Disinfection

The object of disinfection is to kill disease-causing organisms present in the water. With regard to water treatment, disinfection refers to the destruction of most intestinal or fecal bacteria. Sometimes disinfection is not complete. Some viruses and especially some protozoa, such as *Giardia* or *Cryptosporidium,* could survive the disinfection process. The only method of complete protection is to sterilize the water by boiling it for a period of 15 to 20 minutes. This process kills most living organisms, but it is only practical as an emergency measure for the individual users.

DISINFECTION AGENTS

The methods of disinfection practical in public water supplies are chlorination, ozonation, use of ultra-violet light, and over-liming. Potassium permanganate, iodine, bromine, and silver are also used, but less frequently. Of these, only bromine has been found to be effective and economical in the treatment of water. Chlorination is so widely used that the terms disinfection and chlorination are almost the same in waterworks practice. Chlorination will be fully discussed later in this chapter.

Ozone is produced by passing a high voltage current through air. Disinfection is accomplished by introducing this ozone into the water to be disinfected. Ultra-violet (UV) treatment is accomplished by passing a thin film of water over a quartz-enclosed mercury vapor lamp. UV will sterilize almost completely but only when the water is clear. Its advantages are that no chemicals are used, no odors are formed, and there is no possibility of overdosage. Disadvantages of UV are that, when used alone, a large lamp surface is required and it does not produce a residual to cope with subsequent contamination in the distribution system. The lamp can be costly to maintain.

Over-liming water, usually done in connection with softening, is destructive to intestinal bacteria, especially when the pH is over 10.3 for a period greater than 6 hours. A residual disinfectant must be used in conjunction with softening.

DISCOVERY AND EARLY CONCEPTS

The disinfection of water has been practiced for several hundred years, even though initially there was no understanding of the principals involved. Historical records show that the boiling of water had been recommended at least as early as 500 B.C.

Chlorine was identified as a chemical element in the early 1800s. Because of its characteristic color, the name chlorine was derived from the Greek word chlorous, meaning pale green. It was not until sometime later, however, that its value as a disinfectant was recognized.

The first record of chlorine being used directly for water disinfection was on an experimental basis, in 1896 in connection with filtration studies in Louisville, Kentucky. It was employed for a short time in 1897 in England, again on an experimental basis, to sterilize water distribution mains following a typhoid outbreak. Its first continuous use was in Belgium, beginning in 1902, for the dual objective of aiding coagulation and disinfection. The first permanent use in the United States was in Jersey City, New Jersey. The practice was contested in court, but the court found that it represented a public-health safeguard. This action paved the way for its rapid extension to other public water supplies in North America.

CHLORINATION

Originally, chlorination was the final treatment process after clarification and filtration. In some cases, it was the only treatment provided. In 1915, the influence of ammonia on the disinfection qualities of chlorine was discovered. This led to prolonging widespread adoption of combined treatment with chlorine and ammonia. The combination of chlorine and ammonia produced a more stable disinfection residual than chlorine alone. However, a combined chlorine and ammonia residual is not as effective as a free-chlorine residual.

The most effective chlorine residual is created by breakpoint-chlorination. This concept began to emerge in the early 1940s. It was reported that some waters exhibited a break in the chlorine residual curve upon addition of a supplementary amount of chlorine, creating a free chlorine residual. (This will be discussed more later in the chapter) For most supplies, chlorinating to create a free available chlorine residual, or the practice of breakpoint chlorination, is the best form of disinfection. However, free chlorine may produce undesirable by-products, especially when water that contains organic chemicals is treated. In these cases, the system may have to switch to the use of chlorine with ammonia or the use of chlorine dioxide or ozone as the disinfectant.

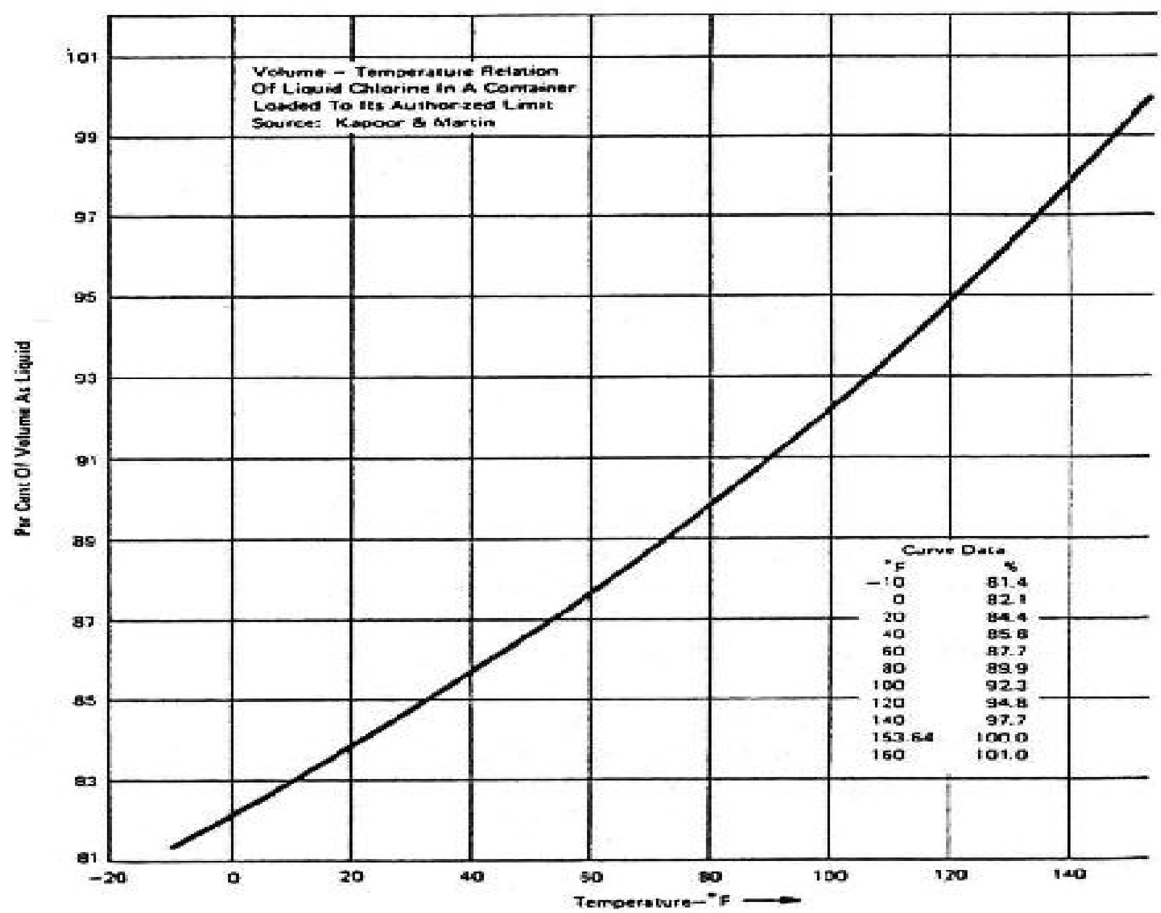
Improvements in chlorine disinfection materials and in chemical feeders contributed to the popularity and widespread adoption of chlorination. Disinfection dosages originally were based largely on the application of a fixed amount of chemical. No provisions were made for the effects of variations in water quality and the fluctuations in chlorine demand or in the amount of chlorine used by the water before a stable residual could be measured. Testing the residual amount of chlorine after the chlorination brought about the practice of varying the amount of feed. The testing of chlorine residual was originally done with the chemical orthotolidine (OTD), which was used until the mid- 1970s when the much safer N,N-diethyl-p-phenylenediamine (DPD) test procedure was developed as the standard. The OTD method should not be used as OTD is toxic and possibly carcinogenic.

