CHAPTER 5. DISINFECTION

(Lesson 2 of 2 Lessons)

5.4 OPERATION OF CHLORINATION EQUIPMENT

5.40 Description of Various Units

5.400 Field Equipment

1. *HYPOCHLORINATORS* (equipment that feeds liquid chlorine (bleach) solutions)

Hypochlorinators used on small water systems are very simple and relatively easy to install. Typical installations are shown in Figures 5.8 and 5.9. Hypochlorinator systems usually consist of a chemical solution tank for the hypochlorite, diaphragm-type pump (Figure 5.10), power supply, water pump, pressure switch, and water storage tank.

There are two methods of feeding the hypochlorite solution into the water being disinfected. The hypochlorite solution may be pumped directly into the water (Figure 5.11). In the other method, the hypochlorite solution is pumped through an *EJECTOR*[23] (also called an eductor or injector), which draws in additional water for dilution of the hypochlorite solution (Figure 5.12).

2. *CHLORINATORS* (equipment that feeds gaseous chlorine)

Disinfection by means of gaseous chlorine is typically accomplished in small systems with the equipment shown in Figure 5.13. For small water treatment systems, small chlorinators, which are mounted directly on a chlorine container (as shown in Figures 5.13, 5.14, and 5.15), have proven to be safer, easier to operate and maintain, and less expensive to install than larger in-place chlorination systems, yet they provide the same reliable service.

A direct-mounted chlorinator meters prescribed (preset or selected) doses of chlorine gas from a chlorine cylinder, conveys it under a vacuum, and injects it into the water supply. Direct cylinder mounting is the safest and simplest way to connect the chlorinator to the chlorine cylinder. The valves on the cylinder and chlorinator inlet are connected by a positive metallic yoke, which is sealed by a single lead or fiber gasket.

CHLORINATOR PARTS AND THEIR PURPOSE

THE EJECTOR: The ejector, fitted with a Venturi nozzle, creates the vacuum that moves the chlorine gas. Water supplied by a pump moves across the Venturi nozzle creating a differential pressure, which establishes the vacuum. The gas chlorinator is able to transport the chlorine gas to the water supply by reducing the gas pressure from the chlorine cylinder to less than the atmospheric pressure (vacuum). Figure 5.13 illustrates such an arrangement. The flow diagrams in Figure 5.14 are cutaway views of the ejector and check valve assembly.

In the past, it was not uncommon to find the ejector and the vacuum regulator mounted inside some type of cabinet. However, it makes better sense to locate the ejector at the site where the chlorine is to be applied, eliminating the necessity of pumping the chlorine over long distances and the associated problems inherent with gas pressure lines. Also, by placing the ejector at the application point, any tubing break will cause the chlorinator to shut down. This halting of operation stops the flow of gas and any damage that could result from a chlorine solution leak.

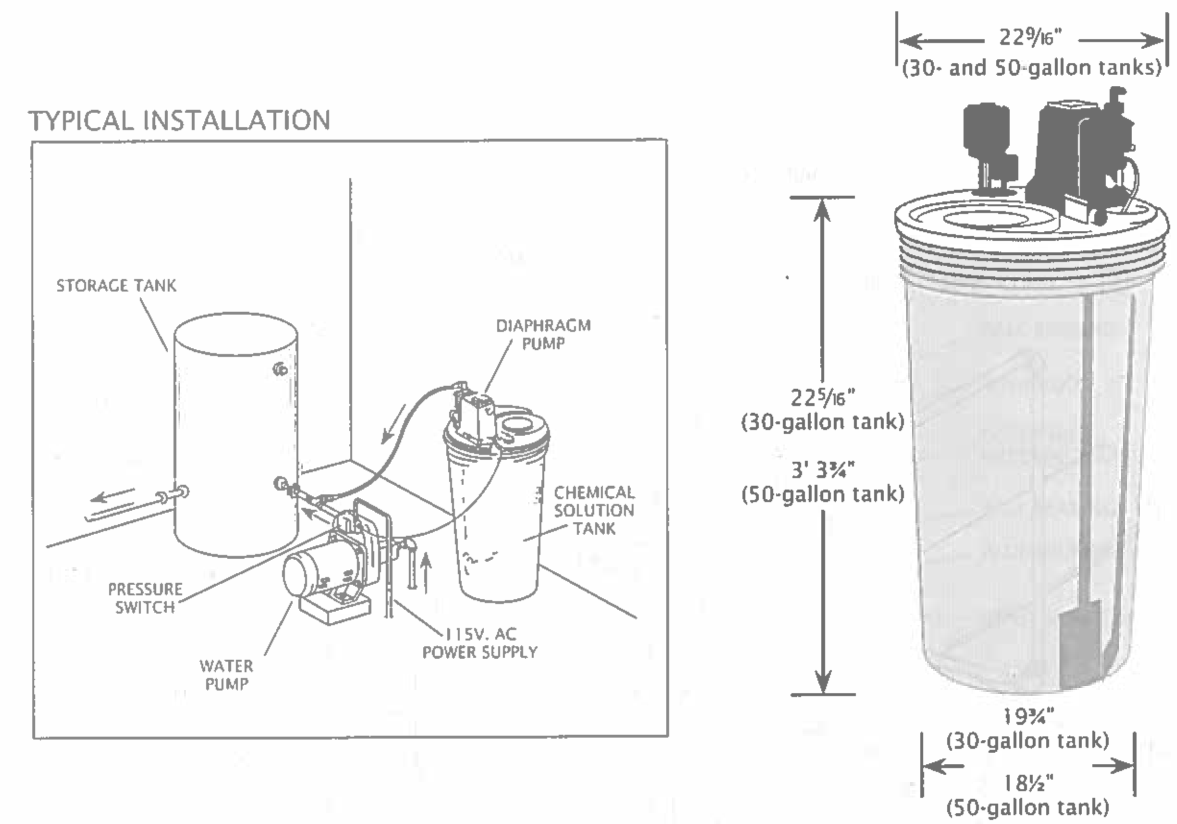
CHECK VALVE ASSEMBLY: The vacuum created by the ejector moves through the check valve assembly. This assembly prevents water from back-feeding, that is, entering the vacuum-regulator portion of the chlorinator (Figure 5.14).

RATE VALVE: The rate valve controls the flow rate at which chlorine gas enters the chlorinator. The rate valve controls the vacuum level and thus directly affects the action of the diaphragm assembly in the vacuum regulator. A reduction in vacuum lets the diaphragm close, causing the needle valve to reduce the inlet opening, which restricts chlorine gas flow to the chlorinator. An increase in the rate valve setting applies more vacuum to the diaphragm assembly, pulling the needle valve back away from the inlet opening and permitting an increased chlorine gas flow rate.

DIAPHRAGM ASSEMBLY: This assembly connects directly to the inlet valve of the vacuum regulator, as described above. A vacuum (of at least 20 inches (508 mm) of water column) exists on one side of the diaphragm; the other side is open to atmospheric pressure through the vent. This differential in pressure causes the diaphragm to open the chlorine inlet valve allowing the gas to move (under vacuum) through the *ROTAMETER*,[24] past the rate valve and through the tubing to the check valve assembly, into the ejector nozzle area, and then to the point of application. If for some reason the vacuum is lost, the diaphragm

[23] *Ejector.* A device used to disperse a chemical solution into water being treated.

[24] *Rotameter* (ROTE-uh-ME-ter). 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.



Pump-tank system for chemical mixing and metering. Cover supports pump, impeller-type mixer, and liquid-level switch.

Fig. 5.8 Typical hypochlorinator installation

(Permission of Wallace & Tiernan Division, Pennwalt Corporation)

will seat the needle valve on the inlet, stopping chlorine gas flow to the chlorinator.

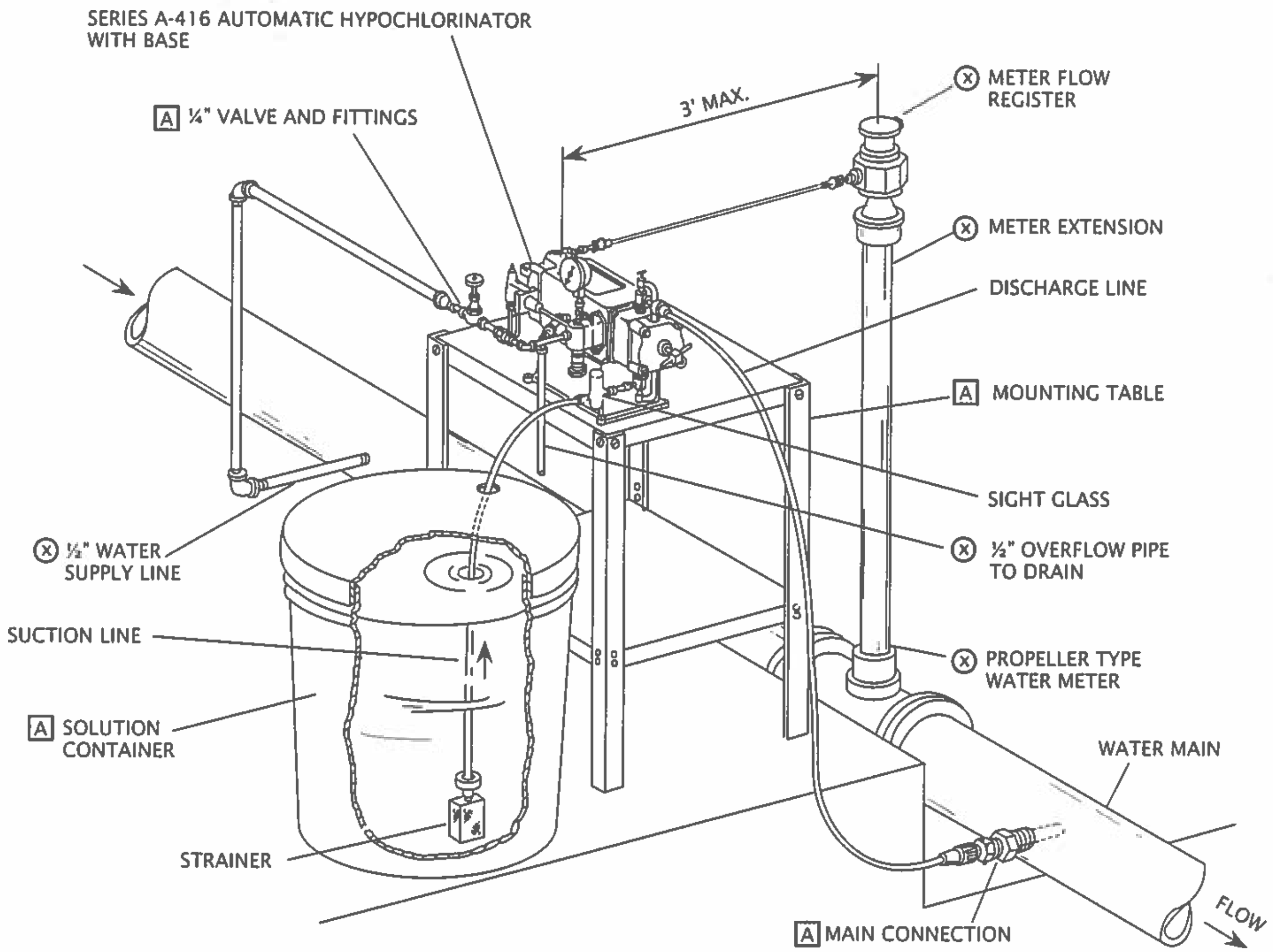
INTERCONNECTION MANIFOLD: If several gas cylinders provide the chlorine gas, direct cylinder mounting is not possible. An interconnection manifold made of seamless steel pipe and flexible connectors of cadmium-plated copper fitted with isolation valves must be used as the bridge between the chlorinator and the various cylinders.

The steel gas manifold with chlorine valve is mounted to the chlorinator. The flexible connector links the rigid manifold and the chlorine cylinder. The isolation valve between the flexible connector and the cylinder valve provides a way to close off the flexible connector when a new gas cylinder must be attached. This limits the amount of moisture that enters the system. Moisture in the system will combine with the chlorine gas to produce hydrochloric acid and cause corrosion. Corrosion can cause the manifold to fail.

The chlorine is usually injected directly into the water supply pipe and there may not be contact chambers or mixing units. The location of the injection point is important. The injection should never be on the intake side of the pump as it will cause corrosion problems. There should be a check valve and a meter to monitor the chlorine dose.

On most well applications a chlorine booster pump is needed to overcome the higher water pump discharge pressures. The low-volume, high-pressure booster pump shown in Figure 5.13 must have extremely small clearance between the impeller and the casing. If the well produces sand in the water, this pump will wear rapidly and become unreliable. In this situation, the chlorine solution should be introduced down the well through a polyethylene tube.

The polyethylene tube (½ inch or 12 mm) must be installed in the well so as to discharge a few inches below the suction screen. The chlorinator should operate only when the pump is running.

