 8.34
  2. Flow (MGD) =  $\frac{\text{Feed Rate (lbs/day)}}{[\text{Dosage (mg/L)} \times 8.34]}$
  3. Dosage (mg/L) =  $\frac{\text{Feed Rate (lbs/day)}}{[\text{Flow(MGD)} \times 8.34]}$
- In order to use any of these formulas, all flows or volumes must be converted to either million gallons per day (MGD) or million gallons (MG).
- To convert feed rates from lbs/day use the following calculations:
  - lbs/hour = lbs/day ÷ 24.
  - lbs/30 days = lbs/day X 30 days
- You can use the following equation to calculate chlorine dose, chlorine demand or chlorine residual.
  - Chlorine Dose (mg/L) = Chlorine Demand (mg/L) + Chlorine Residual (mg/L)
- To calculate CT values, use the following formula:
  - CT = disinfectant concentration x contact time = C (mg/L) x T (**minutes**)
  - Remember to convert hours into **minutes** before using the formula.
- To calculate a **reduced dosage** when the **feed rate is decreasing**, you can

**Step 1:** Set up the variables in vertical format to solve for the dose, using **feed rate difference value**:

$$? \text{ Dose (mg/L)} = \frac{\text{Feed Rate Difference Value (lbs/day)}}{(\text{Flow, MGD}) \times (8.34)}$$

**Step 2:** Convert gallons per day into MGD and insert known values into equation.

**Step 3:** Multiply FLOW x 8.34 in the denominator.

**Step 4:** Perform the **DOSAGE** division of the **feed rate difference value**. (i.e., numerator ÷ denominator)

- **To calculate a reduced feed rate** when your plant **flow decreases**, you can create a ratio comparing the **original feed rate and flow** to the reduced feed rate and reduced flow and then cross multiply using the following steps:

**Step 1:** Create the ratio of  $\frac{\text{Original Feed Rate}}{\text{Original Flow}} = \frac{X(\text{Unknown Feed Rate})}{\text{Reduced Flow}}$

**Step 2:** To get "X" alone, cross multiply **original feed rate X reduced flow** (MGD)

**Step 3:** Then divide Step 2 numerator by original flow (MGD) denominator.

**Unit 4 Exercise**

1. If your chlorine feed rate is 20 lbs/day, how much chlorine will you use in 28 days? \_\_\_\_\_
  
2. If your chlorine feed rate is 50 lbs/day, what is the feed rate in lbs/hour? \_\_\_\_\_ lbs/hr
  
3. When calculating the CT value, time is measured in what units?
  - a) Seconds
  - b) Minutes
  - c) Hours
  
4. In order to perform the feed rate/dosage calculations, the flow must be converted to million gallons per day. (MGD)
  - a. True \_\_\_\_\_
  - b. False \_\_\_\_\_
  
5. Chlorine \_\_\_\_\_ = Chlorine demand + chlorine residual
  
6. Chlorine \_\_\_\_\_ = Chlorine dose – chlorine residual

**Reference**

Math principles and rules taken from Joanne Kirkpatrick Price, *Basic Math Concepts for Water and Wastewater Plant Operators*.

## **Safety Data Sheets (formerly MSDS)**

A Safety Data Sheet, or SDS, is available from the chemical manufacturer/supplier for every chemical. For years, these sheets were commonly known as MSDS for Material Safety Data Sheet. However, the Occupational Safety and Health Administration (OSHA) Hazard Communication Standard of 2012 (HazCom 2012) mandates the use of a single format for safety data sheets featuring **16 sections**. **MSDS sheets can be used by manufacturers until June 1, 2015**, but many manufacturers are complying before this date.

You should read and understand the SDS for each chemical used in the plant. You should also maintain a personal copy for all hazardous chemicals that are used.

