DISINFECTION

The process of killing pathogenic organisms in the drinking water supply is known as disinfection. Disinfection is the final step in the treatment process and is necessary to provide a "bacteriologically safe" drinking water for the public. Disinfection is now required for all public water supplies. Chlorination is the most common means of killing disease-causing organisms in water supplies.

While chlorine is used primarily for disinfection in water treatment, it also has other uses in the treatment process. Chlorine can be used to remove iron and manganese, some kinds of tastes and odors, and some dissolved gases, such as Ammonia (NH_3) and Hydrogen sulfide (H_2S). The use of chlorine in these instances usually occurs early in the treatment process. Pre-treatment of raw water by pre-chlorinating used to be a fairly common practice until the mid-1970's. Concerns over disinfection by-products, such as TriHaloMethanes (THM's) and halo acetic acids, have almost eliminated the practice of pre-chlorination in the United States. The removal of taste and odors from raw water is now accomplished using Powdered Activated Carbon (PAC) or oxidizing agents other than chlorine, that do not result in chlorinated by-products. The growing concern regarding the use of chlorine as a disinfectant may eventually mean a change to one of these other oxidizing agents as the primary means of disinfection at sometime in the future.

Chlorine is the most widely used disinfectant because it is readily available, easily applied, and cheaper than other oxidizing agents such as potassium permanganate ($KMnO_4$), chlorine dioxide (ClO_2), or ozone (O_3). Chlorine is applied in one of three forms; chlorine gas, chlorine powder (HTH), or an aqueous solution like chlorine bleach.

CHLORINE GAS

Chlorine gas (Cl_2) is compressed into a liquid for storage. It can be purchased in cylinders containing 150 or 2000 pounds of the liquefied gas. Chlorine gas is cheaper per pound than either of the other forms.

CHLORINE POWDER

Chlorine in its dry form is calcium hypochlorite [$Ca(OCl)_2$]. It is also most commonly known by the trade name HTH (High Test Hypochlorite). Only about 65 – 70% of the HTH is available as chlorine. The rest is calcium, which is not a disinfectant. Dry chlorine is 2-3 times more expensive, per pound of chlorine, than chlorine gas.

CHLORINE BLEACH

Chlorine bleach is a liquid solution of sodium hypochlorite ($NaOCl$). Bleach is usually 6 – 15% available chlorine. Bleach is the most expensive form of chlorine and is normally used for disinfecting small wells and water lines. A bleach solution will lose 2-4% of its available chlorine each month at room temperature. It should be used with 60-90 days.

CHLORINE TREATMENT TERMS

Several terms are used to identify the various stages and reactions that occur when chlorine is used as a disinfectant. The basic unit of measurement for chlorination, or any other chemical treatment is milligrams per liter (mg/l) or parts per million (ppm). These are very small units reflecting concentrations that are essentially one part chemical for every million parts of water. To get some idea of how small a concentration this really is it should be pointed out that 1% is equal to 10,000 mg/l or ppm.

CHLORINE DOSAGE

The chlorine dosage is the amount of chlorine that is added to the water. The dosage can be determined from the number of pounds of chlorine used and the number of millions of pounds of water treated.

CHLORINE DEMAND

Chlorine is a very reactive oxidizing agent. It will react with a certain substances that may be found in water. This list includes; iron, manganese, hydrogen sulfide, organic compounds and ammonia. When chlorine reacts with these substances, it loses it disinfecting properties. This is referred to as the chlorine demand. For chlorine to be effective as a disinfectant, the dosage must always exceed the demand that is present in the water. The chlorine demand may vary from day to day in a surface water supply. It is usually fairly constant in a ground water supply.

CHLORINE RESIDUAL

The chlorine that remains in the water, after it has finished reacting with those substances that represent the demand, is known as the chlorine residual. The concentration of the residual is determined by subtracting the demand from the dosage.

EXAMPLE: A 4.0 mg/l dosage is added to water that has a demand of 2.5 mg/l. What is the residual?

Dosage - Demand = Residual
4.0 mg/l - 2.5 mg/l = 1.5 mg/l Residual

There are two types of residuals that result from the chlorination of water. They are free chlorine residual and combined chlorine residual.

FREE CHLORINE RESIDUAL

After the demand has been satisfied, any chlorine that is left will react with water to form hydrochloric acid and hypochlorous acid.

$$Cl_2 + H_2O > HCl + HOCl$$

The hypochlorous acid is the disinfecting agent and the free chlorine residual is the concentration of the hypochlorite ion ($OC1^-$). Calcium hypochlorite will react with water to form hypochlorous acid and calcium hydroxide. Sodium hypochlorite will react with water to form hypochlorous acid and sodium hydroxide.

COMBINED CHLORINE RESIDUAL

Chlorine reacts with water to form hypochlorous acid. If ammonia is present, the hypochlorous acid will react with it to form compounds known as chloramines.

$$HOC1 + NH_3 > NH_2Cl + H_2O$$

Chloramines are found in three forms. They may contain from one (NH_2Cl) up to three (NCl_3) atoms of chlorine. They are referred to as monochloramine, dichloramine and trichloramine respectively. The chemistry of the water and concentration of chlorine will dictate which of the chloramines are formed. Chloramines are weak disinfectants. They require longer contact times and higher concentrations to achieve disinfection than free chlorine residual. However, they do not breakdown as quickly as free chlorine and remain in the system longer.