Gaseous chlorine is the least expensive form of chlorine for water supplies. In small-water utility installations or for field-emergency or other specialized uses, other chlorine-containing compounds may be easier to use and more economical. Such materials are various hypochlorites or liquid bleach solutions, chlorinated lime, or chlorine dioxide.

Chlorine Gas Properties

At room temperature, elemental chlorine is a greenish-yellow gas about 2½ times heavier than air. Therefore, it will sink to the floor if released from its container. It is sold to the water supplies as a compressed liquid that is amber in color and about 1 to 1½ times heavier than water. If liquid chlorine is unconfined, it rapidly vaporizes to gas (one volume of liquid chlorine equals about 450 volumes of gas).

Chlorine confined in a container may exist as a gas, liquid, or both. The gas vapor pressure in the container (the 150-pound cylinder, the ton container, or the rail car) is a function of the temperature. It is independent of the volume of chlorine in the container. Thus, the gauge pressure of a container with one pound of chlorine is the same as a container with 100 pounds of chlorine at the same temperature.



Volume-Temperature Relation of Liquid Chlorine in a Container Loaded to Its Authorized Limit

Chlorine is only slightly soluble in water; its maximum solubility is approximately one percent at 49° C. At temperatures below this point it combines with water to form chlorine ice, a crystalline substance. When the water supply to a gas chlorinator is below normal room temperature, it may cool the chlorine gas to the point at which chlorine ice is formed and accumulates on the needle valve and gas outlet tube, resulting in erratic feed results. Because the vapor pressure of chlorine increases with rising temperatures, its solubility also decreases. At 212° F. chlorine is insoluble in water.

Chlorine dissolved in water forms a weak corrosive mixture of hydrochloric and hypochlorous acid. The corrosivity of chlorine solutions in water creates problems in handling chlorine spills and chlorine containers.

Chlorine reacts with many compounds. Because of its great affinity for hydrogen, it removes hydrogen from some compounds, such as hydrogen sulfide. It also reacts with ammonia or other nitrogen-containing compounds to form various mixtures of chloramines. It reacts with organic materials, sometimes with explosive violence. The operator should be cautious with chlorine compounds and avoid handling them with greasy or dirty scoops.

Although it is neither explosive nor flammable by itself, chlorine is capable of supporting the combustion of certain substances. It should be handled and stored away from compressed gases, such as ammonia and other flammable materials.

Most common metals are not affected at normal temperatures by dry chlorine, either gas or liquid. Chlorine is, however, reactive with aluminum and ignites carbon steel at temperatures above 450° F. Moist chlorine is corrosive to all common metals with the exception of gold, silver, platinum, titanium, and certain specialized alloys.

Physical Effects of Exposure to Chlorine Gas

Chlorine gas is primarily a respiratory irritant and concentrations in air above one part per million (ppm) can usually be detected by most persons. Chlorine causes varying degrees of irritation of the skin, mucus membranes, and the respiratory system, depending on the concentration and the duration of exposure. Severe exposure can cause death, but the severe irritating effect makes it unlikely that anyone would remain in the chlorine-containing atmosphere unless trapped or unconscious.

Liquid chlorine may cause skin and eye burns upon contact with these tissues. Chlorine produces no known cumulative or chronic effect, and complete recovery usually can be expected to occur shortly following mild, short-term exposure. An eight-hour time-weighted exposure of one ppm and a one-hour weighted exposure are the current federal Occupational Safety and Health Administration (OSHA) standards.