An SDS contains detailed assessments of chemical characteristics, hazards and other information relative to health, safety and the environment. The SDS includes:

- **Section 1, Identification**
- **Section 2, Hazard(s) identification**
- **Section 3, Composition/information on ingredients**
- **Section 4, First-aid measures**
- **Section 5, Fire-fighting measures**
- **Section 6, Accidental release measures**
- **Section 7, Handling and storage**
- **Section 8, Exposure controls/personal protection**
- **Section 9, Physical and chemical properties**
- **Section 10, Stability and reactivity**
- **Section 11, Toxicological information**
- **Section 12, Ecological information**
- **Section 13, Disposal considerations**
- **Section 14, Transport information**
- **Section 15, Regulatory information**
- **Section 16, Other information**, includes the date of preparation or last revision.

# Safety Data Sheet



Chlorine

## Section 1. Chemical product and company identification

<b>Product name</b>	: Chlorine
<b>Supplier</b>	: AIRGAS INC., on behalf of its subsidiaries 259 North Radnor-Chester Road Suite 100 Radnor, PA 19087-5283 1-610-687-5253
<b>Product use</b>	: Synthetic/Analytical chemistry.
<b>Synonym</b> 1017	: Cl <sub>2</sub> ; Bertholite; Chloor; Chlor; Chlore; Chlorine mol.; Cloro; Molecular chlorine; UN
<b>MSDS #</b>	: 001015
<b>Date of Preparation/ Revision</b>	: <b>12/4/2013.</b>
<b>In case of emergency</b>	: 1-866-734-3438

## Section 2. Hazards identification

<b>Physical state</b>	: Gas. [GREENISH-YELLOW GAS WITH SUFFOCATING ODOR]
<b>Emergency overview</b>	: DANGER! OXIDIZER. CAUSES SEVERE RESPIRATORY TRACT, EYE AND SKIN BURNS. HARMFUL IF INHALED. MAY CAUSE TARGET ORGAN DAMAGE, BASED ON ANIMAL DATA. CONTACT WITH COMBUSTIBLE MATERIAL MAY CAUSE FIRE. CONTENTS UNDER PRESSURE.  Do not puncture or incinerate container. Do not breathe gas. Do not get on skin or clothing. May cause target organ damage, based on animal data. Use only with adequate ventilation. Keep container closed. Do not get in eyes, on skin or on clothing. Avoid breathing gas. Wash thoroughly after handling. Store in tightly-closed container. Avoid contact with combustible materials.  Contact with rapidly expanding gases can cause frostbite.
<b>Target organs</b>	: May cause damage to the following organs: lungs, upper respiratory tract, skin, eyes.
<b>Routes of entry</b>	: Inhalation Dermal Eyes
<b>Potential acute health effects</b>	
<b>Eyes</b>	: Severely corrosive to the eyes. Causes severe burns. Contact with rapidly expanding gas may cause burns or frostbite.
<b>Skin</b>	: Severely corrosive to the skin. Causes severe burns. Contact with rapidly expanding gas may cause burns or frostbite.
<b>Inhalation</b>	: Toxic by inhalation. Severely corrosive to the respiratory system.
<b>Ingestion</b>	: Ingestion is not a normal route of exposure for gases
<b>Potential chronic health effects</b>	
<b>Chronic effects</b>	: May cause target organ damage, based on animal data.
<b>Target organs</b>	: May cause damage to the following organs: lungs, upper respiratory tract, skin, eyes.
<b>Medical conditions aggravated by over- exposure</b>	: Pre-existing disorders involving any target organs mentioned in this MSDS as being at risk may be aggravated by over-exposure to this product.

See toxicological information (Section 11)

Chlorine

## Section 3. Composition, Information on Ingredients

<u>Name</u>	<u>CAS number</u>	<u>% Volume</u>	<u>Exposure limits</u>
Chlorine STEL: 2.9 mg/m <sup>3</sup> 15 minutes. STEL: 1 ppm 15 minutes. TWA: 1.5 mg/m <sup>3</sup> 8 hours. TWA: 0.5 ppm 8 hours. <b>NIOSH REL (United States, 1/2013).</b> CEIL: 1.45 mg/m <sup>3</sup> 15 minutes. CEIL: 0.5 ppm 15 minutes. <b>OSHA PEL (United States, 6/2010).</b> CEIL: 3 mg/m <sup>3</sup> CEIL: 1 ppm <b>OSHA PEL 1989 (United States, 3/1989).</b> STEL: 3 mg/m <sup>3</sup> 15 minutes. STEL: 1 ppm 15 minutes. TWA: 1.5 mg/m <sup>3</sup> 8 hours. TWA: 0.5 ppm 8 hours.	7782-50-5	100	<b>ACGIH TLV (United States, 3/2012).</b>

## Section 4. First aid measures

No action shall be taken involving any personal risk or without suitable training. If it is suspected that fumes are still present, the rescuer should wear an appropriate mask or self-contained breathing apparatus. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation.