DISINFECTION REQUIREMENTS

Two factors must be taken into consideration when disinfecting drinking water. First, enough chlorine must be added to reach a predetermined concentration in the water. Then the bacteria must come in contact with the solution for a certain period of time. This is referred to as achieving the proper residual and contact time. Killing pathogenic bacteria requires a minimum of 0.2-0.4 milligrams per liter (mg/l) of free chlorine residual and a contact time of 20 minutes. The contact time can be reduced if the residual is increased. Viruses and protozoa like Giardia, and Cryptosporidium are harder to destroy than the other waterborne pathogens. Free residuals of 1.5-2.0 mg/l and much longer contact times may be required to destroy these organisms.

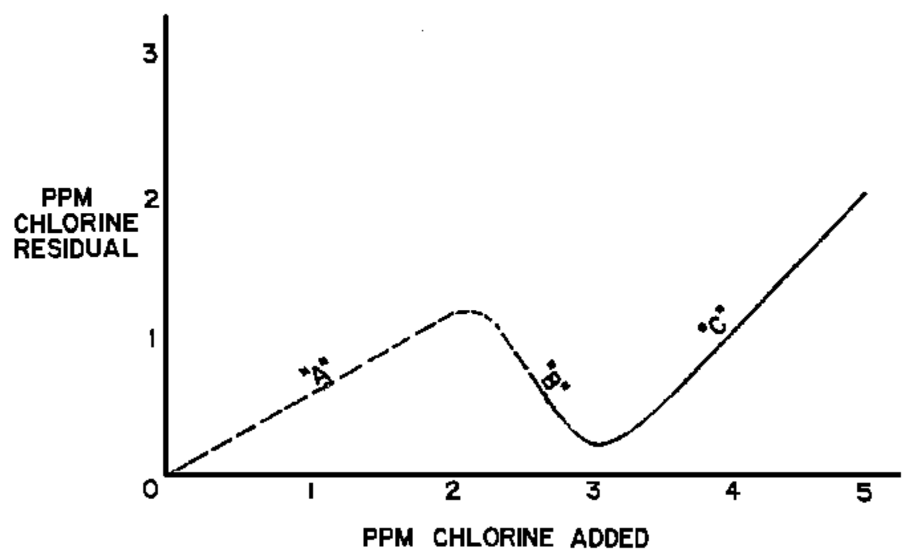
EFFECTS OF TEMPERATURE AND pH

Changes in temperature and pH of the water can reduce the effectiveness of chlorine. Colder temperatures slow down reaction times requiring higher concentrations and longer contact times to achieve proper disinfection. Hypochlorous acid is more effective killing pathogens than the hypochlorite ion. At a higher pH hypochlorous acid dissociates into hydrogen ions and hypochlorite ions. This is why water with a high pH requires a higher chlorine dosage to achieve proper disinfection.

BREAKPOINT CHLORINATION

When chlorine is added to water that contains no ammonia, the residual that is obtained will be free available chlorine. If ammonia is present, and the demand has been satisfied, some of the free chlorine will react with the ammonia to form chloramines or combined chlorine residual. As more chlorine is added, it will convert the chloramines that have been formed from monochloramine to trichloramine. The trichloramines are the weakest disinfectants and as a result, the combined residual will begin to drop. A point will be reached where the residual will begin to rise again. There may be some combined residual left in the water at this point. From this point, any additional chlorine dosage will result in the formation of only free chlorine residual. This is known as the "breakpoint". All water systems that chlorinate their water will, in fact, practice breakpoint chlorination. They will add enough chlorine to the water to achieve a free chlorine residual of at least 0.2-0.5 mg/l.

The Breakpoint Curve shown on below illustrates the formation and destruction of chloramines before free residuals are achieved. Every system's breakpoint will vary depending on the chemical makeup and chlorine demand of the raw water.



BREAKPOINT CURVE

As chlorine is added to the water, it reacts with the ammonia that is present and a combined residual reading is obtained (A). In this case, as the dosage increases to about 2ppm (mg/l) the combined residual drops because the chloramines are being destroyed (B). When the dosage reaches 3ppm (mg/l), the breakpoint occurs and first free chlorine residual is obtained. Once the breakpoint has been reached, the free residual will increase at the same rate as the dosage (C). There may still be some combined residual in the water even though the breakpoint has been reached, but it will remain at this minimum level as long as the dosage is greater that 3 ppm (mg/l).

A common complaint received by many operators is that the water has a "chlorine odor." These odors are almost always caused by chloramines in the water rather than a free chlorine residual. Understanding the break point curve may help solve this problem.

The initial reaction to this type of call may be to reduce the chlorine dosage to reduce the odors. This is actually the last thing that you would want to do. First, the problem may be able to re remedied by simply flushing the line in the area of the complaint. The odors are usually a result of stale water sitting in the lines. The free chlorine that was originally present may have broken back down into chloramines. Flushing will remove the stale water and the odor problem, until the water gets stale again. If flushing doesn't correct the problem, look at the breakpoint curve before adjusting the chlorine feed rate.

If the current conditions place us on the left side of the breakpoint there is no free residual present. This can be confirmed with a residual test. That means the water is on the "B" portion of the curve. Decreasing the chlorine dosage will result in moving further to the left on the curve into the "A" portion. Here the chlormine concentration is even higher and the odors may become worse instead of better. If the dosage is increased to the point where free chlorine residuals are present again, the amount of chloramines (and their odors) will be kept to a minimum.