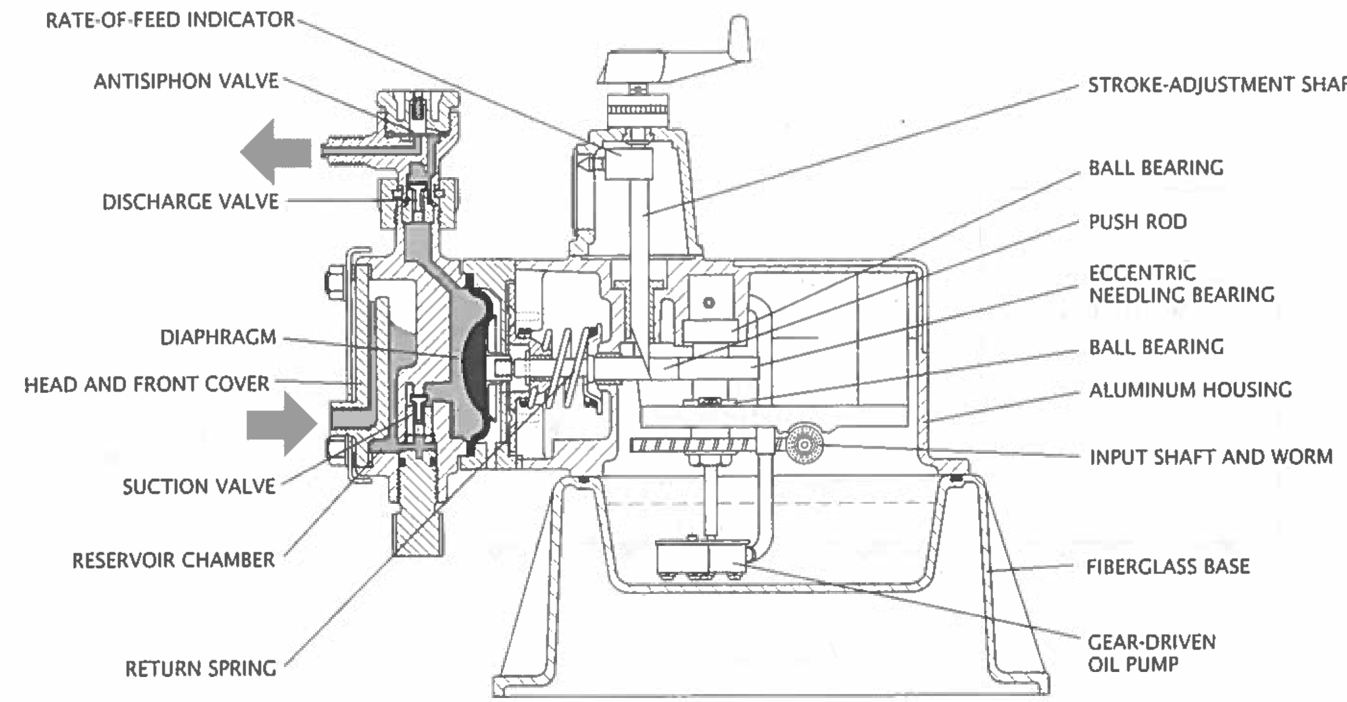


⊗ *NOT FURNISHED BY W & T.*

A *ACCESSORY ITEM FURNISHED ONLY IF SPECIFICALLY LISTED IN QUOTATION AND AS CHECKED ON THIS DRAWING.*

NOTE: Hypochlorinator paced by a propeller-type water meter.

Fig. 5.9 Typical hypochlorinator installation
(Permission of Wallace & Tiernan Division, Pennwalt Corporation)



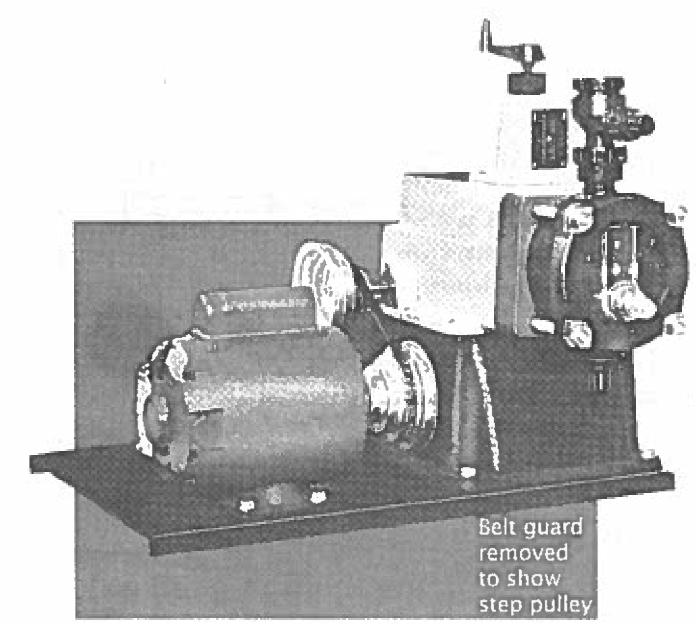


Fig. 5.10 Diaphragm-type pump
(Permission of Wallace & Tiernan Division, Pennwalt Corporation)

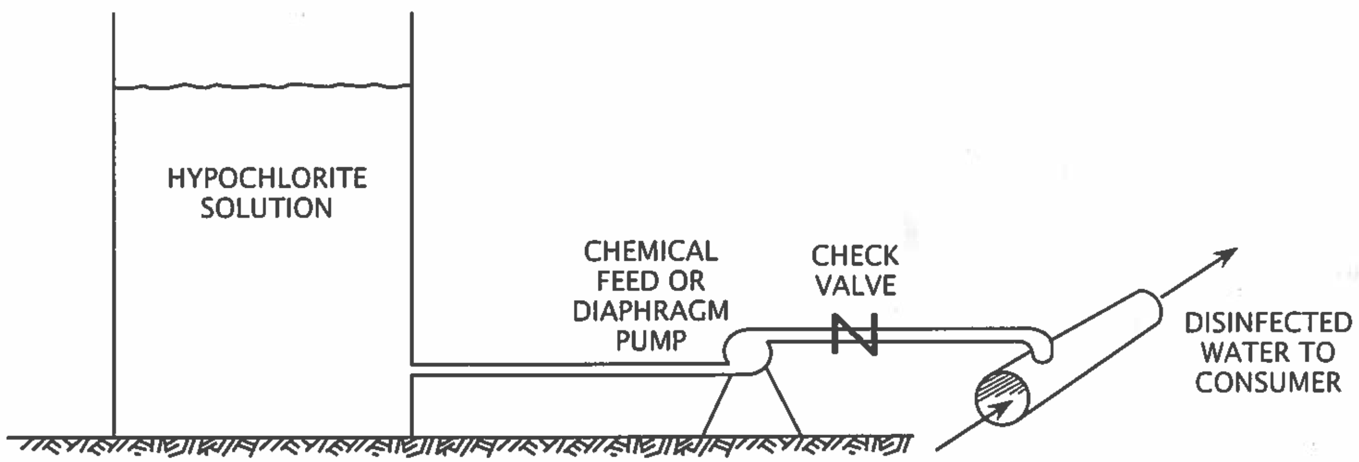
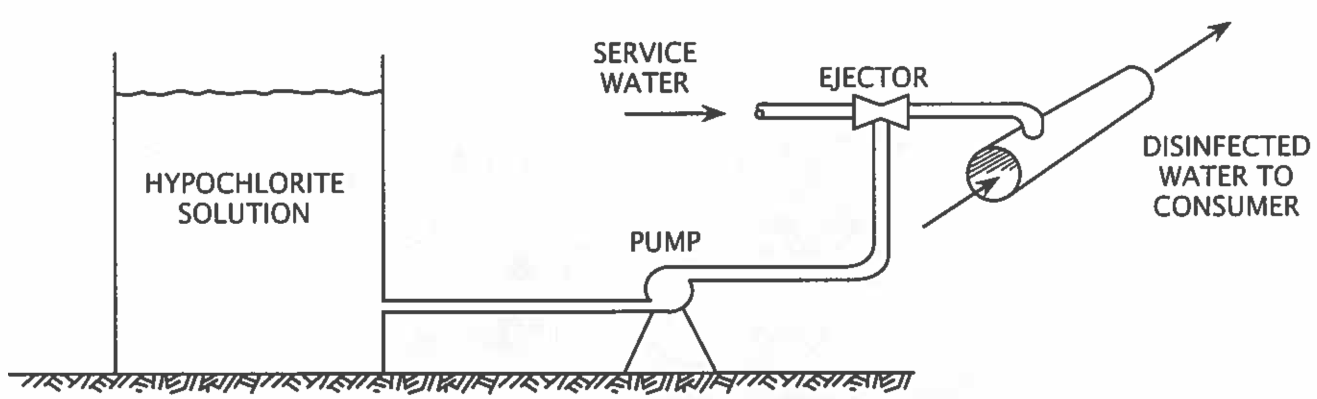


Fig. 5.11 Hypochlorinator direct pumping system



NOTE: Pump is chemical feed or diaphragm pump.

Fig. 5.12 Hypochlorinator injector feed system

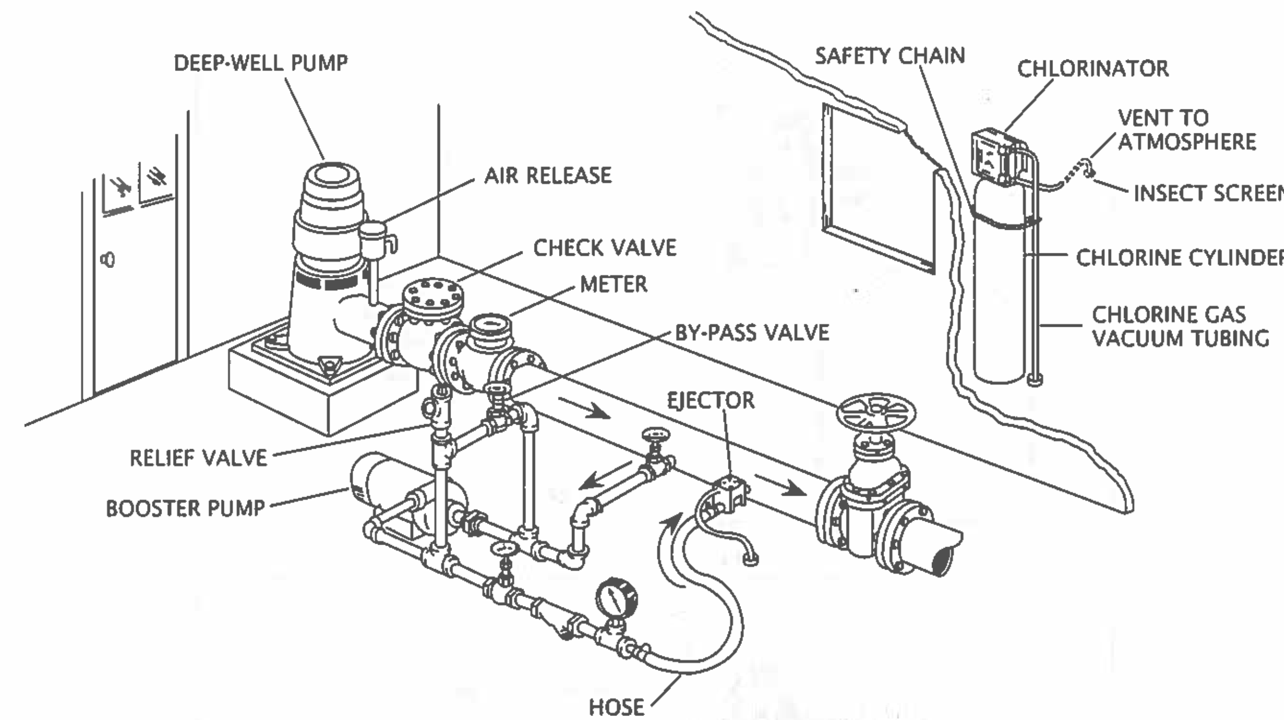


Fig. 5.13 Typical deep-well chlorination system
(Permission of Capital Controls Company, Colmar, PA)

The chlorine solution flowing through the polyethylene tube is extremely corrosive. If the tube does not discharge into flowing water, the effect of the solution touching the metal surface can be disastrous. Wells have been destroyed by corrosion from chlorine.

5.401 Chlorine Containers

1. *HYPOCHLORINATORS*

Plastic containers are commonly used for storage of hypochlorite solution (Figures 5.8 and 5.9). Container size depends on usage. Plastic containers should be large enough to hold a two or three days' supply of hypochlorite solution. The solution should be prepared every two or three days. If a larger amount of solution is mixed, the solution may lose its strength and thus affect the chlorine feed rate. Normally, a week's supply of hypochlorite should be in storage and available for preparing hypochlorite solutions. Store the hypochlorite in a cool, dark place. Sodium hypochlorite can lose from two to four percent of its available chlorine content per month at room temperature. Therefore, manufacturers recommend a maximum shelf life of 60 to 90 days.