Hypochlorites

Hypochlorites are calcium or sodium salts of hypochlorous acid and are supplied either dry or in liquid form (as, for instance, in commercial bleach). The same residuals are obtained as with gas chlorine, but the effect on the pH of the treated water is different. Hypochlorite compounds contain an excess of alkali and tend to raise the pH of the water. Calcium hypochlorite tablets are the predominant form in use in the United States for swimming pools. Sodium hypochlorite is the only liquid hypochlorite disinfectant in current use. There are several grades and proprietary forms available. Pound-for-pound of available chlorine, hypochlorite compounds have oxidizing powers equal to gas chlorine and can be employed for the same purposes in water treatment. Gas chlorination requires a larger initial investment for feed equipment than what is needed for hypochlorite compounds.

Calcium hypochlorite materials used in the water industry are chemically different from those materials variously marketed for many years as bleaching powder, chloride of lime, or chlorinated lime. Materials now in common use are high-test calcium hypochlorites containing about 70 percent available chlorine and marketed under several trade names.

High-test calcium hypochlorites are white corrosive solids that give off a strong chlorine odor. Granular powdered or tablet forms are commercially available and all are readily soluble in water.

Sodium hypochlorite is sold only as a liquid and is normally referred to as liquid bleach. It is generally available in concentrations of 5 to 15 percent available chlorine. These solutions are clear, light yellow, strongly alkaline, and corrosive in addition to having a strong chlorine smell.

High-test hypochlorites, though highly active, are relatively stable throughout production, packaging, distribution, and storage. Storage at 86° F. for a year may reduce the available chlorine by about 10 percent. Storing at lower temperatures reduces the loss. All sodiumhypochlorite solutions are unstable to some degree and deteriorate more rapidly than the dry compounds. Most producers recommend a shelf life of 60 to 90 days. Because light and heat accelerate decomposition, containers should be stored in a dry, cool, and dark area.

Chlorine Dioxide

Chlorine dioxide is created by mixing solutions of sodium chlorite and chlorine. The advantages of chlorine dioxide are it is a strong bactericide and viricide over a wide pH range; it forms a slight residual in the distribution system; it does not react with nitrogen to form chloramines; and it does not react with organic matter to form trihalomethanes (THMs). The disadvantages of chlorine dioxide are its high cost and its tendency to create chlorate and chlorite, which are potential toxins. Chlorine dioxide is used for taste and odor control as well as disinfection.

CHLORINATION PRACTICES

Early chlorination practices were developed for the purpose of disinfection. Combined chlorine and ammonia treatment was introduced to limit the development of objectionable tastes and odors often associated with marginal chlorine disinfection. Super chlorination was developed for the additional purpose of destroying objectionable taste and odor producing substances often associated with chlorine containing compounds. The discovery of breakpoint chlorination, followed by the recognition that chlorine residuals can exist in two distinct forms, led to the establishment of the two methods for water chlorination used today.

Use of Combined Residual Chlorination

Combined residual chlorination involves the addition of chlorine to water to produce, with natural ammonia present or with ammonia added, a combined available chlorine residual. Combined available chlorine forms have lower oxidation potentials than free available chlorine forms and are less effective as oxidants. They are also less effective as disinfectants. In fact, 25 times more combined available residual chlorine must be obtained to meet the same disinfectant level as a free available residual. The contact time has to be up to 100 times greater to obtain the same level of bacterial kill at the same pH and temperature conditions.

When a combined available chlorine residual is desired, the character of the water determines how it can be accomplished. These conditions may have to be considered:

1. If the water contains sufficient ammonia to produce the desired level of combined residual, the application of sufficient chlorine alone is all that is needed.
2. If the water contains too little or no ammonia, then addition of both chlorine and ammonia is required.
3. If the water has a free available chlorine, the addition of ammonia alone is all that is required. A combined chlorine residual should contain little or no free available chlorine.

The practice of combined residual chlorination is the most effective way of maintaining a stable residual throughout the distribution system to the point of consumer use. Combined residuals in the distribution system are generally longer-lasting and will carry farther into the system, but they are not as effective as free residuals are at disinfecting. The levels required by the regulatory agencies, when using combined residuals, are 1.0 ppm to 2.0 ppm.

Use of Free Residual Chlorination

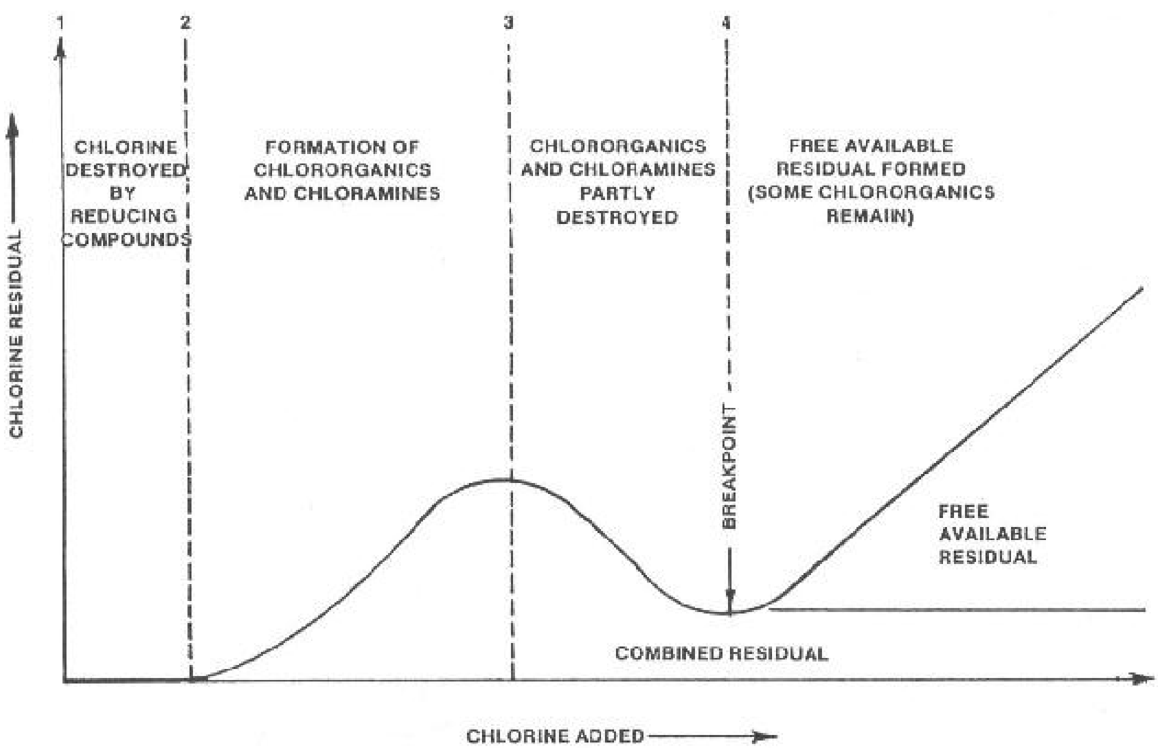
Free residual chlorination involves the application of chlorine to water to produce—either directly or by first destroying any naturally present ammonia—a free available chlorine residual and to maintain this residual through part or all of the water treatment plant and distribution system. Free available residual forms have higher oxidation potentials than combined available chlorine forms and are more effective as disinfectants.