TESTING FOR CHLORINE RESIDUALS

There are three methods that are used to test water for chlorine residual. Two of them are field tests. The Ortho-Tolidine-Arsenite (OTA) test was the industry standard until the mid - 1970's. The problem with the OTA test was that iron and nitrites in the water would interfere with the test. In addition, OTA was found to be a carcinogen. It is no longer used for chlorine residual testing today. Instead, the Diethyl-p-Phenylene-Diemine (DPD) test is used for field work. It is similar to the OTA test and there is no interference from iron or nitrites. A third test for chlorine residual is known as the amperometric titration method. It is normally run in a laboratory.

The DPD test is a colormetric analysis. The reagent is added to a vile of sample water. Another vile of sample water serves as a "blank." If chlorine is present the sample will turn pink or red. The blank is placed in front of the "color wheel" and the sample is compared to the color wheel and blank. There are two chemical packets for the DPD test. One is used for free chlorine and the other is used for total chlorine residual. Subtracting the free residual from the total residual will give you the combined residual.

General Chlorine Safety

Chlorine is a greenish-yellow gas. It is 2.5 times heavier than air. Chlorine gas is very corrosive. It turns into hydrochloric acid when it comes in contact with moisture (in the water, in the chlorine lines, or in your eyes or lungs). It does not support combustion though. It can be harmful if inhaled in small quantities and fatal in larger doses. Chlorine leaks can be located using ammonia vapors. The following table lists the effects of chlorine gas in various concentrations in the atmosphere.

SYMPTOM	CONCENTRATION
Noticeable odor	0.2 ppm
Irritation after several hours	1.0 ppm
Irritation of throat after a few minutes	15 ppm
Immediate coughing	30 ppm
Dangerous after 30 minute exposure	50 ppm
Lethal in minutes	1000 ppm

CHLORINATOR ROOM

The chlorinator room should have a window in the door so that the operator in the room can be seen from the outside. The light and vent switches should also be located outside the room. The room should have ventilation located at floor level since chlorine gas is heavier than air and will settle in the lowest spot in the room.

The room should be kept between 60^{o}F and 120^{o}F. Below 60^{o}F, chlorine gas forms chlorine hydrate, also known as "green ice," when it comes in contact with water. This green ice can clog the injector and gas piping, creating a serious maintenance problem.

When a chlorine cylinder is full and at room temperature, it is about 85% full of liquefied chlorine. As the temperature rises, the liquid expands and takes up more space in the cylinder. At 157^{o} F the liquid will expand to occupy 100% of the cylinder. If the liquid expands any further the cylinder will rupture, causing a massive chlorine leak.

NEVER enter a chlorine facility without ventilating for several minutes first. The National Fire Code now requires that new gas chlorine facilities be equipped with a scrubber system that will remove chlorine gas that may be present in the ventilation exhaust. These systems must have a backup power supply to keep the scrubber running in the event of a power failure. Check with local Fire authorities before new chlorine facilities are built to make sure they will be in compliance.

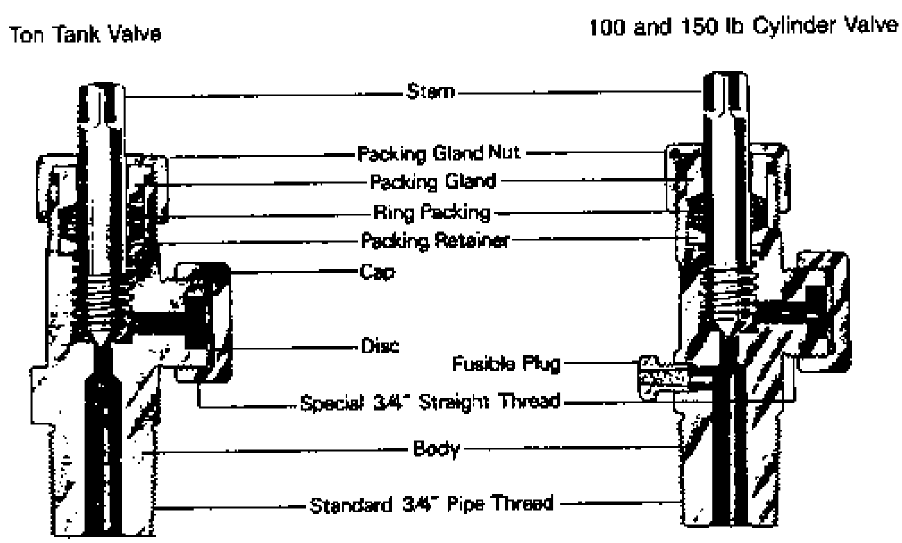
CHLORINE STORAGE

The room where chlorine cylinders or HTH drums are stored must be kept dry and well ventilated. Chlorine should always be stored in a room separate from other chemicals. Chlorine cylinders that are empty should be separated from those that are full. When not in use, all cylinders should be chained to the wall.

CHLORINE CYLINDERS

NEVER remove the valve hood from a chlorine cylinder unless it is chained to the scales and ready to be put on the system. All cylinders should be chained to the wall or the scales unless they are being moved. Emergency repair kits are available that can be used to seal leaks in the broken valves or leaking cylinders. Every system that operates a gas chlorine system should have an emergency kit or be able to get access to one on very short notice.