2. *GAS CHLORINATORS*

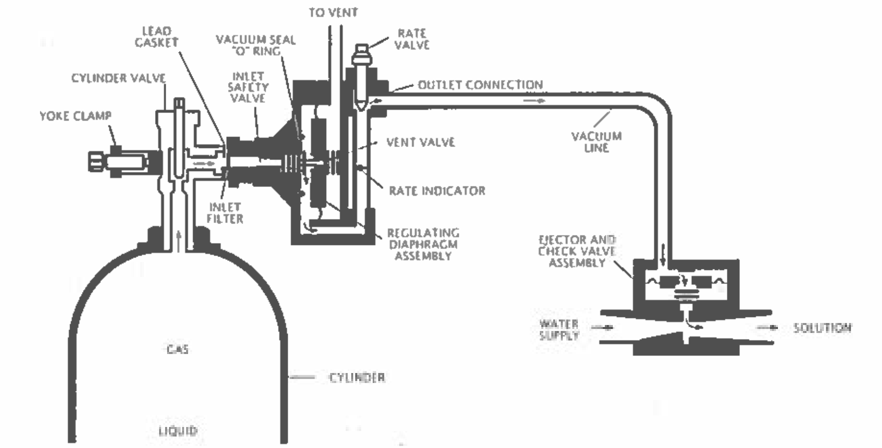
Chlorine is delivered for use by chlorinators in 100- and 150-pound (45- to 68-kg) cylinders (Figures 5.16 and 5.17), one-ton (900-kg) tanks, or chlorine tank cars in sizes from 16 to 90 tons (14,500 to 81,800 kg). The 100- and 150-pound (45- to 68-kg) cylinders will be discussed in this section.

These cylinders are usually made of seamless carbon steel. A fusible plug is placed in the valve below the valve seat (Figure 5.18). This plug is a safety device. The fusible metal softens or melts at 158 to 165°F (70 to 74°C) to prevent buildup of excessive pressures and the possibility of rupture due to fire or high surrounding temperatures.

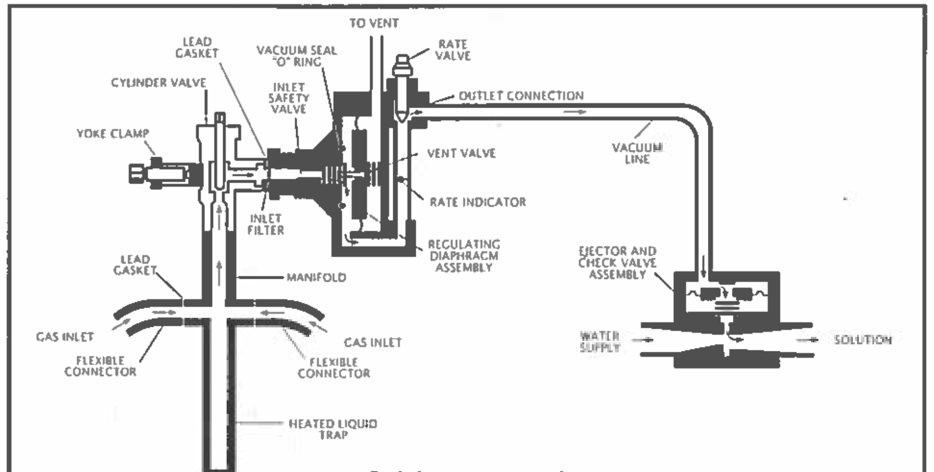
The maximum rate of chlorine removal from a 150-pound (68-kg) cylinder is 40 pounds (18 kg) of chlorine per day. If the rate of removal is greater, freezing can occur and less chlorine will be delivered.

WARNING

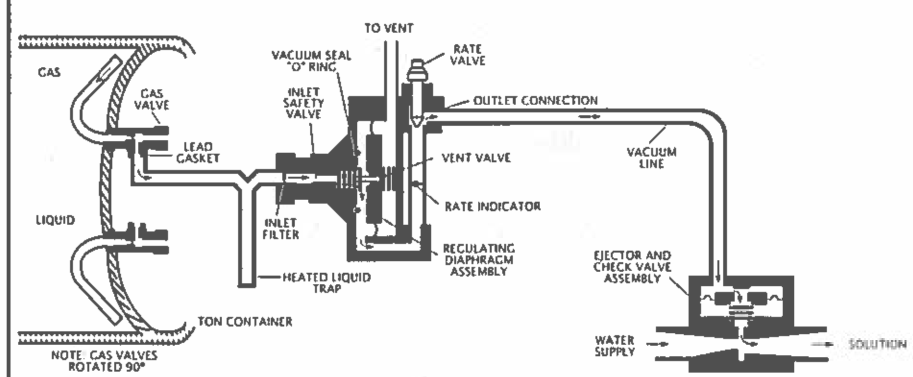
When frost appears on valves and flex connectors conveying chlorine gas, the chlorine gas may condense to liquid (reliquefy). The liquid chlorine may plug the chlorine supply lines (sometimes this is referred to as chlorine ice or frozen chlorine). If you disconnect the chlorine supply line to unplug it, be very careful. The liquid chlorine in the line could reevaporate, expand as a gas, build up pressure in the line, and cause liquid chlorine to come shooting out the open end of a disconnected chlorine supply line.



Direct Cylinder Mounted Unit



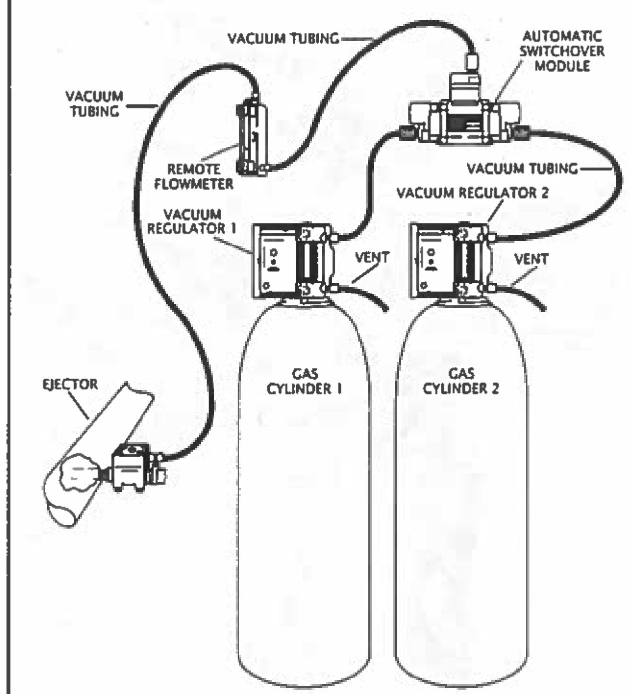
Manifold Mounted Unit



Ton Container Mounted Unit

Fig. 5.14 Typical chlorinator flow diagrams

(Permission of Capital Controls Company, Colmar, PA)



Automatic Switchover Operation
100 PPD (2000 g/hr) Cylinder Mounted System Shown

Fig. 5.14 Typical chlorinator flow diagrams (continued)

(Permission of Capital Controls Company, Colmar, PA)

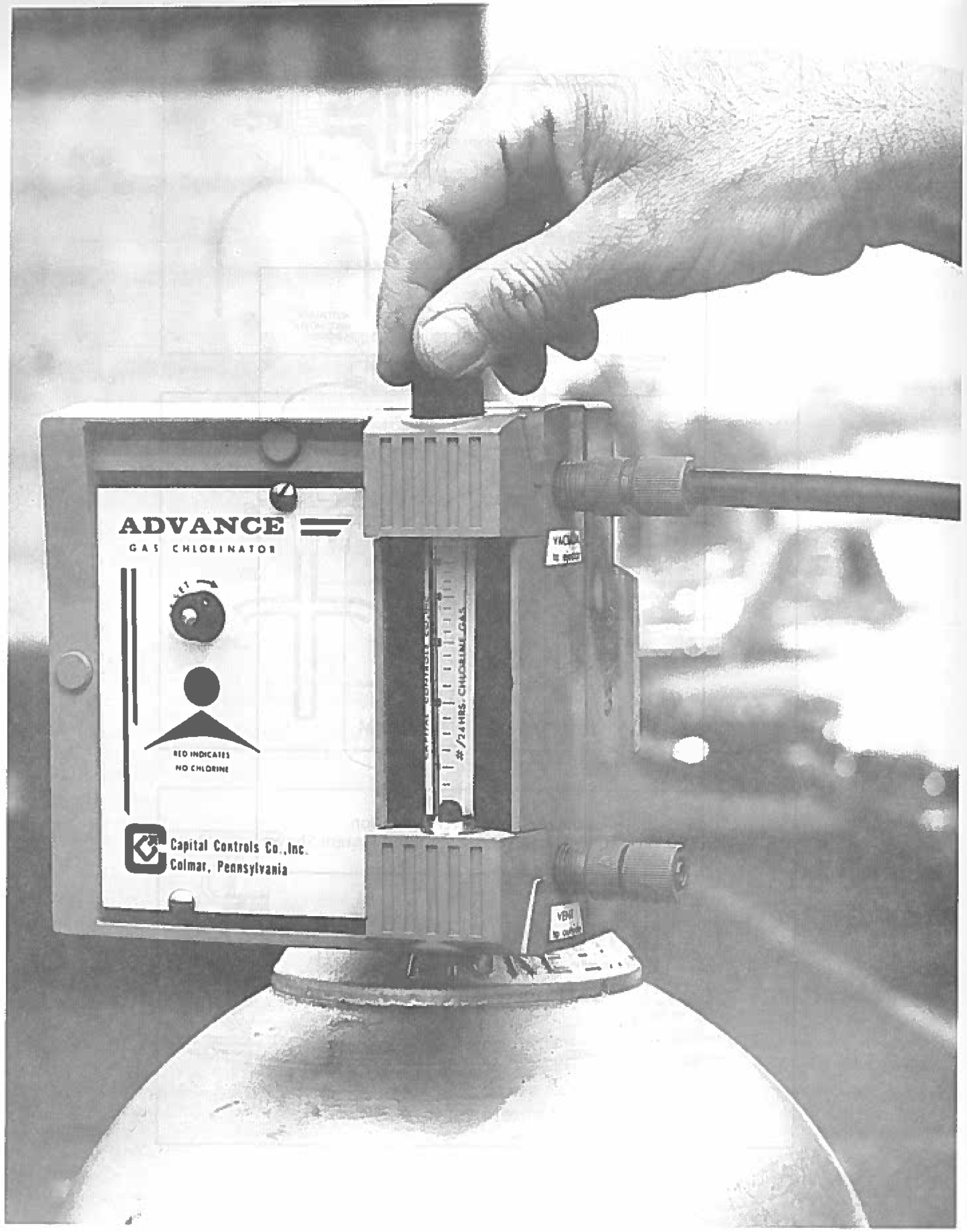
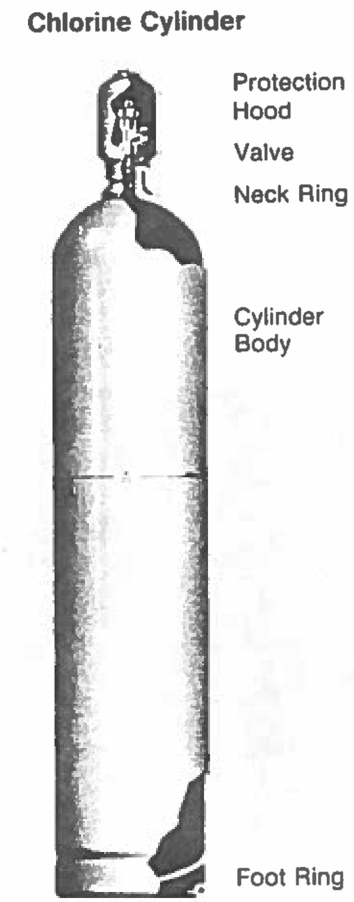


Fig. 5.15 Chlorinator with rotameter showing feed rate in #/24 hr (lbs/day) chlorine gas
(Permission of Capital Controls Company, Colmar, PA)



Net Cylinder Contents	Approx. Tare, Lbs.*	Dimensions, Inches	
		A	B
100 Lbs.	73	8 1/4	54 1/2
150 Lbs.	92	10 1/4	54 1/2

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

Fig. 5.16 Chlorine cylinder
(Courtesy of PPG Industries)

NOTES:
1. Scale for weighing chlorine cylinders and chlorine.
2. Flexible tubing (pigtail).
3. Cylinders chained to wall.