<b>Eye contact</b>	: Check for and remove any contact lenses. Immediately flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical attention immediately.
<b>Skin contact</b>	: In case of contact, immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Wash clothing before reuse. Clean shoes thoroughly before reuse. Get medical attention immediately.
<b>Frostbite</b>	: Try to warm up the frozen tissues and seek medical attention.
<b>Inhalation</b>	: Move exposed person to fresh air. If not breathing, if breathing is irregular or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. Loosen tight clothing such as a collar, tie, belt or waistband. Get medical attention immediately.
<b>Ingestion</b>	: As this product is a gas, refer to the inhalation section.

## Section 5. Fire-fighting measures

<b>Flammability of the product</b>	: Non-flammable.
<b>Products of combustion</b>	: Decomposition products may include the following materials: halogenated compounds
<b>Fire hazards in the presence of various substances</b>	: Extremely flammable in the presence of the following materials or conditions: reducing materials, combustible materials, organic materials and alkalis.
<b>Fire-fighting media and instructions</b>	: Use an extinguishing agent suitable for the surrounding fire.

Apply water from a safe distance to cool container and protect surrounding area. If involved in fire, shut off flow immediately if it can be done without risk.

Contains gas under pressure. Contact with combustible material may cause fire. This material increases the risk of fire and may aid combustion. In a fire or if heated, a pressure increase will occur and the container may burst or explode.

<b>Special protective equipment for fire-fighters</b>	: Fire-fighters should wear appropriate protective equipment and self-contained breathing
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apparatus (SCBA) with a full face-piece operated in positive pressure mode.

**Chlorine****Section 6. Accidental release measures**

- Personal precautions** : Immediately contact emergency personnel. Keep unnecessary personnel away. Use suitable protective equipment (section 8). Eliminate all ignition sources if safe to do so. Do not touch or walk through spilled material. Shut off gas supply if this can be done safely. Isolate area until gas has dispersed.
- Environmental precautions** : Avoid dispersal of spilled material and runoff and contact with soil, waterways, drains and sewers.
- Methods for cleaning up** : Immediately contact emergency personnel. Stop leak if without risk. Use spark-proof tools and explosion-proof equipment. Note: see Section 1 for emergency contact information and Section 13 for waste disposal.

**Section 7. Handling and storage**

- Handling** : Use only with adequate ventilation. Wash thoroughly after handling. High pressure gas. Do not puncture or incinerate container. Use equipment rated for cylinder pressure. Close valve after each use and when empty. Do not get in eyes, on skin or on clothing. Keep container closed. Do not get on skin or clothing. Store in tightly-closed container. Avoid contact with combustible materials. Protect cylinders from physical damage; do not drag, roll, slide, or drop. Use a suitable hand truck for cylinder movement.
- Storage** : Keep container tightly closed. Keep container in a cool, well-ventilated area. Separate from acids, alkalis, reducing agents and combustibles. Cylinders should be stored upright, with valve protection cap in place, and firmly secured to prevent falling or being knocked over. Cylinder temperatures should not exceed 52 °C (125 °F).