To prevent the cylinder from rupturing when it gets too hot, every gas cylinder will have a "fusible plug" that is designed to melt at 157^{o} F. There is one in the valve assembly of every 150 lb. Cylinder and six (three on each end) in the body of every 1-ton cylinder. As one of these fusible plugs melts, it will allow the release of chlorine gas from the cylinder. This still represents a serious problem, but the release will be more gradual than it would if the tank ruptured.



Chlorine Cylinder Valves

HTH and Bleach Handling Safety

Powdered chlorine should be stored in a cool dry place separate from other chemicals. HTH must never be allowed to come in contact with petroleum products or organic solvents. If this happens, it will explode violently! This is also true for the other forms of chlorine, but is more likely to occur during the handling of HTH. Care must also be taken to avoid contact with the eyes or bare skin.

Bleach should also be handled with care. In higher concentrations it becomes unstable. Bleach decomposes (releases chlorine vapors) at temperature above 104-176^{o}F. Materials that should not come in contact with bleach include strong acids, heavy metals, oxidizable materials, reducing agent, hydrocarbons, and other organic materials.

Respiratory Protection

Anyone involved in handling chlorine should have access to respiratory protection equipment. Chlorine gas forms hydrochloric acid when it gets in the eyes or lungs. This can result in serious injury or death depending on the concentration and exposure time. The damage caused by exposure to chlorine gas is cumulative. Several incidents involving minor exposure can contribute to serious health problems at sometime in the future.

There are two basic types of respiratory protection. One is the gas mask that uses a filtering device to remove chlorine. These are either a full-face mask or a mouth/nose type respirator. The other type of respirator is the self-contained breathing apparatus (SCBA). The SCBA unit is full-face mask with an air tank to provide the operator with fresh air to breathe when in hazardous atmospheres. Both of these devices may be rendered ineffective if the wearer has facial hair that interferes with the face-to-mask seal.

Gas Masks

The gas mask is designed to allow the operator time to escape the chlorine room when a leak occurs. **THESE DEVICES ARE INTENDED FOR ESCAPE PURPOSES ONLY! A GAS CANISTER MASK MUST NEVER BE USED TO ENTER ANY AREA WHERE CHLORINE GAS IS PRESENT!** If an operator is wearing a canister mask he must still leave the area immediately upon detection of a chlorine leak. The gas canisters should be changed every six months or anytime it has been exposed to chlorine gas.

Self-Contained Breathing Apparatus (SCBA)

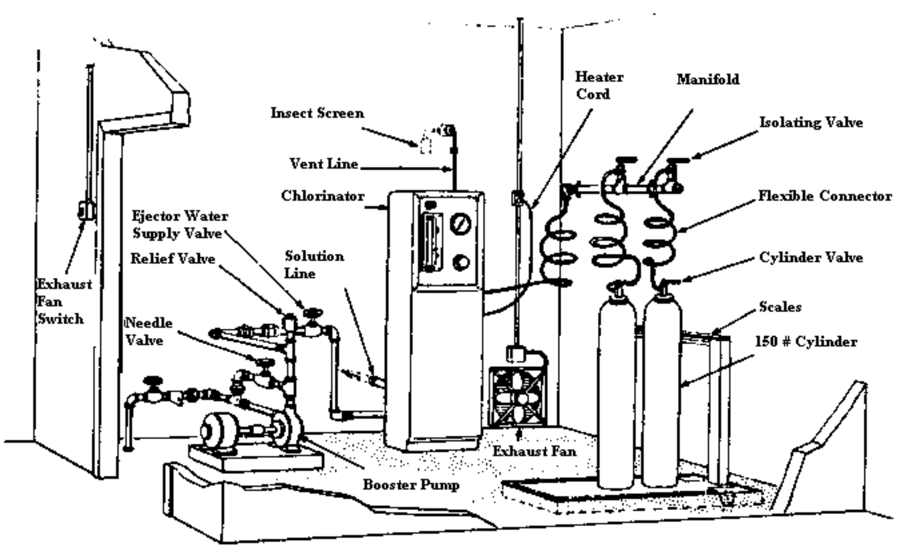
The SCBA unit must be used when working in a chlorine gas atmosphere. It has an air tank that allows the wearer to breathe uncontaminated air while attempting to correct a chlorine leak situation. The SCBA tank will hold enough air for approximately 30 minutes, depending on working conditions. When the air pressure drops to a point where there is about five minutes of air remaining in the tank (500 psi), an alarm will ring to signal the operator that it is time to exit the area and change tanks. Employees should have refresher training in SCBA use monthly.