When free available chlorine residuals are desired, the characteristics of the water will determine how this will be accomplished. This may have to be considered:

1. If the water contains no ammonia or other nitrogen compounds, any application of chlorine will yield a free residual once it has reacted with any bacteria, virus and other microorganisms present in the water.
2. If the water contains ammonia, it results in the formation of a combined residual, which must be destroyed by applying an excess of chlorine (see the breakpoint chlorination curve).

Breakpoint Chlorination

Breakpoint chlorination is the name of the process of adding chlorine to water until the chlorine demand has been satisfied. Chlorine demand equals the amount of chlorine used up before a free available chlorine residual is produced. Further additions of chlorine will result in a chlorine residual that is directly proportional to the amount of chlorine added beyond the breakpoint. Public water supplies normally chlorinate past the breakpoint.



Breakpoint chlorination

When chlorine is initially added to water, the following may happen:

1. If the water contains some iron, manganese, organic matter, and ammonia, the chlorine reacts with these materials and no residual is formed, meaning that no disinfection has taken place.
2. If additional chlorine is added at this point, it will react with the organics and ammonia to form chloramines. The chloramines produce a combined chlorine residual. As the chlorine is combined with other substances, it loses some of the disinfection strength. Combined residuals have poor disinfection power and may be the cause of taste and odor problems.
3. With a little more chlorine added, the chloramines and some of the chlororganics are destroyed.
4. With still more chlorine added, a free chlorine residual is formed, free in the sense that it can react quickly.

Free available chlorine is the best residual for disinfection. It disinfects faster and without the swimming-pool odor of combined residual chlorine. The free available residual forms at the breakpoint; therefore, the process is called breakpoint chlorination. The common practice today is to go just beyond the breakpoint to a residual of about .2 to .5 ppm.

A variety of reactions take place during chlorination. When chlorine is added to a water containing ammonia (NH_3), the ammonia reacts with hypochlorous acid (HOCL) to form monochloramine, dichloramine, and trichloramine. The formation of these chloramines depends on the pH of the water and the initial chlorine-ammonia ratio.

Ammonia + Hypochlorous acid ➔ Chloramine + Water

$NH_3 + HOC1 \rightarrow NH_2C1 + H_20$ Monochloramine

$NH_2C1 + HOC1 \rightarrow NHC1_2 + H_20$ Dichloramine

$NHC1_2 + HOC1 \rightarrow NC1_3 + H_20$ Trichloramine

At the pH of most natural water (pH 6.5 to 7.5*)*, monochloramine and dichloramine exist together. At pH levels below 5.5*,* dichloramine exists by itself. Below pH 4.0, trichloramine is the only compound found. The monochloramine and dichloramine forms have a definite disinfection power. Dichloramine is a more effective disinfecting agent than monochloramine. However, dichloramine is not recommended as a disinfectant due to the possibility of the formation of taste and odor compounds. Chlorine reacts with phenol and salicylic acid to form chlorophenol, which has an intense medicinal odor. This reaction is much slower in the presence of monochloramines.

Both the chlorine residual and the contact time are essential for effective disinfection. It is important to have complete mixing. The operator also needs to be aware that changes in the pH may affect the ability of the chlorine to disinfect the water. The operator must examine the application and select the best point of feed and the best contact time to achieve the results desired. The operator needs to consider:

1. Whether the injection point and the method of mixing is designed so that the disinfectant is able to get into contact with all of the water to be disinfected. This also depends on whether pre- and/or post-chlorination is being used.
2. Contact time. In situations of good initial mixing, the longer the contact time, the more effective the disinfection.
3. Effectiveness of upstream treatment processes. The lower the turbidity of the water, the more effective the disinfection.
4. Temperature. At higher temperatures the rate of disinfection is more rapid.
5. Dosage and type of chemical. Usually the higher the dose, the quicker the disinfection rate. The form of disinfectant (chloramine or free chlorine) and the type of chemical used influence the disinfection rate.
6. pH. The lower the pH, the better the disinfection.

Points of Chlorine Application

The points of application of chlorine must be selected carefully, considering the different reactions that may occur at different points of the water treatment process. The common application points are:

1. PRECHLORINATION

Prechlorination is the application of chlorine ahead of any other treatment process. While prechlorination may increase the formation of trihalomethanes—potentially carcinogenic substances formed through the combination of chlorine and organics in the raw water—it provides the following benefits:

a. Control of algae and slime growths.
b. Control of mud ball formation in the filters.
c. Improved coagulation.
d. Reduction of tastes and odors.
e. Increased safety factor in disinfection of heavily contaminated waters.