**Section 8. Exposure controls/personal protection**

- Engineering controls** : Use only with adequate ventilation. Use process enclosures, local exhaust ventilation or other engineering controls to keep worker exposure to airborne contaminants below any recommended or statutory limits.
- Personal protection**
- Eyes** : Safety eyewear complying with an approved standard should be used when a risk assessment indicates this is necessary to avoid exposure to liquid splashes, mists or dusts.
- Skin** : Personal protective equipment for the body should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.
- Respiratory** : Use a properly fitted, air-purifying or air-fed respirator complying with an approved standard if a risk assessment indicates this is necessary. Respirator selection must be based on known or anticipated exposure levels, the hazards of the product and the safe working limits of the selected respirator.  
The applicable standards are (US) 29 CFR 1910.134 and (Canada) Z94.4-93
- Hands** : Chemical-resistant, impervious gloves complying with an approved standard should be worn at all times when handling chemical products if a risk assessment indicates this is necessary.
- Personal protection in case of a large spill** : Self-contained breathing apparatus (SCBA) should be used to avoid inhalation of the product. Full chemical-resistant suit and self-contained breathing apparatus should be worn only by trained and authorized persons.

**Product name**

chlorine

**ACGIH TLV (United States, 3/2012).**STEL: 2.9 mg/m<sup>3</sup> 15 minutes.

STEL: 1 ppm 15 minutes.

TWA: 1.5 mg/m<sup>3</sup> 8 hours.

TWA: 0.5 ppm 8 hours.

**NIOSH REL (United States, 1/2013).**CEIL: 1.45 mg/m<sup>3</sup> 15 minutes.

CEIL: 0.5 ppm 15 minutes.

**OSHA PEL (United States, 6/2010).**CEIL: 3 mg/m<sup>3</sup>

## Chlorine

CEIL: 1 ppm

OSHA PEL 1989 (United States, 3/1989).

STEL: 3 mg/m<sup>3</sup> 15 minutes.

STEL: 1 ppm 15 minutes.

TWA: 1.5 mg/m<sup>3</sup> 8 hours.

TWA: 0.5 ppm 8 hours.

Consult local authorities for acceptable exposure limits.

## Section 9. Physical and chemical properties

<b>Molecular weight</b>	: 70.9 g/mole
<b>Molecular formula</b>	: Cl <sub>2</sub>
<b>Boiling/condensation point</b>	: -34°C (-29.2°F)
<b>Melting/freezing point</b>	: -101°C (-149.8°F)
<b>Critical temperature</b>	: 143.85°C (290.9°F)
<b>Vapor pressure Vapor density</b>	: 85.3 (psig)
	: 2.5 (Air = 1)
<b>Specific Volume (ft<sup>3</sup>/lb)</b>	: 5.4054
<b>Gas Density (lb/ft<sup>3</sup>)</b>	: 0.185

## Section 10. Stability and reactivity

<b>Stability and reactivity</b>	: The product is stable.
<b>Incompatibility with various substances</b>	: Extremely reactive or incompatible with the following materials: reducing materials, combustible materials, organic materials and alkalis.
<b>Hazardous decomposition products</b>	: Under normal conditions of storage and use, hazardous decomposition products should not be produced.
<b>Hazardous polymerization</b>	: Under normal conditions of storage and use, hazardous polymerization will not occur.

## Section 11. Toxicological information

### Toxicity data

Product/ingredient name	Result	Species	Dose	Exposure
chlorine	LC50 Inhalation Gas.	Rat	293 ppm	1 hours
LC50 Inhalation Gas.		Rat	293 ppm	1 hours

**IDLH** : 10 ppm

**Chronic effects on humans** : **CARCINOGENIC EFFECTS:** A4 (Not classifiable for humans or animals.) by ACGIH. May cause damage to the following organs: lungs, upper respiratory tract, skin, eyes.

**Other toxic effects on humans** : Hazardous by the following route of exposure: of skin contact (irritant), of eye contact (irritant), of inhalation (lung irritant).