Fig. 5.17 Typical chlorine cylinder station for water treatment
(Courtesy of PPG Industries)

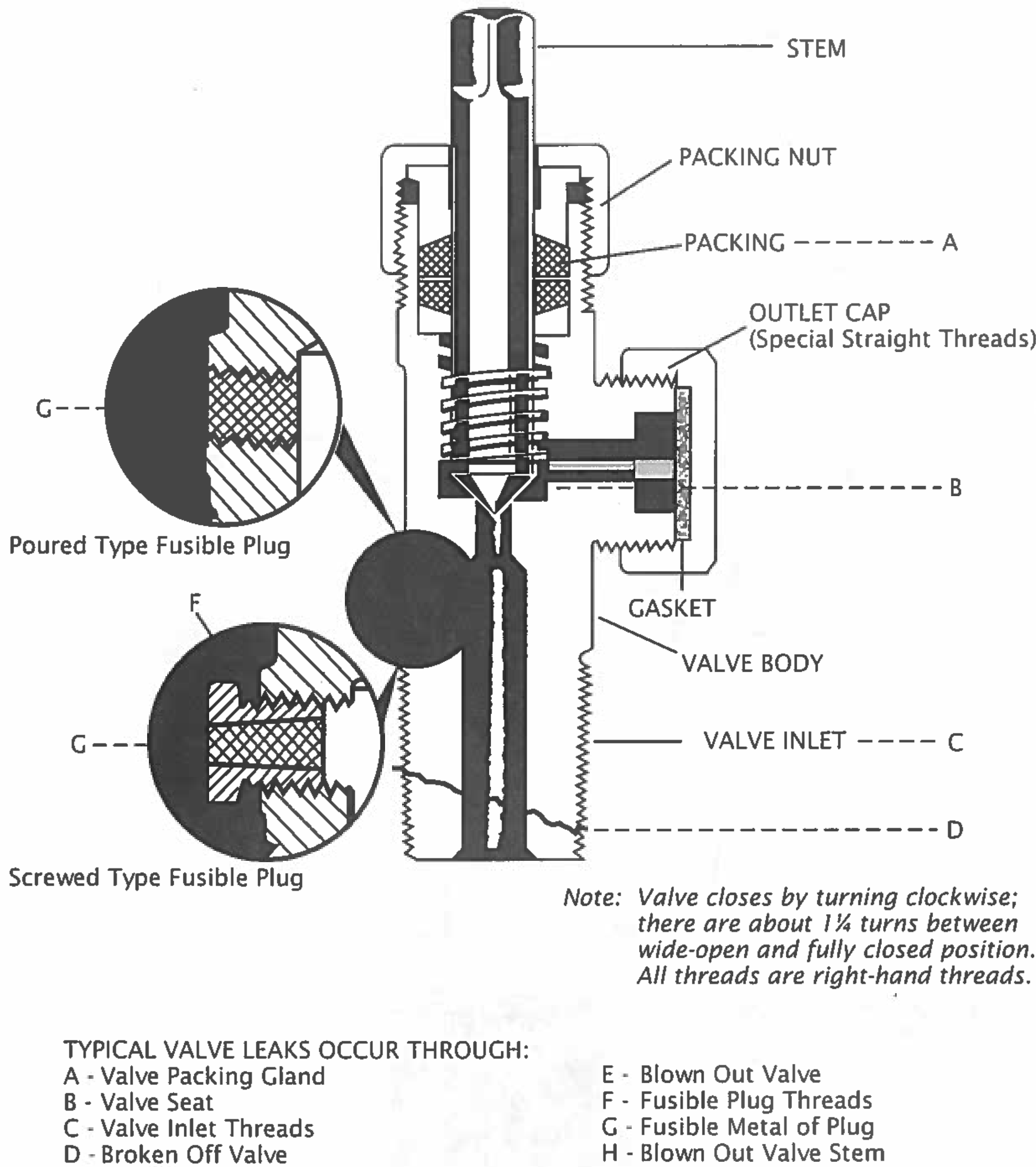


Fig. 5.18 Standard chlorine cylinder valve
(Permission of Chlorine Specialties, Inc.)

5.41 Chlorine Handling

Cylinders containing 100 to 150 pounds (45 to 68 kg) of chlorine are convenient for very small plants with capacities less than 0.5 MGD (1,890 cu m/day or 1.89 *ML*/day).[25]

The following are procedures for safely handling chlorine cylinders.

1. Move cylinders with a properly balanced hand truck with clamp supports that fasten at least two-thirds of the way up the cylinder (Figure 5.19).

Fig. 5.19 Hand truck for chlorine cylinder
(Courtesy of PPG Industries)

2. 100- and 150-pound (45- to 68-kg) 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 chains, rope slings, or magnetic hoists. Never roll, push, or drop cylinders off the back of trucks or loading docks.
3. Always replace the protective cap when moving a cylinder.
4. Keep cylinders away from direct heat (steam pipes or radiators) and direct sun, especially in warm climates.
5. Transport and store cylinders in an upright position.
6. Firmly secure cylinders to an immovable object.
7. Store empty cylinders separately from full cylinders. All empty chlorine cylinders must be tagged as empty. (*NOTE:* Never store chlorine cylinders near turpentine, ether, anhydrous ammonia, finely divided metals, hydrocarbons, or other materials that are flammable in air or will react violently with chlorine.)
8. Remove the outlet cap from the cylinder and inspect the threads on the outlet. Cylinders having outlet threads that are corroded, worn, cross-threaded, broken, or missing should be rejected and returned to the supplier.
9. The specifications and regulations of the US Interstate Commerce Commission require that chlorine cylinders be tested at 800 psi (5,516 kPa or 56.24 kg/sq cm) every five years. The date of testing is stamped on the dome of the cylinder. Cylinders that have not been tested within that period of time should be rejected and returned to the supplier.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on pages 350 and 351.

5.4A List the two major types of chlorine feeders.

5.4B Why are chlorine booster pumps needed on most well applications?

5.4C What is the maximum rate of chlorine removal from a 150-pound cylinder?

5.42 Performance of Chlorination Units

Before attempting to start or stop any chlorination system, read the manufacturer's literature and your plant's operation and maintenance instructions to become familiar with the equipment. Review the plans and drawings of the facility. Determine what equipment, pipelines, pumps, tanks, and valves are to be placed into service or are in service. The current status of the entire system must be known before starting or stopping any portion of the system. This section provides the procedures for a typical system and will give you ideas for your system.

5.420 Hypochlorinators

1. *START-UP OF HYPOCHLORINATORS*

   a. Prepare the chemical solution. Most agencies buy commercial or industrial hypochlorite at a strength of 12- to 15-percent chlorine. This solution is usually diluted down to a 2-percent solution. If using commercially prepared solutions, you will need to calculate feed rates.

   b. Lock out the electric circuit and then inspect the circuit. Normally, no adjustments are needed. Look for frayed wires. Turn the power back on. Leave the solution switch off.

   c. Turn on the chemical pump. Make adjustments while the pump is running. Never adjust the pump while it is off because damage to the pump will occur.

   d. Calibrate the pump to ensure accurate delivery of chlorine solution. See *WATER TREATMENT PLANT OPERATION*, Volume I, Chapter 4, "Coagulation and Flocculation," Appendix B, "Adjustment and Calibration of Chemical Feeders," for more information.

[25] *ML/day* = Megaliters or million liters per day.

e. Make sure solution is being fed into the system. Measure the chlorine residual just downstream from where solution is being fed into the system. You may have a target residual you wish to maintain at the beginning of the system such as 2.0 mg/*L*.

f. Check the chlorine residual in the system. The residual should be measured at the most remote test location within the distribution system and should be at least 0.2 mg/*L* free residual chlorine. This chlorine residual is necessary to protect the treated water from any recontamination. Adjust the chemical feed as needed.

2. *SHUTDOWN OF HYPOCHLORINATORS*

a. Short Duration

(1) Turn water supply pump off. You do not want to pump any unchlorinated water and possibly contaminate the rest of the system. Never pump any unchlorinated water into your distribution system.

(2) Turn the hypochlorinator off.

(3) When making repairs, lock out the circuit or pull the plug from an electric socket.

b. Long Duration

(1) Obtain and place another hypochlorinator in service.

3. *NORMAL OPERATION OF HYPOCHLORINATORS*

Normal operation of the hypochlorination process requires routine observation and preventive maintenance.

DAILY

a. Inspect the building to make sure only authorized personnel have been there.

b. Read and record the level of the hypochlorite solution tank at the same time every day.

c. Read the meters and record the amount of water pumped.

d. Check the chlorine residual (at least 0.2 mg/*L*) in the system and adjust the chlorine feed rate as necessary. Try to maintain a chlorine residual of 0.2 mg/*L* at the most remote point in the distribution system. The suggested free chlorine residual for treated water or well water is 0.5 mg/*L* at the point of chlorine application provided the 0.2 mg/*L* residual is maintained throughout the distribution system and coliform test results are negative.

e. Check the chemical feed pump operation. Most hypochlorinators have a dial with a range from 0 to 10 that adjusts the chlorine feed rate. Start with a setting around 6 or 7 on the dial and use a 2-percent hypochlorite solution. The pump should operate in the upper ranges of the dial so that the strokes or pulses from the pump will be close together. In this way, the chlorine will be fed continuously to the water being treated. Adjust the feed rate after testing chlorine residual levels.

WEEKLY

a. Clean the building.

b. Replace the chemicals and wash the chemical storage tank. Try to have a 15- to 30-day supply of chlorine in storage for future needs. When preparing hypochlorite solutions, prepare only enough for a two- or three-day supply.

MONTHLY

a. Check the operation of the check valve.

b. Perform any required preventive maintenance suggested by the manufacturer.

c. Cleaning

Commercial sodium hypochlorite solutions (such as Clorox) contain an excess of caustic (sodium hydroxide (NaOH)). When this solution is diluted with water containing calcium and also carbonate alkalinity, the resulting solution becomes supersaturated with calcium carbonate. This calcium carbonate tends to form a coating on the poppet valves in the solution feeder. The coated valves will not seal properly and the feeder will fail to feed properly.

Use the following procedure to remove the carbonate scale:

(1) Fill a 1-quart (1-liter) Mason jar half-full of tap water.

(2) Place 1 fluid ounce (20 m*L*) of 30- to 37-percent hydrochloric acid (swimming pool acid) in the jar. Always add acid to water, never the reverse.

(3) Fill the jar with tap water.

(4) Place the suction hose of the hypochlorinator in the jar and pump the entire contents of the jar through the system.

(5) Return the suction hose to the hypochlorite solution tank and resume normal operation.

You can prevent the formation of the calcium carbonate coatings by obtaining the dilution water from an ordinary home water softener.

NORMAL OPERATION CHECKLIST

a. Check chemical usage. Record solution level and the water pump meter reading or number of hours of pump operation. Calculate the amount of chemical solution used and compare with the desired feed rate. See Example 4.

b. Determine if every piece of equipment is operating.

c. Inspect the lubrication of the equipment.

d. Check the building for any possible problems.

e. Clean up the area.

FORMULAS

When operating a hypochlorinator, you should compare the actual chlorine dose applied to the water being treated with the desired chlorine dose in milligrams per liter. The actual dose is calculated by determining the amount of chlorine actually used and the amount of water treated. The amount of chlorine used is found by measuring the amount of hypochlorite solution used and knowing the strength of the hypochlorite solution. The amount of water used is determined from a flowmeter.

To calculate the amount of water treated, determine the amount in gallons from a flowmeter and convert this amount from gallons to pounds.

$$\text{Water Treated, lbs} = (\text{Water Treated, gal})(8.34\ \text{lbs/gal})$$

To calculate the amount of hypochlorite used in gallons, determine the volume of hypochlorite used in gallons.

$$\text{Hypochlorite Used, gallons} = (0.785)(\text{Diameter, ft})^2(\text{Depth, ft})(7.48\ \text{gal/cu ft})$$

To determine the pounds of chlorine used to disinfect the water being treated, we have to convert the hypochlorite used from gallons to pounds of chlorine by considering the strength of the hypochlorite solution.

$$\text{Chlorine Used, lbs} = (\text{Hypochlorite, gal})(8.34\ \text{lbs/gal})\left(\frac{\text{Hypochlorite, \%}}{100\%}\right)$$

Finally, to estimate the actual chlorine dose in milligrams of chlorine per liter of water treated, we divide the pounds of chlorine used by the millions of pounds of water treated. Pounds of chlorine per million pounds of water is the same as parts per million or milligrams per liter (ppm = mg/*L*).

$$\text{Chlorine Dose, mg/}L = \frac{\text{Chlorine Used, lbs}}{\text{Water Treated, Million lbs}}$$

EXAMPLE 4

Water pumped from a well is disinfected by a hypochlorinator. A chlorine dose of 1.2 mg/*L* is necessary to maintain an adequate chlorine residual throughout the system. During a 1-week time period, the water meter indicated that 2,289,000 gallons of water were treated. A 2-percent sodium hypochlorite solution is stored in a 3-foot diameter plastic tank. During this 1-week period, the level of hypochlorite in the tank dropped 2 feet 8 inches (2.67 feet). Does the chlorine feed rate appear to be too high, too low, or about right?

Known		Unknown
Desired Chlorine Dose, mg/*L*	= 1.2 mg/*L*	1. Actual Chlorine Dose, mg/*L*
Water Treated, gal	= 2,289,000 gal	2. Is Actual Dose OK?
Hypochlorite, %	= 2%	
Chemical Tank Diameter, ft	= 3 ft	
Chemical Drop in Tank, ft	= 2.67 ft	

1. Calculate the pounds of water disinfected.

$$\begin{aligned}\text{Water Treated, lbs} &= (\text{Water Treated, gallons})(8.34\ \text{lbs/gal})\\ &= (2{,}289{,}000\ \text{gal})(8.34\ \text{lbs/gal})\\ &= 19{,}090{,}000\ \text{lbs}\\ \text{or} &= 19.09\ \text{Million lbs}\end{aligned}$$

2. Calculate the volume of 2-percent sodium hypochlorite solution used in gallons.

$$\begin{aligned}\text{Hypochlorite Used, gallons} &= (0.785)(\text{Diameter, ft})^2(\text{Depth, ft})(7.48\ \text{gal/cu ft})\\ &= (0.785)(3\ \text{ft})^2(2.67\ \text{ft})(7.48\ \text{gal/cu ft})\\ &= 141.1\ \text{gallons}\end{aligned}$$

3. Determine the pounds of chlorine used to disinfect the water.

$$\begin{aligned}\text{Chlorine Used, lbs} &= (\text{Hypochlorite Used, gal})(8.34\ \text{lbs/gal})\left(\frac{\text{Hypochlorite, \%}}{100\%}\right)\\ &= (141.1\ \text{gal})(8.34\ \text{lbs/gal})\left(\frac{2\%}{100\%}\right)\\ &= 23.5\ \text{lbs Chlorine}\end{aligned}$$

4. Estimate the chlorine dose in mg/*L*.

$$\begin{aligned}\text{Chlorine Dose, mg/}L &= \frac{\text{Chlorine Used, lbs}}{\text{Water Treated, Million lbs}}\\ &= \frac{23.5\ \text{lbs Chlorine}}{19.09\ \text{Million lbs Water}}\\ &= 1.23\ \text{mg/}L\end{aligned}$$

Because the actual estimated chlorine dose (1.23 mg/*L*) was similar to the desired dose of 1.2 mg/*L*, the chlorine feed rate appears OK.