2. POSTCHLORINATION

Postchlorination is the application of chlorine after treatment and before it enters the distribution system. This is the primary point of disinfection and is normally the last application of any disinfectant. It is also the only point where chlorine is added in a water system where it has no other purpose except to disinfect.

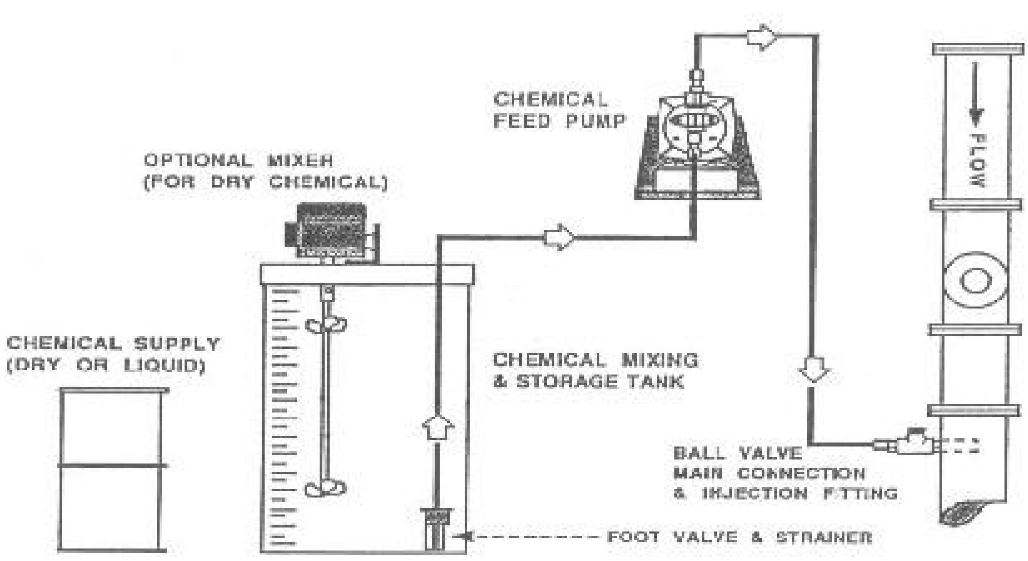
3. TANKS AND RESERVOIRS

Usually tanks and reservoirs are not chlorinated continuously, but they must be disinfected after any maintenance has been done on the inside of the tank. A chlorine concentration of 50 ppm is required in the water used for this "superchlorination." This chlorine must then be flushed out before the tank can be put back into service. Refer to AWWA Standard C652 for additional information on Tank and Reservoir disinfection.

CHLORINE CONTAINER TYPES

The type of container used to transport chlorine will depend on the type of chlorine product used:

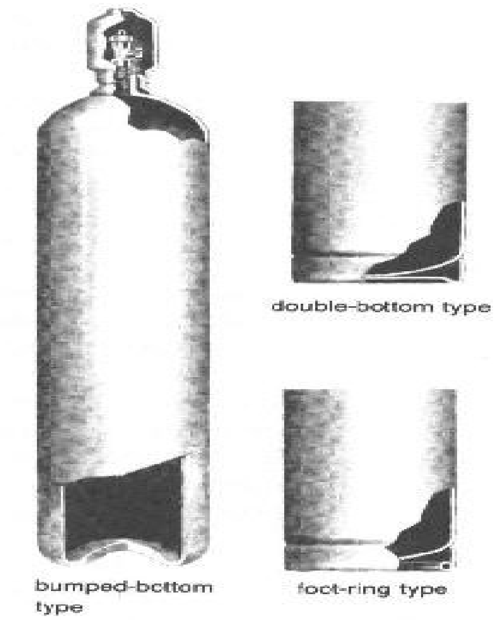
<u>Hypochlorites</u>
For hypochlorites to be mixed with water, a container made of plastic is required. The container size depends on the amount needed. Normally, it should hold a week's supply. The feed equipment for hypochlorites is often a diaphragm pump similar to the pump used to feed fluoride.



Gas Chlorine

Gas chlorine is normally shipped in 100-pound, 150-pound, or 2,000-pound (one ton) cylinders. If the demand is great enough, the chemical can be supplied in tank cars.

Cylinders containing 100 and 150 pounds of chlorine are convenient for small plants with capacities of less than 0.5 million gallons per day (MGD). A fusible plug is placed in the valve below the valve seat as a safety device set to melt at 158 to 165 degrees F. to prevent buildup of pressure and the possibility of rupture due to a fire or high surrounding temperatures.



Net Cylinder Contents	Approx. Tare, Lbs. *	Dimensions, Inches	
		A	B
100 Lbs.	73	8 ¼	54 ½
150 Lbs.	92	10 ¼	54 ½

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

The following are safety procedures that should be observed when moving cylinders:

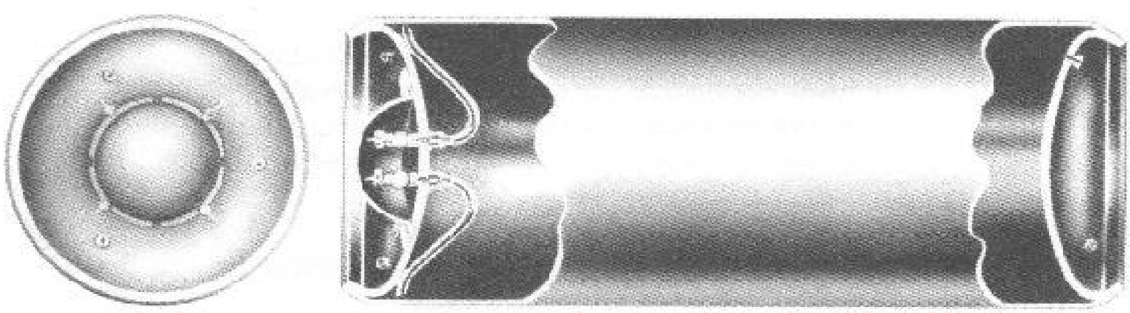
1. Always replace the protective cap when moving a cylinder.
2. Move cylinders with a properly balanced hand truck that has supports that fasten around the cylinder two-thirds of the way up on the cylinder.
3. The 100- and 150-pound cylinders can be rolled in a vertical position. Avoid lifting these cylinders except with approved equipment. Use a lifting clamp, cradle or carrier. Never lift with homemade chain devices, rope slings, or magnetic hoists and never lift the cylinder by its protective cap.
4. Keep cylinders away from direct heat and direct sunlight, especially in warm climates.
5. Transport and store cylinders in an upright position.
6. Firmly secure cylinders to an immoveable object when stored or in use.
7. Store empty cylinders separately from full cylinders, and label them clearly with information as to whether they are full or empty.