CHLORINATION EQUIPMENT

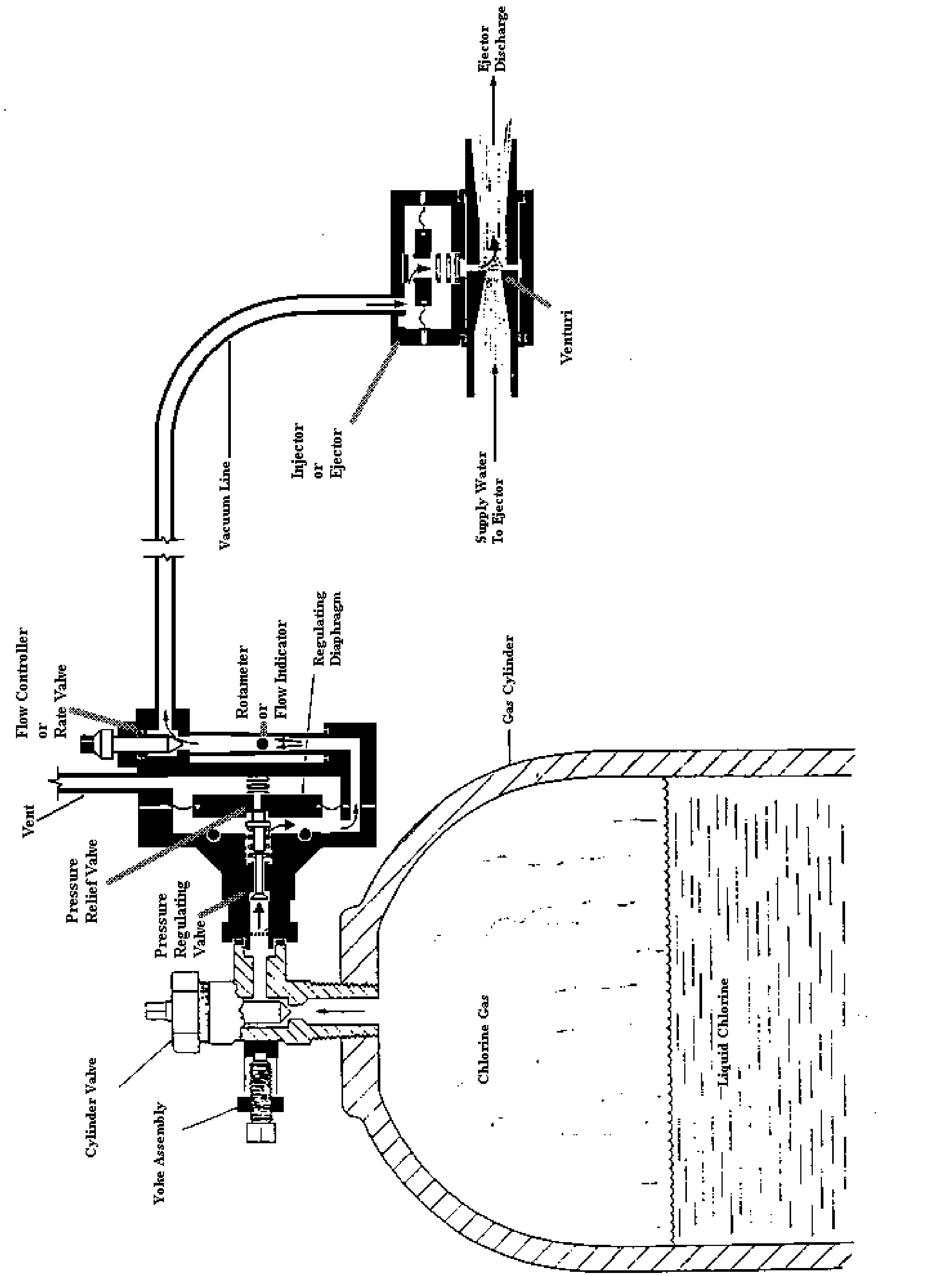
There are two ways to feed chlorine into the water system. Gas chlorination uses liquefied chlorine gas. Hypochlorination uses a positive displacement pump to feed a solution of dissolved HTH or bleach into the system. Many smaller systems will use a hypochlorination system because the equipment cost is lower. The solution of dissolved HTH or bleach is much easier to handle and presents less of a risk compared to a gas system. Gas chlorinating is used where the system requires larger dosages of chlorine than can be delivered by hypochlorination. Though capital costs are higher for gas chlorination, the chemical costs are significantly lower than when HTH or bleach is used.

GAS CHLORINATION

A gas chlorine system consists of one or more gas cylinders connected to gas chlorinator. The gas chlorinator consists of a pressure regulating valve, a feed rate indicator, a flow-regulating device (a V-notch plug or needle valve), and an injector. The injector (or ejector) has a venturi assembly and a diaphragm/check valve assembly. Water must pass through the venturi fast enough to create a vacuum. Chlorine will pass through the hole in the middle of the diaphragm and mix with the make-up water when the vacuum is created. The chlorine pressure-regulating valve (CPRV) opens when a vacuum is created by the injector and maintains a constant negative pressure inside the chlorinator. When there is no vacuum, the injector and CPRV will close to isolate the system. The feed rate indicator consists of a ball floating inside a glass tube. The feed rate is indicated on the glass tube and is read in "pounds per day." The feed rate should be read at the widest point of the ball or bead. The feed rate is controlled using the needle valve or V-notch plug. If the CPRV does not seal properly, as will enter the chlorinator under pressure when the unit is not feeding. The gas will pass through a hole in the CPRV diaphragm and vent to atmosphere.