4. *ABNORMAL OPERATION OF HYPOCHLORINATORS*

a. Inform your supervisor of the problem.

b. If the hypochlorinator malfunctions, it should be repaired or replaced immediately. See Step 2 in this section for shutdown operation procedures.

c. Solution tank level.

(1) If too low: Check the adjustment of the pump.
Check the hour meter on the water pump.

(2) If too high: Check the chemical pump.
Check the hour meter on the water pump.

d. Determine if the chemical pump is not operating.

Troubleshooting Guidelines

(1) Check the electrical connection.

(2) Check the circuit breaker.

(3) Check for stoppages in the flow lines.

Corrective Measures

(1) Shut off the water pump so that no unchlorinated water is pumped into the system.

(2) Check for a blockage in the solution tank.

(3) Check the operation of the check valve.

(4) Check the electric circuits.

(5) Replace the chemical feed pump with another pump while repairing the defective unit.

e. The solution is not being pumped into the water line.

Troubleshooting Guidelines

(1) Check the solution level.

(2) Check for blockages in the solution line.

5. *MAINTENANCE OF HYPOCHLORINATORS*

Hypochlorinators on small systems are normally small, sealed systems that cannot be repaired so replacement of the entire unit is the only solution. Some units are repairable and can be serviced by following manufacturer's instructions. Maintenance requirements are normally minor such as changing the oil and lubricating the moving parts. Review the manufacturer's specifications and instructions for maintenance requirements.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 351.

5.4D What is the basis for adjusting the chemical feed of a hypochlorinator?

5.4E When should the level of the hypochlorite solution tank be read?

5.4F How should the chemical feed pump operation of a hypochlorinator be checked and adjusted?

5.4G What maintenance is usually required on hypochlorinators?

5.421 Chlorinators

1. *SAFETY EQUIPMENT REQUIRED AND AVAILABLE OUTSIDE THE CHLORINATOR ROOM*

a. Protective clothing

(1) Gloves

(2) Rubber suit

b. Self-contained, pressure-demand air supply system (Figure 5.20)

c. Chlorine leak detector/warning device should be located outside the room storing chlorine and should have a battery backup in case of a power failure. The chlorine sensor unit should be in the chlorine room and connected to the leak detector/warning device, which is located outside the chlorine storage room.

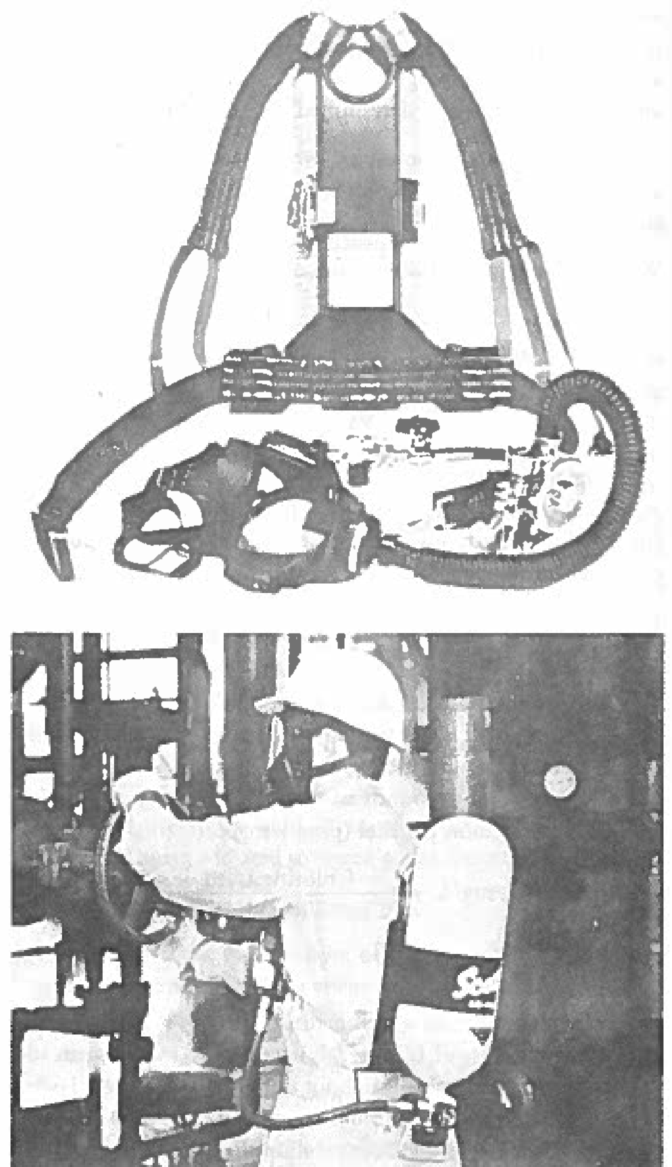


Fig. 5.20 Self-contained breathing apparatus
(Courtesy of PPG Industries)

2. *START-UP OF CHLORINATORS*

Work in pairs. Never work alone when hooking up a chlorine system.

a. Inspect the chlorine container for leaks. Position the container or chlorine cylinder in its location for connection. Install safety chains or locking devices to prevent cylinder or container movement. Remove the valve protective hood on cylinders, or the valve bonnet on 1-ton containers.

b. Inspect the chlorination equipment.

c. Use new gaskets for connection of the chlorinator to the chlorine cylinder. The chlorine supplier usually attaches two fiber gaskets to the cylinder valve for connection. Most agencies prefer to use lead gaskets because they seat better, permitting fewer connection leaks. Fiber gaskets tend to leave a deposit of fiber material on the faces of both the cylinder valve outlet and the chlorinator inlet. This deposited material must be scraped or wire brushed off both faces to obtain a leakproof connection.

d. Prior to the hookup, inspect for moisture and foreign substances in the lines.

e. Have an ammonia[26] bottle readily available to detect any leaks in the system. Dip a rag on the end of a stick in the ammonia bottle and place the rag near the location of suspected leaks. A white cloud will reveal the location of a chlorine leak.

f. Have safety equipment available that may be used in case of a leak.

g. Hook up the chlorinator to the chlorine container with the chlorine valve turned off. Use the gas side (not liquid side) if using a ton tank. Remove the chlorine cylinder valve outlet cap and check the valve outlet face for burrs, deep scratches, or debris left from former connections; clean or wire brush if necessary. If the valve face is smooth, clean, and free of deep cuts or corrosion, proceed with hooking up the cylinder. If there is any evidence of damage to the valve face, replace the outlet cap and protection hood, and ask the supplier to pick up the cylinder and replace the damaged valve. Check the inlet face of the chlorinator and clean if necessary. Place a new lead gasket on the chlorinator inlet, place the chlorinator on the cylinder valve, install the yoke clamp, and slowly tighten the yoke until the two faces are against the lead gasket. Continue to slowly tighten the yoke, compressing the gasket connection one-half to three-quarters of a turn. Do not overtighten; this can damage the yoke or the chlorinator and cause a leak.

h. Open the cylinder valve one-quarter of a turn and check for leaks. If the valve is difficult to open, return the cylinder to your supplier. Some agencies require suppliers to torque the valve stems to no more than 35 psi; this permits operation of the valve stem with the correct valve wrench, without having to strike the wrench with the palm of your hand to unseat the valve stem. Striking the wrench usually results in the cylinder rotating because the safety chain usually does not securely hold the cylinder. Jarring the cylinder in this way may result in a gas leak, particularly if two cylinders are used with a manifold and pigtails. Remember—do not leave the valve in this position for a long time because it will plug up. Commercial chlorine usually contains small amounts of chlorinated organic compounds, which are not volatile. Trace amounts of these compounds can be carried over in the chlorine vapor. A slightly opened valve, with the resulting change in velocity, is an ideal place for these materials to collect, build up, and cause the valve to plug up. Open the valve one turn; this provides sufficient gas flow to prevent plugging and permits quick shutoff in case of a leak.

i. Adjust the chlorinator to the proper setting. The desired chlorine residual should be maintained throughout the distribution system. Coliform test results should be negative when the chlorination system is operating properly.

j. Check the system for leaks by applying a concentrated ammonia solution (28- to 30-percent ammonia as NH_3) vapor from a squeeze bottle to the chlorine cylinder valve and the chlorinator. Any leaks will be detected by the presence of a white smoke. If a leak is present, close the gas cylinder valve.

- Make sure the packing nut on the chlorine cylinder valve stem is tight.
- Check the lead gasket. If the lead gasket is distorted, clean the connection and refit with a new gasket. Then, repeat the above procedure for checking the system for leaks.

[26] Use a concentrated ammonia solution containing 28- to 30-percent ammonia as NH_3 (this is the same as 58-percent ammonium hydroxide, NH_4OH, or commercial 26° Baumé).

3. *CHLORINATOR SHUTDOWN*

Work in pairs. A plan should be used where both people are not exposed to the chlorine at the same time.

a. Have safety equipment available in the event of a chlorine leak.

b. Shut off the chlorine valve from the supply source.

c. Allow sufficient time for the chlorine to purge out of the line.

d. Turn the chlorinator off.

e. Leave the discharge line open. If chlorine is trapped between two valves, the chlorine gas can expand when heated by sunlight and develop high pressures in the line. Leave the discharge line open to prevent this hazard from developing.

4. *NORMAL OPERATION OF CHLORINATORS*

Normal operation of a chlorinator requires routine observation and preventive maintenance.

DAILY

a. Inspect the building to make sure that only authorized personnel have been there.

b. Read the chlorinator rotameter.

c. Record the reading, time, and date and initial the entries.

d. Read the meters and record the number of gallons of water pumped.

e. Check the chlorine residual. If the residual is below 0.2 mg/*L* in the distribution system, increase the feed rate by adjusting the rotameter. If the residual is too high, lower the feed rate by adjusting the rotameter.

f. Calculate the chlorine usage. Refer to Examples 6 and 7 on page 333.

WEEKLY

a. Clean the equipment and the building.

b. Perform preventive maintenance on the equipment.

c. Calculate the chlorine usage so that replacement supply containers can be ordered and constant chlorination can be maintained. Refer to Example 7. Try to have a 15- to 30-day supply of chlorine in storage.

NORMAL OPERATION CHECKLIST

a. Chemical usage in pounds.

b. Meter readings for water usage in gallons.

c. Equipment log.

d. Lubrication inspection log.

e. Building inspection.

5. *ABNORMAL OPERATION*

a. Inform supervisor of the problem.

b. If the chlorinator malfunctions, repair the unit immediately.

c. If repairs cannot be completed quickly, shut off the water supply so that unchlorinated or contaminated water will not be delivered to the consumers.

d. Follow standard chlorinator shutdown procedures.

ABNORMAL OPERATION, TROUBLESHOOTING

TABLE 5.7 DIRECT-MOUNT CHLORINATOR TROUBLESHOOTING GUIDE

Operating Symptoms	Probable Cause	Remedy
1. Water in the chlorine metering tube.	Check valve failure, deposits on seat of check valve, or check valve seat distorted by high pressure.	Clean deposits from check ball and seat with dilute muriatic acid. Badly distorted check valve may have to be replaced.
2. Water venting to atmosphere.	Excess water pressure in the vacuum regulator.	Remove vacuum regulator from chlorine cylinder and allow chlorinator to pull air until dry.
3. No indication on flowmeter when vacuum is present.	Vacuum leak due to bad or brittle vacuum tubing, connections, rate valve o-rings, or gasket on top of flowmeter.	Check the vacuum tubing, rate valve o-rings and flowmeter gasket for vacuum leaks. Replace bad tubing connectors, o-rings, or gasket.
4. Indication on flowmeter but air present, not chlorine gas.	Connection below meter tube gasket leaks.	Check connections and replace damaged elements.

6. *MAINTENANCE*

Most direct-mounted chlorinators are simple units and are more easily replaced than repaired on line. Remove and repair these units in shop or have them repaired by others who are qualified to repair direct-mounted chlorinators.