Never store chlorine near turpentine, ether, anhydrous ammonia, finely divided metals, hydrocarbons, or other materials that are flammable in air or will react violently with chlorine.

Ton containers are the most common type used in larger plants. This type of container holds 2,000 pounds (one ton or 1,000 kilos) of chlorine. The container itself weighs about 1,300 pounds, giving it a total weight of approximately 3,300 pounds when full. Ton containers are normally of the following construction:

Welded steel construction with a length of approximately 80 inches and an outside diameter of 30 inches. The ends of the ton containers are crimped inwardly to provide a substantial grip for the lifting clamps.

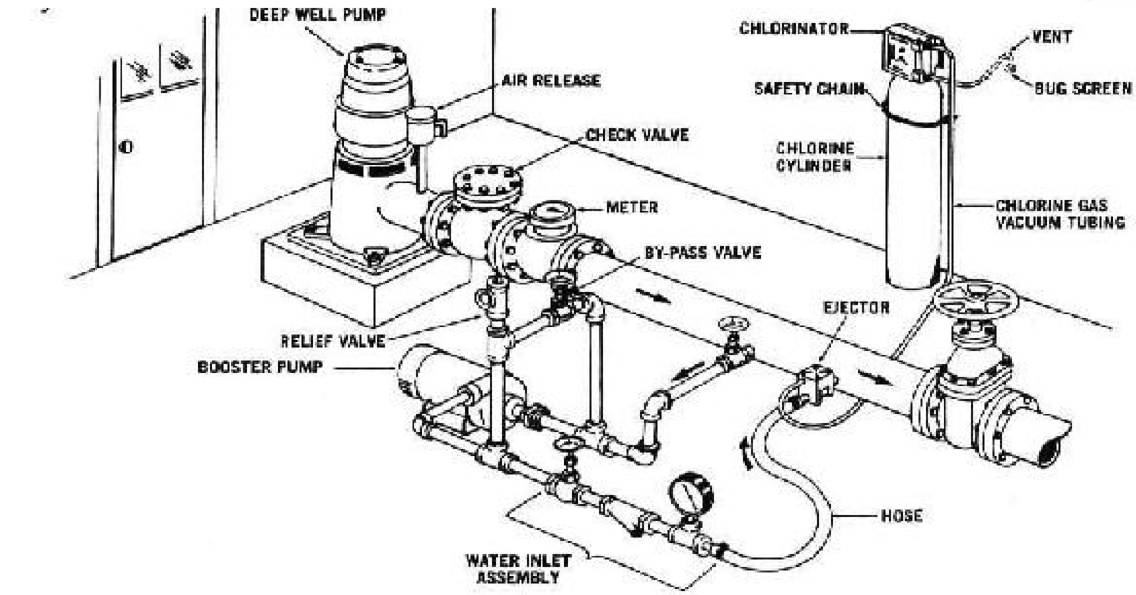
- Ton containers generally have about eight openings for valve and fusible plugs. Normally two valves are placed on one end of the cylinder, along with three fusible plugs. The other end of the cylinder contains three additional fusible plugs. The fusible plugs melt at 158 to 165° F., the same temperatures as the ones on the 150-pound cylinder.

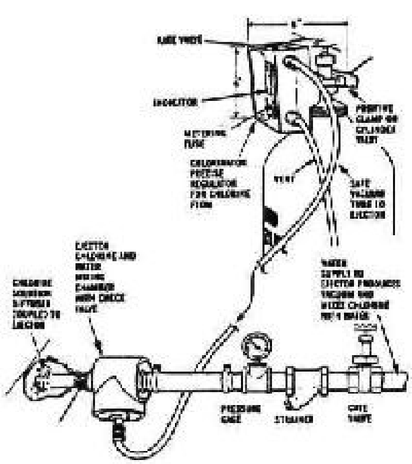


CHLORINATOR INSTALLATION

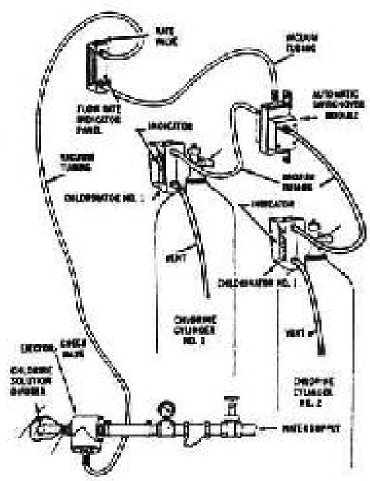
The chlorine room should have fans located either on the roof or in another place where it can push fresh air into the room and vent any chlorine out. The fans should be large enough to make one complete air change per minute. The intake for the vents should be located in the lower area of the room because chlorine is heavier than air and sinks to the floor. In some parts of Minnesota, the local fire marshal may require chlorine scrubber units to be installed. These units capture any chlorine gas or liquid that has escaped and neutralizes it with caustic soda before discharging it to the atmosphere.