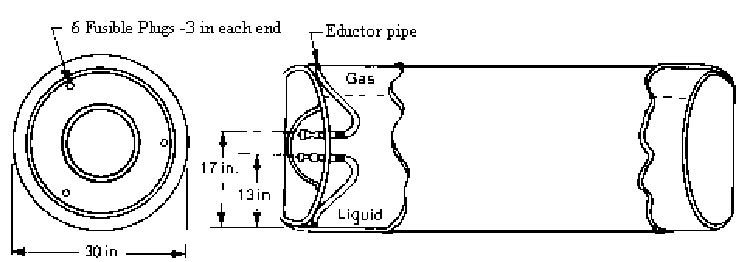
Gas Chlorination Installation (150 Lb. Cylinders)


Ejector Discharge
Venturi
Injector or Ejector
Vacuum Line
Supply Water To Ejector
Flow Controller or Rate Valve
Rotameter or Flow Indicator
Regulating Diaphragm
Gas Cylinder
Vent
Pressure Relief Valve
Pressure Regulating Valve
Cylinder Valve
Yoke Assembly
Chlorine Gas
Liquid Chlorine

TROUBLESHOOTING GAS CHLORINATORS

Symptom	Probable Cause
Low Feed Rate and Low Vacuum	Clogged Injector/Ejector
Low Feed Rate and High Vacuum	Clogged Gas Feed Line Closed Cylinder Valve Empty Cylinder
Feed Rate Jumps	Clogged Flow Controller/Needle Valve
Feed Rate Won't "Zero"	Dirty Flow Indicator/Rotameter
Chlorine Gas at Vent	Dirty Pressure Regulating Valve
No Vacuum	No Supply Water Vacuum Leak

The maximum fed rate for gas drawn from a 150 lb. Cylinder is 40 pounds/day. The maximum gas feed rate for a 1-ton cylinder is 400 pounds/day. If these feed rates are exceeded, the tanks will frost over because heat can't pass through the tanks as fast as it is used to evaporate the chlorine from a liquid to a gas. This can also occur in situations where several tanks are manifolded to the chlorinator. If one of the cylinder valves is partially closed the other tanks may try to feed too much gas and frost over. When this happens, check the tank that isn't frosted for a closed valve or plugged pigtail line. Ton cylinders are sometimes set up to feed liquefied gas. These systems used an evaporator to change the liquid to a gas before it goes to the chlorinator. There is no limit to how much liquid chlorine can be removed from a cylinder since the heat for evaporation is supplied by an outside source. NEVER manifold cylinders together when feeding liquefied chlorine to an evaporator. Expansion tanks equipped with rupture disks are used to protect all liquid feed piping. These provide protection from expansion of liquefied gas that may become isolated in the line.



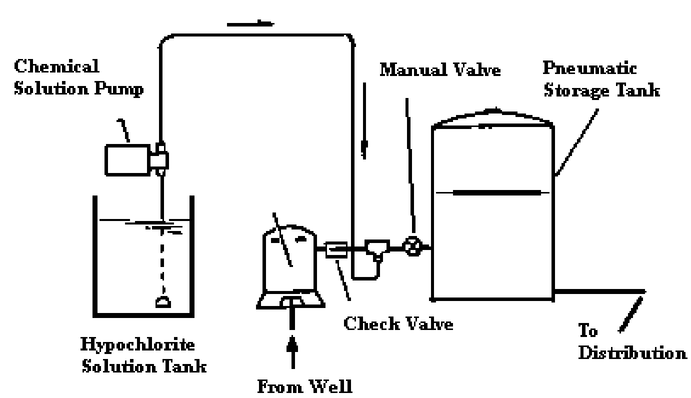
Cross Section of a 1-ton Cylinder

HYPOCHLORINATION SYSTEMS

A typical hypochlorination system will consist of:

- **A solution tank holding bleach or an HTH solution.**
- **A chemical feed pump, usually a diaphragm-type pump.**
- **A tee into the well line as the point of application.**

The solution tank should hold at least a one-day supply of chlorine solution. If the solution is bleach, it will have between 5.25% and 12% available chlorine (1/3 to 1 lb./gallon respectively). If HTH is used, add 1.5 pounds of HTH per gallon of water to achieve a 1.0-lb./gallon chlorine solution. Using breakpoint chlorination, adjust the stroke on the pump to achieve the desired dosage. Small systems may need to dilute the solution further, since the low flows may require feed rates too low for most feed pumps.



Typical Hypochlorination System

The chemical feed pump consists of a diaphragm driven pump chamber, and two check valves. The check valves, that provide the one-way flow through the pump, can get clogged with lime deposits. This occurs because the HTH that is added to the solution tank is 30-35% lime. The strainer on the pump suction line should be located several inches above the bottom of the solution tank to prevent lime and grit from being drawn into the pump and fouling the check valves.

If the check valves get fouled, the pump will not pump any solution. Flushing the line with clean water or a weak acid, like vinegar, may also correct the problem. In severe cases the valves may have to be disassembled and cleaned. Always make sure the pump is primed before putting it back into service. It may also be advantageous to locate the pump so that it has a positive suction head.

EMERGENCY RESPONSE PROCEDURES

When chlorine systems are located in areas where a chlorine release might endanger the general public, the water system is responsible for developing an emergency response program.