FORMULAS

To determine the setting on a chlorinator in pounds per day, multiply the flow in MGD times the dose in mg/*L* times 8.34 lbs/gal.

$$\text{Chlorinator Setting, lbs/day} = (\text{Flow, MGD})(\text{Dose, mg}/L)(8.34 \text{ lbs/gal})$$

To calculate the number of chlorine cylinders used per month, determine the pounds of chlorine used per month and divide by the pounds of chlorine per cylinder.

$$\text{Cylinders Used, number/month} = \frac{\text{Chlorine Used, lbs/mo}}{\text{Chlorine Cylinders, lbs/cylinder}}$$

EXAMPLE 5

A deep well turbine pump delivers approximately 200 GPM against typical operating heads. If the desired chlorine dose is 2 mg/*L*, what should be the setting on the rotameter for the chlorinator (lbs chlorine per 24 hours)?

Known		Unknown
Pump Flow, GPM	= 200 GPM	Rotameter Setting, lbs Chlorine/24 hours
Chlorine Dose, mg/*L*	= 2 mg/*L*	

1. Convert pump flow to million gallons per day (MGD).

$$\text{Flow, MGD} = \frac{(200 \text{ GPM})(60 \text{ min/hr})(24 \text{ hr/day})}{1{,}000{,}000/\text{Million}}$$

$$= 0.288 \text{ MGD}$$

2. Calculate the rotameter setting in pounds of chlorine per 24 hours.

$$\text{Rotameter Setting, lbs/day} = (\text{Flow, MGD})(\text{Dose, mg}/L)(8.34 \text{ lbs/gal})$$

$$= (0.288 \text{ M Gal/day})(2 \text{ mg}/L)(8.34 \text{ lbs/gal})$$

$$= 4.8 \text{ lbs/day}$$

$$= 4.8 \text{ lbs/24 hours}$$

EXAMPLE 6

Using the results from Example 5 (a chlorinator setting of 4.8 lbs/day), how many pounds of chlorine would be used during one week if the pump hour meter showed 100 hours of pump operation? If the chlorine cylinder contained 78 pounds of chlorine at the start of the week, how many pounds of chlorine should be remaining at the end of the week?

Known		Unknown
Chlorinator Setting, lbs/day	= 4.8 lbs/day	1. Chlorine Used, lbs/week
Time, hr/week	= 100 hr/week	2. Chlorine Remaining, lbs
Chlorine Cylinder, lbs	= 78 lbs	

1. Calculate the chlorine used in pounds per week.

$$\text{Chlorine Used, lbs/week} = (\text{Chlorinator Setting, lbs/day})(\text{Time, hr/week})$$

$$= (4.8 \text{ lbs/day})\left(\frac{100 \text{ hr/wk}}{24 \text{ hr/day}}\right)$$

$$= 20 \text{ lbs Chlorine/week}$$

2. Determine the amount of chlorine that should be remaining in the cylinder at the end of the week.

$$\text{Chlorine Remaining, lbs} = \text{Chlorine at Start, lbs} - \text{Chlorine Used, lbs}$$

$$= 78 \text{ lbs} - 20 \text{ lbs}$$

$$= 58 \text{ lbs Chorine remaining at end of week}$$

EXAMPLE 7

Given the pumping rate and chlorination system in Examples 5 and 6, if 20 pounds of chlorine are used during an average week, how many 150-pound chlorine cylinders will be used per month (assume 30 days per month)?

Known		Unknown
Chlorine Use, lbs/week	= 20 lbs/week	1. Amount of Chlorine Used per Month, lbs
		2. Number of 150-lb Cylinders Used per Month

1. Calculate the amount of chlorine used in pounds of chlorine per month.

$$\text{Chlorine Used, lbs/month} = (\text{Chlorine Use, lbs/week})(\text{Number Weeks/mo})$$

$$= (20 \text{ lbs/week})\left(\frac{(1 \text{ week})(30 \text{ days})}{(7 \text{ days})(1 \text{ month})}\right)$$

$$= 85.7 \text{ lbs/month}$$

2. Determine the number of 150-pound chlorine cylinders used per month.

$$\text{Cylinders Used, number/month} = \frac{\text{Chlorine Used, lbs/mo}}{\text{Chlorine Cylinders, lbs/Cylinder}}$$

$$= \frac{85.7 \text{ lbs/mo}}{150 \text{ lbs/Cylinder}}$$

$$= 0.57 \text{ Cylinder/month}$$

This installation requires less than one 150-pound chlorine cylinder per month.

5.43 Laboratory Tests

Two water quality laboratory tests are run on samples of water from a water supply system: chlorine residual tests and bacteriological analyses (coliform tests).

1. Chlorine Residual in the System

   a. Chlorine residual tests using the *DPD*[27] *METHOD*[28] should be taken daily at various locations in the system. A remote tap is ideal for one sampling location. Take the test sample from a tap as close to the main as possible. Allow the water to run at least 5 minutes before sampling to ensure a representative sample from the main.

   Operators using the DPD colorimetric method to test water for a free chlorine residual need to be aware of a potential error that may occur. If the DPD test is run on water containing a combined chlorine residual, a precipitate may form during the test. The particles of precipitated material will give the sample a turbid appearance or the appearance of having color. This turbidity can produce a positive test result for free chlorine residual when there is actually no chlorine present. Operators call this error a "false positive" chlorine residual reading.

   b. Chlorine residual test kits are available for small systems.

2. Bacteriological Analyses (Coliform Tests)

Samples should be taken routinely in accordance with EPA and health department requirements. Take samples according to approved procedures.[29] Be sure to use a sterile plastic or glass bottle. If the sample contains any chlorine residual, sufficient sodium thiosulfate should be added to neutralize all of the chlorine residual. Usually, 0.1 milliliter of 10-percent sodium thiosulfate in a 120-m*L* (4-oz) bottle is sufficient for distribution systems. The "thio" should be added to the sample bottle before sterilization.

5.44 Troubleshooting

TABLE 5.8 DISINFECTION TROUBLESHOOTING GUIDE

Operating Symptom	Probable Cause	Remedy
1. Increase in coliform level	Low chlorine residual	Raise chlorine dose
2. Drop in chlorine level	a. Increase in chlorine demand b. Drop in chlorine feed rate	Raise chlorine dose and find out why chlorine demand increased or chlorine feed rate dropped

5.45 Chlorination System Failure

If your chlorination system fails, do not allow unchlorinated water to enter the distribution system. Never allow unchlorinated water to be delivered to your consumers. If your chlorination system fails and cannot be repaired within a reasonable time period, notify your supervisor and officials of the health department. To prevent this problem from occurring, your plant should have backup or standby chlorination facilities.

5.46 Emergency Disinfection Plan

All water treatment plants should have an emergency disinfection plan. The plan must be ready to be implemented any time a disinfection failure occurs in order to prevent the delivery to the distribution system of any water that is not disinfected or is inadequately disinfected. The plan should be posted in the plant or at a place that is readily available to the plant operator or an emergency crew.

The emergency disinfection plan should include information outlining the corrective actions that must be taken until the disinfection problem is properly corrected. The plan should include a description of the existing disinfection facilities and the operating and monitoring procedures of these facilities. Emergency telephone numbers must be listed for the appropriate health department officials and also for the operators available and the equipment suppliers needed to make the repairs. Review your emergency disinfection plan at least once a year and check to be sure all phone numbers are still current.

Procedures should be outlined for the emergency response if the disinfection system failed but no inadequately disinfected water entered the water distribution system. These procedures should include how to immediately shut down the water treatment plant if possible. Use of alternative water sources, if available, should be explained and procedures for implementation of water conservation measures should be outlined. If a backup chlorinator or a chemical feeder from a less critical treatment process is available, this equipment should be used. If no backup equipment is available, procedures for manual disinfection at the plant and also the distribution reservoirs need to be outlined. Also, increased monitoring of bacteriological quality and chlorine residual levels of the water being delivered to and within the distribution system must be performed.

If inadequately disinfected water entered the water distribution system, additional procedures must be implemented. Health department officials must be notified immediately. The distribution system must be flushed to remove inadequately disinfected water using properly disinfected water and properly disinfected water must be distributed within the system as quickly as possible.

[27] *DPD Method.* A method of measuring the chlorine residual in water. The residual may be determined by either titrating or comparing a developed color with color standards. DPD stands for N,N-diethyl-p-phenylenediamine.

[28] See Section 5.5, "Measurement of Chlorine Residual," for details on how to perform the DPD test for measuring chlorine residual.

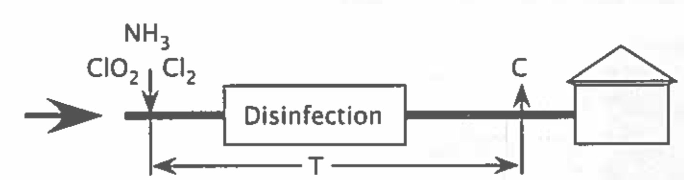
[29] See Chapter 7, "Laboratory Procedures," for proper procedures for collecting and analyzing samples for chlorine residuals and coliform tests.

5.47 CT Values

The purpose of the Surface Water Treatment Rule (SWTR) is to ensure that pathogenic organisms are removed or inactivated by the treatment process. To meet this goal, all systems are required to disinfect their water supplies. For some water systems using very clean source water and meeting the other criteria to avoid filtration, disinfection alone can achieve the 3-log (99.9%) *Giardia* and 4-log (99.99%) virus inactivation levels required by the SWTR. For extremely clean source waters, there may be virtually no *Giardia* or viruses and achieving 3-log or 4-log inactivation levels will be impossible and not necessary. (For procedures to calculate log removals, see Section A.16, "Calculation of Log Removals," in the Arithmetic Appendix at the end of this manual.)

Several methods of disinfection are in common use, including free chlorination, chloramination, use of chlorine dioxide, and application of ozone. The concentration of chemical needed and the length of contact time needed to ensure disinfection are different for each disinfectant. Therefore, the efficiency of the disinfectant is measured by the time, T, in minutes of the disinfectant's contact in the water and the concentration, C, in mg/*L* of the disinfectant residual measured at the end of the contact time. The product of these two factors (C × T) provides a measure of the degree of pathogenic inactivation. The required CT value to achieve inactivation depends on the organism in question, the type of disinfectant, and the pH and temperature of the water supply.

Time, T, is measured from the point of application of the disinfectant to the point where free chlorine residual, C, is determined. T must be based on peak hour flow rate conditions. In pipelines, T is calculated by dividing the volume of the pipeline in gallons by the flow rate in gallons per minute (GPM). In reservoirs and basins, dye tracer tests must be used to determine T. In this case, T is the time it takes for 10 percent of the tracer to pass the measuring point.

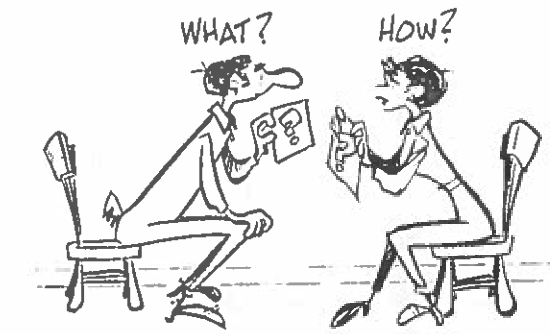


A properly operated filtration system can achieve limited removal or inactivation of microorganisms. Because of this, systems that are required to filter their water are permitted to apply a factor that represents the microorganism removal value of filtration when calculating CT values to meet the disinfection requirements. The factor (removal credit) varies with the type of filtration system. Its purpose is to take into account the combined effects of both disinfection and filtration in meeting the SWTR microbial standards.

Please refer to the Arithmetic Appendix at the end of *WATER TREATMENT PLANT OPERATION,* Volume I, Section A.16, "Calculation of CT Values," in this series of operator training manuals, for instructions on how to perform these calculations for a water treatment plant. Also see Volume II for more information on CT values.

5.48 Acknowledgment

Some of the material in this section on gas chlorinators was prepared by Joe Habraken, Treatment Supervisor, City of Tampa, Florida. His contribution is greatly appreciated.



QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 351.

5.4H What personal safety equipment should be available before attempting to locate and repair a chlorine gas leak?

5.4I How is ammonia used to detect a chlorine leak?

5.4J What would you do if you could not repair a broken chlorinator quickly?

5.4K What two water quality laboratory tests are run on samples of water from a water supply system?

5.5 MEASUREMENT OF CHLORINE RESIDUAL

5.50 Methods of Measuring Chlorine Residual

AMPEROMETRIC TITRATION[30] provides for the most convenient and most repeatable chlorine residual results. However, amperometric titration equipment is more expensive than equipment for other methods. DPD colorimetric tests can be used and are less expensive than other methods, but this method requires the operator to match the color of a sample with the colors on a comparator. See Chapter 7, "Laboratory Procedures," for detailed information on these tests. ORP (oxidation-reduction potential) probes can also be used to measure chlorine residuals.

Residual chlorine measurements of treated water should be taken at least three times per day on small systems and once every two hours on large systems. Residuals are measured to ensure that the treated water is being adequately disinfected. A free chlorine residual of at least 0.5 mg/*L* in the treated water at the point of application is usually recommended.

[30] *Amperometric* (am-purr-o-MET-rick) *Titration.* A means of measuring concentrations of certain substances in water (such as strong oxidizers) based on the electric current that flows during a chemical reaction. Also see TITRATE.

All surface water systems and groundwater systems under the influence of surface water must provide disinfection. Systems are required to monitor the disinfectant residual leaving the plant and at various points in the distribution system. The water leaving the plant must have at least 0.2 mg/*L* of the disinfectant, and the samples taken in the distribution system must have a detectable residual. Certain guidelines must be followed to ensure that there is enough contact time between the disinfectant and the water so that the microorganisms are inactivated.