Chlorine gas is removed from chlorinators. In smaller plants cylinder, the chlorine tanks by a valve and piping arrangement to the chlorine is withdrawn with equipment installed directly on the cylinder.

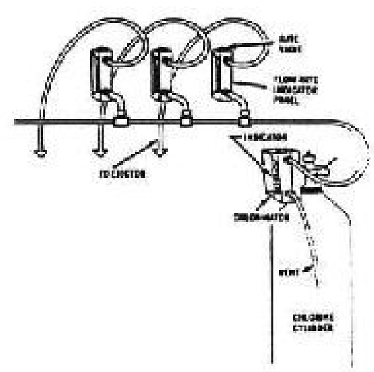




TYPICAL INSTALLATION BASIC SYSTEM



TYPICAL INSTALLATION AUTOMATIC SWITCHOVER SYSTEM



TYPICAL INSTALLATION REMOTE AND MULTI-POINT SYSTEMS

The operating vacuum to pull the chlorine gas out of the cylinders is provided by a hydraulic injector. The water used for the hydraulic injector is the plant's water supply. To get the necessary water pressure for the injector, a small booster pump may have to be installed in the water line to the injector. The water supplied by this injector absorbs the chlorine gas; the resulting chlorine solution is conveyed to a chlorine diffuser through a corrosion resistant pipe. A vacuum regulator valve dampens the fluctuations for a smoother operation.

The primary advantage of vacuum-feed operation is safety. If a failure or breakage occurs in the vacuum system, the chlorinator either stops the flow of chlorine or allows air to enter the vacuum system rather than allowing chlorine to escape into the surrounding atmosphere. In case the chlorine inlet shutoff fails, a vent valve discharges the incoming gas to the outside of the chlorinator building.

MAKING CHLORINE CONNECTIONS

The outlet of a container valve has special threads. They are not ordinary tapered threads. The operator should use only the fittings and gaskets furnished by the chlorine supplier or chlorinator manufacturer when making connections to chlorine containers. Regular pipe thread fittings should not be used. A new gasket should always be used when making a new connection. The outlet threads on the container valve should always be inspected before being connected to the chlorine system. Containers with badly-worn outlet threads should be returned to the supplier. If a connecting nut is used, it should be inspected for corrosion. Since the threads on both the tank and the connecting nut could be worn, the use of a connecting yoke is recommended.

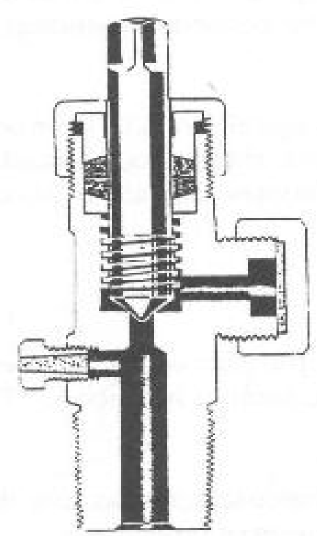
On pressurized systems, a flexible annealed copper line or pig tail coiled at least three times is recommended for the connection between chlorine containers and stationery piping. Care should be taken to prevent sharp bends in the tubing because this will weaken the tubing.

To simplify changing cylinders on a dual cylinder system, a shutoff valve is needed just beyond the cylinder being changed to control backflow from the other cylinder.

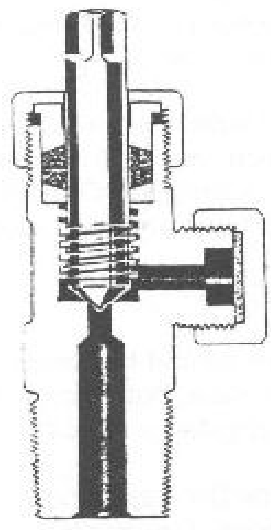
Leak-detection procedures should be followed after any connection of cylinders in the system. The connections should be checked with a 60 percent ammonia solution by applying only the vapors, not the liquid. A rag should be soaked with the ammonia solutions and held near the connections to the tank. If a leak is present, a smoky vapor will be given off from the leak. If a bottle of ammonia solution is used, only its vapors should be puffed near the suspected leak.

CHLORINE VALVES

Valve wrenches longer than six inches should not be used. Pipe wrenches or wrenches with an extension should not be used to open the valves. The valve should be opened by striking the wrench with the heel of the hand to rotate the valve stem in a counter-clockwise direction. Then it should be slowly opened one turn. If the valve cannot be opened in this manner, the packing nut should be loosened slightly and another attempt made. Then the valve should be opened and the packing nut retightened. If all attempts fail, the container should be returned to the supplier. Organic lubricants should not be used on any part of the chlorinator system as chlorine can react violently with organic material.



Standard Cylinder Valve



Standard Ton Container Valve

DEALING WITH CHLORINE LEAKS

Chlorine has the potential to cause serious injury, even death. Concentrations of 1,000 ppm, or one percent by volume, will kill in a very short time. Because the odor of gas chlorine is noticeable in very small amounts, it is generally easy to avoid the heavy concentrations that will cause injury. This characteristic makes chlorine less hazardous than other gases, such as hydrogen sulfide, which kills the sense of smell, and carbon monoxide, which cannot be smelled at all. If a person inhales chlorine, he or she may experience general restlessness, panic, severe irritation of the respiratory system, sneezing, and excessive amounts of saliva. These symptoms may be followed by coughing, retching, vomiting, and difficulty in breathing. People who have respiratory problems, such as asthma and certain types of chronic bronchitis, will have additional problems with chlorine inhalation. Liquid chlorine may cause severe irritation and blistering when in contact with the skin.