COMPONENTS OF AN EMERGENCY RESPONSE PLAN

* **Containment and repair of the leak**
* **Notification of other emergency preparedness agencies**
* **Evacuation plans for the general public**
* **Medical evacuation for casualties**

The following steps should be followed when a leak poses immediate danger to employees or the public:

1) **Evacuate, in an upwind direction, to high ground.**
2) **Once evacuation is complete, notify emergency medical units of casualties and begin administering First Aid to the injured.**
3) **Notify local fire and police departments. Include the following information:**
   a) **Nature of the accident**
   b) **Approximate amount of chlorine that may be released.**
   c) **Location of chlorine facility**
   d) **Current wind direction**
4) **Notify County and State health agencies.**

DECHLORINATING AFTER DISINFECTION

New drinking water regulations do not permit the discharge of water with free chlorine residuals that exceed 2.0 mg/L. Water used to super-chlorinate storage tanks, wells, or water mains must be dechlorinated prior to release into the environment. There are several chemicals that can be used for dechlorination. One is ascorbic acid (Vitamin C) and the others are sodium bisulfite, sodium sulfite, sodium bisulfate, and sulfur dioxide. The most widely used sulfur compound is sodium bisulfite. Water can also be dechlorinated by passing it through a bed of granulated activated carbon.

Powdered ascorbic acid is a weak acid that is reasonably easy to handle. It should be stored separate from other chemicals and kept in a cool, dry and well-ventilated room. Sodium bisulfite is a liquid that is highly reactive in the presence of acids and oxidizers (like bleach). It should be handled with a great deal of care using the proper PPE including respirators, face shields, goggles, chemical gloves and aprons. It should be stored separate from other chemicals. Always refer to the MSDS for both bleach and the dechlorination chemicals when performing these tasks.

A solution of powdered ascorbic acid is mixed in a container and fed into the discharge stream using a venturi. The venturi is attached to the hydrant nozzle or discharge line and the siphon tube is attached to the center. The flow of water through the venturi creates a vacuum that draws the ascorbic acid into the flow stream. Special hydrant discharge diffusers that hold ascorbic acid tablets can also be used. The chlorine residual in the discharge water is used to determine the concentration of ascorbic acid. Sodium bisulfite is fed into the discharge from the hydrant or drain using a positive displacement pump. It takes about 1.4 pounds of sodium bisulfite to neutralize a pound of chlorine. The ratio for ascorbic acid is about 2.5:1.

The chlorine residuals before and after dechlorination should be taken every 5-10 minutes and recorded. When the residual prior to dechlorination drops below 2.0 mg/L the flush can be shut down.

VENTURI EDUCTOR SYSTEM TO FEED ACSORBIC ACID

ALTERNATIVES TO CHLORINATION

The problem of disinfection by-products has caused many systems to consider disinfection alternatives to chlorine. Ozone, chlorine dioxide, potassium permanganate, and ultra-violet radiation are all being used. They all have advantages and disadvantages.

OZONE

Ozone (O_3) is created when high voltage electricity arcs across and oxygen atmosphere. Ozone is created when lightning strikes and when a spark plug in a combustion engine ignites. Ozone is up to 30 times better at disinfection than hypochlorous acid. It must be generated on-site using electricity. The corona tube system is the most common method of producing ozone. A high voltage current is introduced into a dielectric glass tube containing dry filtered air or pure oxygen. The gas is pumped into the water through diffuser heads. The ozone (and some oxygen) dissolves in the water. Ozone is not only a great disinfectant; it is also used to remove color and organic taste and odors. It kills the protozoan pathogens much faster with very low residual requirements.

There are several disadvantages to ozone disinfection. Ozone generation is a very expensive process. When the process is down there is no backup supply available. The only disinfection by-product issue with ozone is the formation of bromate when bromine is present in the water. Because ozone is such a good oxidizer and disinfectant; it doesn't last long in water. It breaks down into dissolved oxygen and has a half-life of about 20 minutes. As a result, ozone does not provide much protection from secondary contamination in the distribution system. Chlorine is usually added after ozonation in order to maintain disinfection protection in the system.

CHLORINE DIOXIDE

Chlorine dioxide (ClO_2) is a colorless odorless gas that is toxic in the same ranges as chlorine gas. Fortunately, it has to be generated on-site in an aqueous solution. It is released by the oxidation of sodium chlorite (Na_2ClO_2). This is accomplished by mixing sodium chlorite with chlorine gas or hydrochloric acid. It can also be released using an electrolytic process. This process is similar to the bleach generation process that uses salt water and electrical current to make bleach. The chlorine dioxide gas is immediately dissolved in the solution.

Chlorine dioxide is 7-10 times stronger than hypochlorous acid as a disinfectant. It doesn't form chloramines and has much lower THM production than chlorine. It is used in surface water treatment for organic pretreatment and *Giardia* and *Cryptosporidium* reduction.

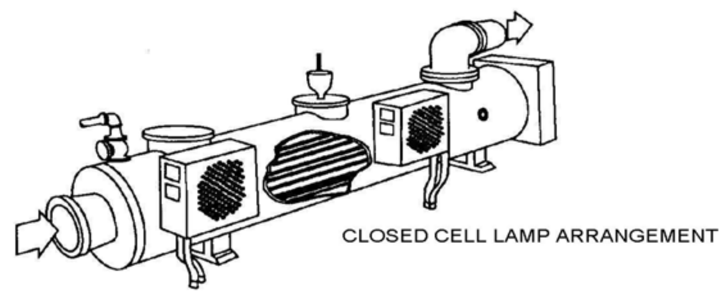
There are some serious chemical handling issues since chlorine gas and hydrochloric acid are the primary oxidizing chemicals for the reaction. Sodium chlorite is also highly reactive. It is combustible in the presence of organic compounds. Spills must be neutralized with a solution of anhydrous sodium sulfite. Face shields, goggles, rubber outerwear, and respiratory equipment are required PPE for handling either of these chemicals.