If at any time the disinfectant residual leaving the plant is less than 0.2 mg/*L*, the system is allowed up to four hours to correct the problem. If the problem is corrected within this time, it is not considered a violation but the regulatory agency must be notified. The disinfectant residual must be measured continuously. For systems serving fewer than 3,300 people, this may be reduced to once per day.

The disinfectant in the distribution system must be measured at the same frequency and location as the total coliform samples. Measurements for heterotrophic plate count (HPC) bacteria may be substituted for disinfectant residual measurements. If the HPC is less than 500 colonies per m*L*, then the sample is considered equivalent to a detectable disinfectant residual. For systems serving fewer than 500 people, the regulatory agency may determine the adequacy of the disinfectant residual in place of monitoring.

5.51 Amperometric Titration for Free Chlorine Residual

1. Place a 200-m*L* sample of water in the titrator.
2. Start the agitator.
3. Add 1 m*L* of pH 7 buffer.
4. Titrate with 0.00564 *N* phenylarsene oxide solution.
5. End point is reached when further additions (drops) will not cause a deflection on the microammeter.
6. m*L* of phenylarsene oxide used in titration is equal to mg/*L* of free chlorine residual.

5.52 DPD Colorimetric Method for Free Chlorine Residual (Figures 5.21 and 5.22)

This procedure is for the use of prepared powder pillows.

1. Collect a 100-m*L* sample.
2. Add color reagent.
3. Match color sample with a color on the comparator to obtain the chlorine residual in mg/*L*.

Fig. 5.21 Direct reading colorimeter for free chlorine residuals

(Permission of the HACH Company)

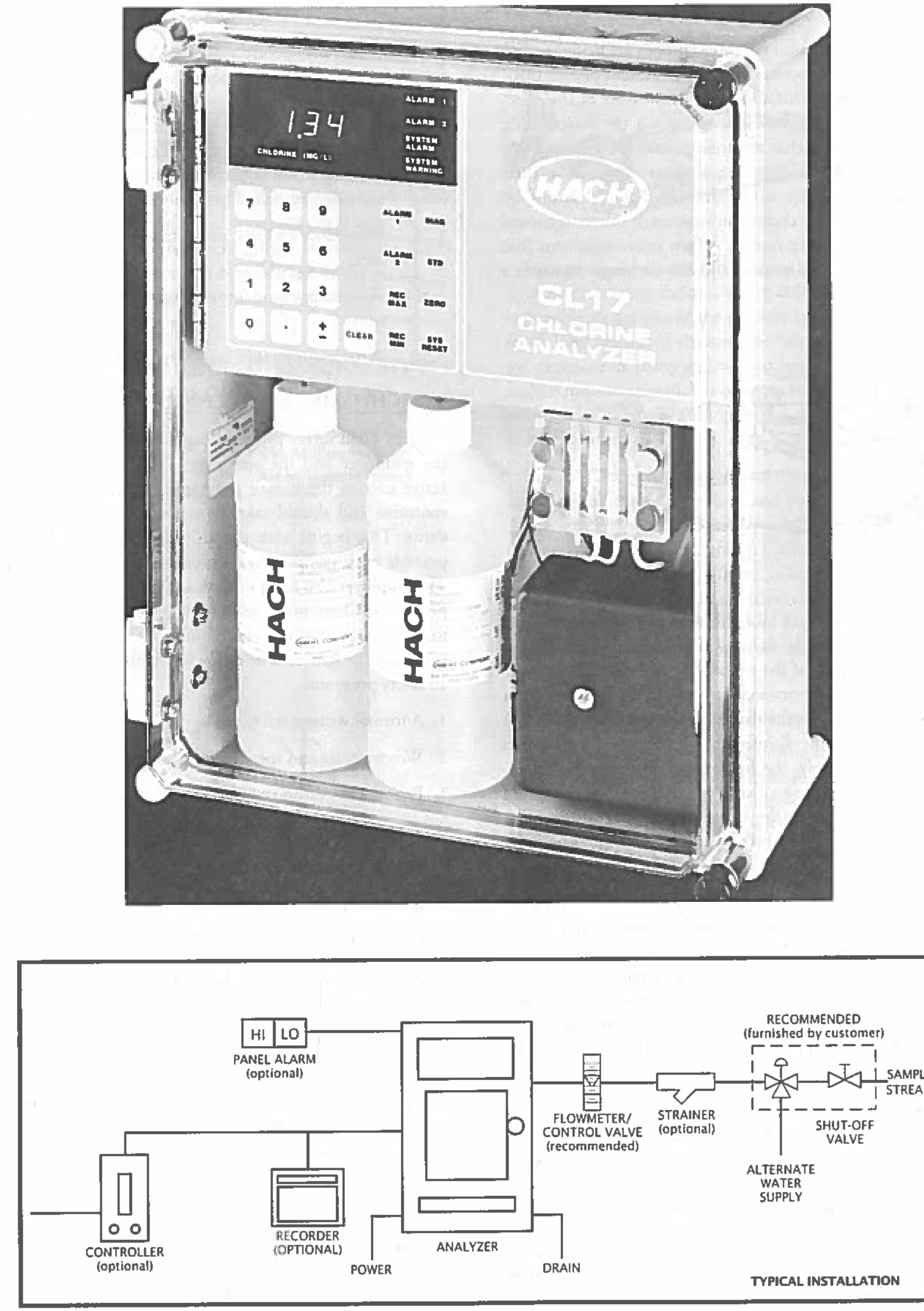
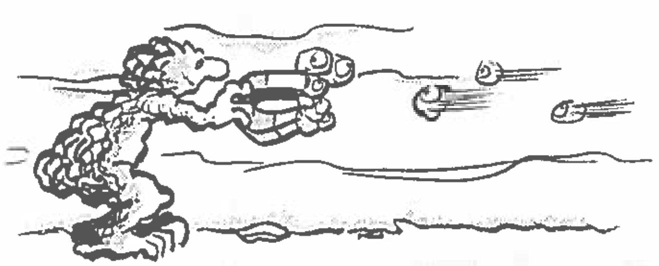


Fig. 5.22 Continuous on-line free chlorine residual analyzer

(Permission of the HACH Company)

5.53 ORP Probes

ORP (oxidation-reduction potential) probes are being used to optimize chlorination processes in water treatment plants. ORP (also called the redox potential) is a direct measure of the effectiveness of a chlorine residual in disinfecting the water being treated. Chlorine forms that are toxic to microorganisms (including coliforms) are missing one or more electrons in their molecular structure. They satisfy their need for electrons by taking electrons from any organic substances or microorganisms present in the water being treated. When microorganisms lose electrons they become inactivated and can no longer transmit a disease or reproduce.



The ability of chlorine to take electrons (the electrical attraction or electrical potential) is the ORP and is measurable in millivolts. The strength of the millivoltage (or the redox measurement) is directly proportional to the oxidative disinfection strength of the chlorine in the treatment system. The higher the concentration of chlorine disinfectant, the higher the measured ORP voltage. Conversely, the higher the concentration of organics (chlorine demanding substances), the lower the measured ORP voltage. The redox sensing unit (ORP probe) measures the voltage present in the water being treated and thus provides a direct measure of the disinfecting power of the disinfectant present in the water.

In a typical installation, a high resolution redox (HRR) chlorine controller monitors the chlorine residual using a redox (ORP) probe suspended in the chlorine contact chamber approximately 6.5 minutes downstream from the chlorine injection point. The controller converts the redox signal to a 4- to 20-milliamp (mA) signal that automatically adjusts the chlorine feed rate from the chlorinator.

The high resolution redox (HRR) units control the chlorination chemical feed rates according to actual demand in the treatment processes. These HRR units automatically treat the water with the chlorine dosages required to maintain chemical residuals in the ideal ranges, regardless of changes in the chemical demand or water flow.

Maintenance for the chlorine ORP probe consists of cleaning the unit's sensor once a month.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 351.

5.5A What three methods are used to measure chlorine residual in treated water?

5.5B How often should treated water residual chlorine measurements be made?

5.5C What does an ORP probe measure in a disinfection system?

5.5D What happens to a microorganism when it loses an electron?

5.5E What maintenance is required on chlorine ORP probes?

5.6 CHLORINE SAFETY PROGRAM

Every good safety program begins with cooperation between the employee and the employer. The employee must take an active part in the overall program. The employee must be responsible and should take all necessary steps to prevent accidents. This begins with the attitude that as good an effort as possible must be made by everyone. Safety is everyone's priority. The employer also must take an active part by supporting safety programs. There must be funding to purchase equipment and to enforce safety regulations required by OSHA and state industrial safety programs. The following items should be included in all safety programs.

1. A formal written safety policy
2. Written rules and specific safety procedures
3. Periodic hands-on training using safety equipment
   a. Leak-detection equipment
   b. Self-contained breathing apparatus (Figure 5.20)
   c. Atmospheric monitoring devices
4. Emergency procedures for chlorine leaks and first aid
5. A maintenance and calibration program for safety devices and equipment
6. Tours of facilities for police and fire departments to locate hazardous areas and provide chlorine safety information.

All persons handling chlorine should be thoroughly aware of its hazardous properties. Personnel should know the location and use of the various pieces of protective equipment and be instructed in safety procedures. In addition, an emergency procedure should be established and each individual should be instructed how to follow the procedures. An emergency checklist also should be developed and available. For additional information on this topic, see the Chlorine Institute's *CHLORINE MANUAL*, 6th Edition.[31] Also see Chapter 6, "Safety."

[31] Write to the Chlorine Institute, Inc., Bookstore, PO Box 1020, Sewickley, PA 15143-1020. Pamphlet 1. Price to members, $28.00; nonmembers, $70.00; plus $6.95 shipping and handling.

5.60 Chlorine Hazards

Chlorine is a gas that is 2.5 times heavier than air, extremely toxic, and corrosive in moist atmospheres. Dry chlorine gas can be safely handled in steel containers and piping, but with moisture must be handled in corrosion-resistant materials such as silver, glass, Teflon, and certain other plastics. Chlorine gas at container pressure should never be piped in silver, glass, Teflon, or any other material that cannot handle the pressure. Even in dry atmospheres, chlorine combines with the moisture in the mucous membranes of the nose and throat, and with the fluids in the eyes and lungs; a very small percentage in the air can be very irritating and can cause severe coughing. Heavy exposure can be fatal (see Table 5.9).

TABLE 5.9 PHYSIOLOGICAL RESPONSE TO CONCENTRATIONS OF CHLORINE GAS[a]

Effect	Parts of Chlorine Gas Per Million Parts of Air by Volume (ppm)
Slight symptoms after several hours' exposure	1[b]
Detectable odor	0.3 to 3.5
Noxiousness	5
Throat irritation	15
Coughing	30
Dangerous from one-half to one hour	40
Death after a few deep breaths	1,000

[a] Adapted from data in US Bureau of Mines *TECHNICAL PAPER 248* (1955).
[b] OSHA regulations specify that exposure to chlorine shall at *NO* time exceed 1 ppm.

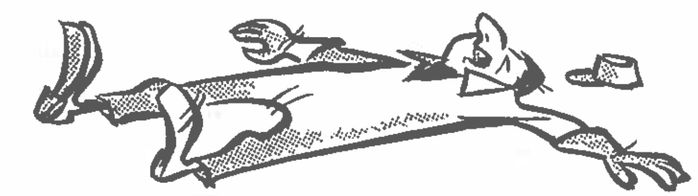
WARNING

When entering a room that may contain chlorine gas, open the door slightly and check for the smell of chlorine. Never go into a room containing chlorine gas with harmful concentrations in the air without a self-contained air supply, protective clothing, and help standing by. Help may be obtained from your chlorine supplier and your local fire department.

Most people can usually detect concentrations of chlorine gas above 0.3 ppm and you should not be exposed to concentrations greater than 1 ppm. However, chlorine gas can deaden your sense of smell and cause a false sense of security. Never rely on your sense of smell to protect you from chlorine because your sense of smell might not be able to detect harmful levels of chlorine.

5.61 Why Chlorine Must Be Handled with Care

You must always remember that chlorine is a hazardous chemical and must be handled with respect. Concentrations of chlorine gas in excess of 1,000 ppm (0.1% by volume in air) may be fatal after a few breaths.



Because the characteristic sharp odor of chlorine can be noticeable even when the amount of chlorine in the air is small, it is possible to get out of the gas area before serious harm is suffered. This feature of chlorine gas helps reduce potential operator exposure as compared with other hazardous gases such as carbon monoxide, which is odorless and gives no warning of exposure, and hydrogen sulfide, which impairs your sense of smell in a short time.

Inhaling chlorine causes general restlessness, panic, severe irritation of the throat, sneezing, and production of much saliva. These symptoms are followed by coughing, retching and vomiting, and difficulty in breathing. Chlorine is particularly irritating to persons suffering from asthma and certain types of chronic bronchitis. Liquid chlorine causes severe irritation and blistering on contact with the skin. Regular exposure to chlorine can produce chronic (long-term) effects such as permanent damage to lung tissue.