PROTECTION

All operators should be trained in the proper methods of handling chlorine. Chlorine is safe *if it is handled properly.* All operators should be trained in the use of self-contained breathing equipment, the methods for detecting leaks, and emergency procedures.

Self-contained air supplies and pressure-demand breathing equipment must fit and be used properly. People using this breathing equipment must first pass a physical exam and be trained in the proper use of the equipment.

It is important that trained backup personnel are available before a person enters an area with a chlorine leak. Protective clothing, such as a chemical suit, may be needed, depending on the concentration of the chlorine.

People who have worked in an area with a chlorine leak may be susceptible to skin irritation from their clothing, which may still be moist with chlorine. If this happens, these people should make sure their clothing is purged of chlorine—standing outside for a few minutes may allow the clothing to dry—before entering a confined space, such as a car or truck.

PLANNING AHEAD

All plant operations should be planned. In the case of a chlorine leak, the plan could include people not working in the plant, but who could be affected by a chlorine leak, such as neighbors. The plan must be practiced regularly. The following should be done:

1. Have the fire department and other available emergency response agencies tour the area to become familiar with the potential dangers and the location of emergency equipment. Give them a clearly marked map indicating the location of the chlorine storage area, chlorinators, and emergency equipment.
2. Have regular practice sessions in the use of respiratory, equipment, chemical suits, and chlorine repair kits. Involve all personnel who may respond to a chlorine-leak emergency.
3. Have a supply of ammonia solution available to detect chlorine leaks.
4. Write chlorine emergency procedures, including:
    a. Telephone numbers of the suppliers.
    b. List of key people who could help or who must be notified of the emergency.
    c. c. Local fire departments.
    d. Local police departments.
5. Follow established procedures when working with a leak:
    a. Never work alone during the emergency.
    b. Obtain help immediately. Quickly repair the problem; *they do not heal themselves.*
    c. Allow only authorized employees to work in the area, and make sure adequate equipment is readily available.
    d. If caught in an area with a chlorine leak, leave immediately. Do not breathe deeply. Walk out of the room with head up; do not crawl out. The effects depend on the length of exposure and the concentration of chlorine in the air.
    e. Use an ammonia solution to find small leaks. The vapor from the ammonia solution will generate a white vapor close to the leak.
    f. Develop emergency evacuation procedures with emergency personnel (police and fire departments) for the residents and businesses around the plant.
6. Post emergency procedures and practice them regularly.

7. Inspect equipment and make necessary repairs on a routine basis. At least twice each week, inspect the area where the chlorine containers are stored and where the chlorinators are operating.
8. At least once each week, inspect the emergency fans which will be needed in the event of a chlorine leak.
9. Conduct a health appraisal of all personnel who may have to respond to a chlorine emergency. Some may have physical problems that necessitate their removal from the emergency team.

MEASUREMENT OF CHLORINE RESIDUAL

The amount of chlorine residual in the water should be measured on a regular schedule. Tests should be done at least twice daily for small plants and more frequently for larger plants. Most large plants will have an automatic chlorine analyzer that automatically measures the residual.

Amperometric titration provides the most accurate measurement of chlorine. However, the equipment is not very portable, and it is not designed for work in the field. Most chlorine analysis is performed with the DPD method. Special DPD tablets that will change color in the presence of chlorine are added to a water sample. A color comparator or a colorimeter that automatically measures the intensity of the color is used to determine the concentration of chlorine residual in the water sample.

Chlorine residual measurements should be done on the distribution system at the areas farthest from the source of the water-treatment plant or the well. This ensures that the entire distribution system is receiving enough chlorine. If breakpoint chlorination is being practiced to obtain a free chlorine residual, the residual should be at least 0.2 to 0.5 ppm. If a combined-chlorine residual is being used for chlorination, the residual should be 1 to 2 ppm.

If the residual is low, the disinfection of the water system *cannot* be assumed to be complete and disease-causing bacteria (pathogens) may still be present in the water distributed.

DISINFECTION PROCEDURES WHEN CUTTING INTO OR REPAIRING EXISTING MAINS

The following procedures apply primarily when existing mains are wholly or partially dewatered. After the appropriate procedures have been completed, the existing main may be returned to service prior to completion of bacteriological testing in order to minimize the time customers are out of water. Leaks or breaks that are repaired with clamping devices while the mains remain full of pressurized water present little danger of contamination and require no disinfection.

Trench Treatment
When an existing main is opened, either by accident or by design, the excavation will likely be wet and may be badly contaminated from nearby sewers. Liberal quantities of hypochlorite applied to open trench areas will lessen the danger from such pollution. Tablets have the advantage in such because they dissolve slowly and continue to release hypochlorite as water is pumped from the excavation.

Swabbing With Hypochlorite Solution
The interior of all pipe fitting (particularly couplings and sleeves) used in making the repair shall be swabbed or sprayed with a 1 percent hypochlorite solution before they are installed.

Flushing
Thorough flushing is the most practical means of removing contamination introduced during repairs. If valve and hydrant locations permit, flushing toward the work location from both directions is recommended. Flushing shall be started as soon as the repairs are completed and shall be continued until discolored water is eliminated.

Slug Chlorination
When practical, in addition to the procedures above, the section of main in which the break is located shall be isolated, all service connections shut off, and the section flushed and chlorinated. Hypochlorite dose may be increased to as much as 300 milligrams per liter and the contact time reduced to as little as 15 minutes. After chlorination, flushing shall be resumed and continued until discolored water is eliminated, and the water is free of noticeable chlorine odor.

Sampling
Bacteriological samples shall be taken after repairs are completed to provide a record of determining the procedure's effectiveness. If the direction of flow is unknown, then samples shall be taken on each side of the main break. If positive bacteriological samples are recorded, then the situation shall be evaluated by the purchaser (or purchaser's representative) who can determine corrective action, and daily sampling shall be continued until two consecutive negative samples are recorded.