### Specific effects

**Carcinogenic effects** : No known significant effects or critical hazards.

**Mutagenic effects** : No known significant effects or critical hazards.

**Reproduction toxicity** : No known significant effects or critical hazards.

## Section 12. Ecological information

### Ecotoxicity data Aquatic ecotoxicity

Product/ingredient name	Test	Result	Species	Exposure
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**Chlorine**

chlorine Marine water	-	Acute EC50 5.1 ppm	Algae - Giant kelp - Macrocystis pyrifera - Young Aquatic plants -	4 days
- Fresh water		Acute EC50 930000 µg/l	Duckweed - Lemna minor	4 days
	-	Acute LC50 102 to 124 µg/l Fresh water	Fish - Brook trout - Salvelinus fontinalis - Juvenile (Fledgling, Hatchling, Weanling) - 10 to 15 cm Daphnia - Water flea - Daphnia	96 hours
	-	Acute LC50 91 µg/l Fresh water	pulex Fish - Spot - Leiostomus	48 hours
	-	Acute LC50 90 µg/l Marine water	xanthurus Daphnia - Water flea - Daphnia	96 hours
	-	Acute LC50 85 µg/l Fresh water	magna Daphnia - Water flea - Daphnia	48 hours
	-	Acute LC50 75 µg/l Fresh water	pulex Daphnia - Water flea - Daphnia	48 hours
	-	Acute LC50 40 µg/l Fresh water	pulex Fish - Atlantic silverside -	48 hours
	-	Acute LC50 37 µg/l Marine water	Menidia menidia Daphnia - Water flea - Daphnia	96 hours
	-	Acute LC50 30 µg/l Fresh water	pulex Fish - Rainbow trout,donaldson	48 hours
	-	Acute LC50 29 µg/l Fresh water	trout - Oncorhynchus mykiss Crustaceans - Scud -	96 hours
	-	Acute LC50 18 µg/l Fresh water	Gammarus minus Fish - Rainbow trout,donaldson	2 days
	-	Acute LC50 14 µg/l Fresh water	trout - Oncorhynchus mykiss Crustaceans - Aquatic sowbug -	96 hours
	-	Acute LC50 13.6 µg/l Fresh water	Asellus racovitzai Crustaceans - Scud -	2 days
	-	Acute LC50 9.67 µg/l Fresh water	Gammarus minus Crustaceans - Calanoid	2 days
	-	Acute LC50 >5 µg/l Marine water	copepod - Acartia tonsa Crustaceans - Aquatic sowbug -	48 hours
	-	Acute LC50 2.03 µg/l Fresh water	Asellus racovitzai	2 days

**Chlorine**




**Environmental hazards** : Water polluting material. May be harmful to the environment if released in large quantities.







**Toxicity to the environment** : Not available.

**Section 13. Disposal considerations**

Product removed from the cylinder must be disposed of in accordance with appropriate Federal, State, local regulation. Return cylinders with residual product to Airgas, Inc. Do not dispose of locally.

**Section 14. Transport information**

Regulatory information	UN number	Proper shipping name	Class	Packing group	Label	Additional information
<b>DOT Classification</b>	UN1017	CHLORINE	2.3	Not applicable (gas).	  	<p>Marine pollutant</p> <p><b>Reportable quantity</b> 10 lbs. (4.54 kg)</p> <p><b>Limited quantity</b> Yes.</p> <p><b>Packaging instruction</b> <b>Passenger aircraft</b> Quantity limitation: Forbidden.</p> <p><b>Cargo aircraft</b> Quantity limitation: Forbidden.</p> <p><b>Special provisions</b> 2, B9, B14, T50, TP19</p>

<b>Chlorine</b>						
<b>TDG Classification</b>	UN1017	CHLORINE	2.3	Not applicable (gas).	  	Marine pollutant  <b>Explosive Limit and Limited Quantity Index</b> 0  <b>ERAP Index</b> 500  <b>Passenger Carrying Ship Index</b> Forbidden  <b>Passenger Carrying Road or Rail Index</b> Forbidden
<b>Mexico Classification</b>	UN1017	CHLORINE	2.3	Not applicable (gas).	  	-

“Refer to CFR 49 (or authority having jurisdiction) to determine the information required for shipment of the product.”