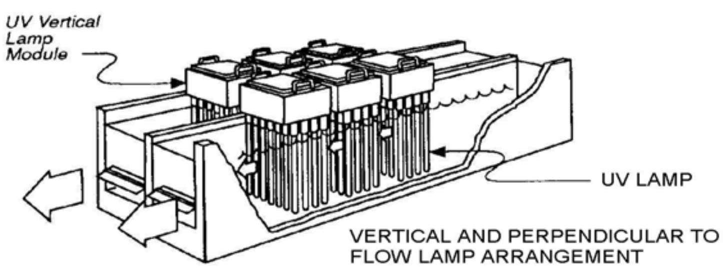
POTASSIUM PERMANGANATE

Potassium permanganate ($KMnO_4$) is a crystalline solid that is fed as a solution. It is several times stronger than chlorine. It can be used for organic pretreatment. There are no THM's or haloacetic acids formed because there is no chlorine involved in the reaction. There are several disadvantages to using potassium permanganate. It is a strong oxidizer and must be stored in stainless steel containers. It is very expensive. If the concentration is too high the water will turn pink.

ULTRA-VIOLET DISINFECTION

Ultra-violet disinfection uses high intensity U-V rays to destroy pathogens. Like sunburn, the U-V rays damage the chromosomes of the organism to kill it. The efficiency of a U-V system is dependent on the water clarity, contact time and bulb intensity. One of the advantages of U-V disinfection is that there are no chemical by-products. These systems are also cheaper to operate than comparable chlorination systems.





ULTRA-VIOLET RADIATION SYSTEMS

One of the disadvantages to the process is that, like ozone, there is no residual. Chlorine will usually be added after the U-V process to provide protection from secondary contamination. The U-V bulbs must be cleaned periodically. Over time they will become coated with lime scale, iron deposits and bio-slime.

BASIC STUDY QUESTIONS

1. What is meant by disinfection?

2. What are some of the uses for chlorine other than disinfection?

3. What is a free chlorine residual?

4. What are trihalomethanes?

5. What is breakpoint chlorination?

6. What are the characteristics of chlorine gas?

7. Which chlorine residual has a noticeable odor?

8. What test is used for chlorine residual analysis?

BASIC SAMPLE TEST QUESTIONS

1. Locate chlorine leaks with:

   A. Ammonia
   B. Bleach
   C. Hydrochloric acid
   D. Water

2. Chlorine gas can be lethal at concentrations as low as 40 ppm.

   A. True
   B. False

3. Breakpoint chlorination occurs when combined chlorine residuals have been achieved.

   A. True
   B. False

4. A fusible plug melts at:

   A. 120^{o} F
   B. 157^{o} F
   C. 188^{o} F
   D. 212^{o} F

5. Calcium Hypochlorite is:

   A. 5-12% available chlorine
   B. 65-70% available chlorine
   C. 100% available chlorine

6. A gas chlorinator rotameter reading is:

   A. Milligrams per liter
   B. Cubic feet per day
   C. Pounds per day

7. Take the rotameter reading at:

   A. The top of the float
   B. The bottom of the float
   C. The widest part of the float

8. A 1-ton cylinder will have how many fusible plugs?

   A. 6
   B. 4
   C. 2
   D. 1

ADVANCED STUDY QUESTIONS

1. What two acids are formed when chlorine reacts with water?

3. What are the advantages and disadvantages of ozone disinfection?

4. What is the maximum gas feed rate for a 150 lb. Cylinder?

5. How should you handle chlorine odor complaints?

6. What additional pieces of equipment will be needed to feed liquefied chlorine gas from a ton cylinder?

7. What chemicals can be used to dechlorinate super-chlorinated water?

ADVANCED SAMPLE TEST QUESTIONS

1. The maximum feed rate for a 150 lb. cylinder is:

   A. 10 pounds/day
   B. 20 pounds per day
   C. 40 pounds per day
   D. 150 pounds per day

2. What is the maximum chlorine residual dechlorination of discharged water?

   A. 2.0 mg/L
   B. 4.0 mg/L
   C. 20 mg/L
   D. 50 mg/l

3. Canister masks are for escape purposes only.

   A. True
   B. False

4. Chlorine dioxide is:

   A. 7-10 times stronger than chlorine
   B. Generated on-site
   C. A colorless odorless gas
   D. All of the above

5. Too much potassium permanganate can turn the water:

   A. Blue
   B. Pink
   C. Black

6. A low vacuum in the system can be caused by:

   A. Dirty rotameter
   B. Clogged injector
   C. Relief valve open

7. Liquefied gas is drawn from a ton cylinder using:

   A. The top valve
   B. The bottom valve
   C. A venturi device

8. Gas coming from an outside vent line would indicate a:

   A. Clogged injector
   B. Dirty pressure regulating valve
   C. Vacuum leak
   D. Closed cylinder valve

9. If more than 40 pounds per day are drawn from a 150-pound chlorine cylinder it will overheat.

   A. True
   B. False