## Section 15. Regulatory information

**United States**

**U.S. Federal regulations** : TSCA 8(a) CAIR: chlorine  
 TSCA 8(a) CDR Exempt/Partial exemption: Not determined  
 United States inventory (TSCA 8b): This material is listed or exempted.  
 SARA 302/304/311/312 extremely hazardous substances: Chlorine  
 SARA 302/304 emergency planning and notification: Chlorine SARA 302/304/311/312 hazardous chemicals: Chlorine  
 SARA 311/312 MSDS distribution - chemical inventory - hazard identification: Chlorine: Fire hazard, Sudden release of pressure, Immediate (acute) health hazard  
 Clean Water Act (CWA) 311: chlorine

Clean Air Act (CAA) 112 regulated toxic substances: chlorine

**SARA 313**

	<u>Product name</u>	<u>CAS number</u>	<u>Concentration</u>
<b>Form R - Reporting requirements</b>	: Chlorine	7782-50-5	100
<b>Supplier notification</b>	: Chlorine	7782-50-5	100

SARA 313 notifications must not be detached from the MSDS and any copying and redistribution of the MSDS shall include copying and redistribution of the notice attached to copies of the MSDS subsequently redistributed.

**State regulations**

**Connecticut Carcinogen Reporting:** This material is not listed.  
**Connecticut Hazardous Material Survey:** This material is not listed.  
**Florida substances:** This material is not listed.  
**Illinois Chemical Safety Act:** This material is not listed.  
**Illinois Toxic Substances Disclosure to Employee Act:** This material is not listed.  
**Louisiana Reporting:** This material is not listed.  
**Louisiana Spill:** This material is not listed. **Massachusetts Spill:** This material is not listed. **Massachusetts Substances:** This material is listed. **Michigan Critical Material:** This material is not listed.  
**Minnesota Hazardous Substances:** This material is not listed.  
**New Jersey Hazardous Substances:** This material is listed.  
**New Jersey Spill:** This material is not listed.  
**New Jersey Toxic Catastrophe Prevention Act:** This material is listed.  
**New York Acutely Hazardous Substances:** This material is listed.  
**New York Toxic Chemical Release Reporting:** This material is not listed.  
**Pennsylvania RTK Hazardous Substances:** This material is listed.  
**Rhode Island Hazardous Substances:** This material is not listed.

**Canada**

**WHMIS (Canada)**

: Class A: Compressed gas.  
 Class D-1A: Material causing immediate and serious toxic effects (Very toxic).  
 Class E: Corrosive material  
**CEPA Toxic substances:** This material is not listed.  
**Canadian ARET:** This material is not listed.  
**Canadian NPRI:** This material is listed.  
**Alberta Designated Substances:** This material is not listed.  
**Ontario Designated Substances:** This material is not listed.  
**Quebec Designated Substances:** This material is not listed.

**Section 16. Other information**

**United States**

**Label requirements**

: OXIDIZER.  
 CAUSES SEVERE RESPIRATORY TRACT, EYE AND SKIN BURNS.  
 HARMFUL IF INHALED.  
 MAY CAUSE TARGET ORGAN DAMAGE, BASED ON ANIMAL DATA.  
 CONTACT WITH COMBUSTIBLE MATERIAL MAY CAUSE FIRE.  
 CONTENTS UNDER PRESSURE.

**Canada**

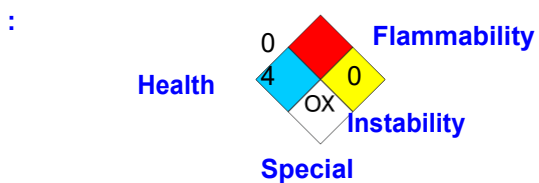
**Label requirements**

: Class A: Compressed gas.  
 Class D-1A: Material causing immediate and serious toxic effects (Very toxic). Class E: Corrosive material

**Hazardous Material Information System (U.S.A.)**

Health	*	3
Flammability		0
Physical hazards		0

**National Fire Protection Association (U.S.A.)**



**Notice to reader**

To the best of our knowledge, the information contained herein is accurate. However, neither the above-named supplier, nor any of its subsidiaries, assumes any liability whatsoever for the accuracy or completeness of the information contained herein.

Final determination of suitability of any material is the sole responsibility of the user. All materials may present unknown hazards and should be used with caution. Although certain hazards are described herein, we cannot guarantee that these are the only hazards that exist.