5.62 Protect Yourself from Chlorine

Every person working with chlorine should know the proper ways to handle it, should be trained in the use of self-contained breathing apparatus (SCBA), and should know what to do in case of emergencies. Wear a SCBA that protects your face, eyes, and nose. The clothing of persons exposed to chlorine can be saturated with chlorine, which can irritate the skin if exposed to moisture or sweat. These people should not enter confined spaces before their clothing is purged of chlorine (stand out in the open air for a while). This is particularly applicable to police and fire department personnel who leave the scene of a chlorine leak and ride back to their stations in closed vehicles. Suitable protective clothing for working in an atmosphere containing chlorine includes a disposable rainsuit with hood to protect your body, head, and limbs, and rubber boots to protect your feet.

WARNING

Canister type gas masks are usually inadequate and ineffective in situations where chlorine leaks occur and are therefore not recommended for use under any circumstances. Self-contained air or oxygen supply type breathing apparatus are recommended. Operators serving on emergency chlorine teams must be carefully selected and receive regular approved training. They must be provided the proper equipment that receives regular maintenance and is ready for use at all times.

Self-contained air supply and positive-pressure (pressure-demand) breathing equipment must fit properly and be used properly. Pressure-demand units and rebreather kits may be safer. Pressure-demand units use more air from the air bottle, which reduces the time a person may work on a leak. There are certain personal physical constraints when using respiratory protection. Contact your local safety regulatory agency to determine these requirements.

The 1991 Uniform Fire Code requires proper ventilation of chlorine storage rooms and rooms where chlorine is used. Mechanical exhaust systems must draw air from the room at a point no higher than 12 inches (30.5 cm) above the floor at a rate of not less than one cubic foot of air per minute per square foot (0.00508 cu m/sec/sq m) of floor area in the storage area. (The system should not draw air through the fan itself because chlorine gas can damage the fan motor.) Normally, ventilated air from chlorine storage rooms is discharged to the atmosphere. When a chlorine leak occurs, the ventilated air containing the chlorine must be treated to reduce the chlorine concentration. A caustic scrubbing system can be used. The treatment must reduce the chlorine concentration to one-half the *IDLH*[32] (Immediately Dangerous to Life or Health) level at the point of discharge to the atmosphere. The IDLH level for chlorine is 10 ppm. A secondary standby source of power is also required for the chlorine detection, alarm, ventilation, and treatment systems.

Before entering an area containing a chlorine leak, wear protective clothing. Gloves and a chemical-resistant suit will prevent chlorine from contacting the sweat on your body and forming hydrochloric acid. Chemical-resistant suits are very cumbersome, but should be worn when the weather is hot and humid and the chlorine concentration is high. A great deal of practice is required to perform effectively while wearing a chemical-resistant suit.

The best protection that one can have when dealing with chlorine is to respect it. Each individual should practice rules of safe handling and good preventive maintenance.

Prevention is the best emergency tool you have. Plan ahead:

1. Have your fire department and other available emergency response agencies tour the area so that they know where the facilities are located. Give them a clearly marked map indicating the location of the chlorine storage area, chlorinators, and emergency equipment.
2. Have regularly scheduled practice sessions in the use of respiratory protective devices, chemical-resistant suits, and chlorine repair kits. Involve all personnel who may respond to a chlorine leak.
3. Have a supply of ammonia available to detect chlorine leaks.
4. Write emergency procedures:

   Prepare a chlorine emergency list of names of companies and phone numbers of persons to call during an emergency and ensure that all involved personnel are trained in notification procedures. This list should be posted at plant telephones and should include:

   a. Fire department
   b. Chlorine emergency personnel
   c. Chlorine supplier
   d. Police department
5. Follow established procedures during all emergencies.
   a. Never work alone during chlorine emergencies.
   b. Obtain help immediately and quickly repair the problem. Problems do not get better.
   c. Only authorized and properly trained persons with adequate equipment should be allowed in the danger area to correct the problem.
   d. If you are caught in a chlorine atmosphere without appropriate respiratory protection, shallow breathing is safer than breathing deeply. Recovery depends upon the duration and amount of chlorine inhaled, so it is important to keep that amount as small as possible.
   e. If you discover a chlorine leak, leave the area immediately unless it is a very minor leak. Small leaks can be found by using a rag soaked with ammonia. A white gas will form near the leak so it can be located and corrected.
   f. Use approved respiratory protection and wear disposable clothing when repairing a chlorine leak.
   g. Notify your police department that you need help if it becomes necessary to stop traffic on roads and to evacuate persons in the vicinity of the chlorine leak.
6. Develop emergency evacuation procedures for use during a serious chlorine leak. Coordinate these procedures with your police department and other officials. Ensure that all facility personnel are thoroughly trained in any evacuation procedure developed.
7. Post emergency procedures in all operating areas.
8. Inspect equipment and routinely make any necessary repairs.
9. At least twice weekly, inspect the area where chlorine is stored and where chlorinators are located. Remove all obstructions from the area.

[32] *IDLH.* Immediately Dangerous to Life or Health. The atmospheric concentration of any toxic, corrosive, or asphyxiant substance that poses an immediate threat to life or would cause irreversible or delayed adverse health effects or would interfere with an individual's ability to escape from a dangerous atmosphere.

10. Schedule routine maintenance on all chlorine equipment at least once every six months or more frequently.
11. Have health appraisal for employees on chlorine emergency duty. No one with heart and respiratory problems should be allowed on emergency teams. There may be other personal physical constraints. Contact your local safety regulatory agency for details.

REMEMBER:

Small amounts of chlorine cause large problems. Leaks never get better.

5.63 First-Aid Measures

MILD CASES

Whenever you have a mild case of chlorine exposure (which does happen from time to time around chlorination equipment), you should first leave the contaminated area. Move slowly, breathe lightly without exertion, remain calm, keep warm, and resist coughing. Notify other operators and have them repair the leak immediately.

If clothing has been contaminated, remove the clothing as soon as possible. Otherwise, the clothing will continue to give off chlorine gas, which will irritate the body even after leaving the contaminated area. Immediately wash any area affected by chlorine. Shower and put on clean clothes.

If the victim has slight throat irritation, immediate relief can be accomplished by drinking milk. Drinking spirits of peppermint also will help reduce throat irritation. See a physician. A mild stimulant such as hot coffee or hot tea is often used for coughing.

EXTREME CASES

1. Follow established emergency procedures.
2. Always use proper safety equipment. Do not enter area without a self-contained breathing apparatus.
3. Remove patient from affected area immediately. Call a physician and begin appropriate treatment immediately.
4. First aid:
   a. Remove contaminated clothes to prevent clothing giving off chlorine gas, which will irritate the body.
   b. Keep patient warm and cover with blankets if necessary.
   c. Place patient in a comfortable position on back.
   d. If breathing is difficult, administer oxygen if equipment and trained personnel are available.
   e. If breathing seems to have stopped, begin artificial respiration immediately. Mouth-to-mouth resuscitation or any of the approved methods may be used.
   f. If even a small amount of chlorine gets into the eyes, they should be flushed immediately with large amounts of lukewarm water so that all traces of chlorine are flushed from the eyes (at least 15 minutes). Hold the eyelids apart forcibly to ensure complete washing of all eye and lid tissues.
5. See a physician.

5.64 Hypochlorite Safety

Hypochlorite does not present the hazards that gaseous chlorine does and, therefore, is safer to handle. When spills occur, wash with large volumes of water. The solution is messy to handle. Hypochlorite causes damage to your eyes and skin upon contact. Immediately wash affected areas thoroughly with water. Consult a physician if the area appears burned. Hypochlorite solutions are very corrosive. Hypochlorite compounds are nonflammable; however, they can cause fires when they come in contact with organics or other easily oxidizable substances.

5.65 Chlorine Dioxide Safety

Chlorine dioxide is generated in much the same manner as chlorine and should be handled with the same care. Of special concern is the use of sodium chlorite to generate chlorine dioxide. Sodium chlorite is very combustible around organic compounds. Whenever spills occur, sodium chlorite must be neutralized with anhydrous sodium sulfite. Combustible materials (including combustible gloves) should not be worn when handling sodium chlorite. If sodium chlorite comes in contact with clothing, the clothes should be removed immediately and soaked in water to remove all traces of sodium chlorite or the clothes should be burned immediately.

5.66 Operator Safety Training

Training is a concern to everyone, especially when your safety and perhaps your life is involved. Every water utility agency should have an ongoing operator chlorine safety training program that introduces new operators to the program and updates previously trained operators. As soon as a training session ends, obsolescence begins. People will forget what they have learned if they do not use and practice their knowledge and skills. Operator turnover can dilute a well-trained staff. New equipment and also new techniques and procedures can dilute the readiness of trained operators. An ongoing training program could include a monthly luncheon seminar, a monthly safety bulletin that is to be read by every operator, and outside speakers who reinforce and refresh specific elements of safety training.

5.67 *CHEMTREC* (800) 424-9300

Safely handling chemicals used in daily water treatment is an operator's responsibility. However, if the situation ever gets out of hand, there are emergency teams that will respond with help anywhere there is an emergency. If an emergency does develop in your plant and you need assistance, call *CHEMTREC* (Chemical Transportation Emergency Center) for assistance. *CHEMTREC* will provide immediate advice for those at the scene of an emergency and then quickly alert experts whose products are involved for more detailed assistance and appropriate follow-up.

CHEMTREC's toll-free 24-hour emergency phone number is (800) 424-9300.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 351.

5.6A What properties make chlorine gas so hazardous?

5.6B What type of breathing apparatus is recommended when repairing a chlorine leak?

5.6C What first-aid measures should be taken if a person comes in contact with chlorine gas?

5.6D What would you do if hypochlorite came in contact with your skin?

5.7 CHLORINATION ARITHMETIC

All calculations in this section can be performed by addition, subtraction, multiplication, and division on a pocket electronic calculator.

FORMULAS

There are two approaches to calculating chlorine doses in milligrams per liter. They both give the same results, but have a slightly different form. From the basic equation,

$$\text{Chlorine, lbs} = (\text{Volume, M Gal})(\text{Dose, mg}/L)(8.34\ \text{lbs/gal}),$$

we can rearrange the equation and solve for the dose in milligrams per liter.

$$\text{Chlorine Dose, mg}/L = \frac{\text{Chlorine, lbs}}{(\text{Volume, M Gal})(8.34\ \text{lbs/gal})}$$

If the basic equation is expressed as a chemical feeder setting in pounds per day, then the flow would be in million gallons per day (MGD).

$$\text{Chlorine Dose, mg}/L = \frac{\text{Chlorine, lbs/day}}{(\text{Flow, MGD})(8.34\ \text{lbs/gal})}$$

Both of the above equations are also expressed in terms of pounds or pounds per day of chlorine per million pounds or million pounds per day of water.

$$\text{Chlorine Dose, mg}/L = \frac{\text{Chlorine, lbs/day}}{\text{Water, Million lbs/day}}$$

5.70 Disinfection of Facilities

5.700 Wells and Pumps

EXAMPLE 8

How many gallons of 5.25-percent sodium hypochlorite will be needed to disinfect a well with an 18-inch diameter casing and well screen? The well is 300 feet deep and there is 200 feet of water in the well. Use an initial chlorine dose of 100 mg/*L*.

Known		Unknown
Hypochlorite, %	= 5.25%	5.25% Hypochlorite, gal
Chlorine Dose, mg/*L*	= 100 mg/*L*	
Diameter, in	= 18 in	
Water Depth, ft	= 200 ft	

1. Find the volume of water in the well in gallons.

$$\text{Water Vol, gal} = \frac{(0.785)(\text{Diameter, in})^2(\text{Water Depth, ft})(7.48\ \text{gal/cu ft})}{144\ \text{sq in/sq ft}}$$

$$= \frac{(0.785)(18\ \text{in})^2(200\ \text{ft})(7.48\ \text{gal/cu ft})}{144\ \text{sq in/sq ft}}$$

$$= 2{,}642\ \text{gal}$$

2. Determine the pounds of chlorine needed.

$$\text{Chlorine, lbs} = (\text{Volume, M Gal})(\text{Dose, mg}/L)(8.34\ \text{lbs/gal})$$

$$= (0.002642\ \text{M Gal})(100\ \text{mg}/L)(8.34\ \text{lbs/gal})$$

$$= 2.2\ \text{lbs Chlorine}$$

3. Calculate the gallons of 5.25-percent sodium hypochlorite solution needed.

$$\text{Sodium Hypochlorite Solution, gallons} = \frac{(\text{Chlorine, lbs})(100\%)}{(8.34\ \text{lbs/gal})(\text{Hypochlorite, }\%)}$$

$$= \frac{(2.2\ \text{lbs})(100\%)}{(8.34\ \text{lbs/gal})(5.25\%)}$$

$$= 5.0\ \text{gallons}$$

Five gallons of 5.25-percent solution of sodium hypochlorite should do the job.

5.701 Mains

EXAMPLE 9

A section of an old 8-inch water main has been replaced and a 350-foot section of pipe needs to be disinfected. An initial chlorine dose of 400 mg/*L* is expected to maintain a chlorine residual of over 300 mg/*L* during the 3-hour disinfection period. How many gallons of 5.25-percent sodium hypochlorite solution will be needed?

Known		Unknown
Diameter of Pipe, in	= 8 in	5.25% Hypochlorite, gallons
or 8 in/12 in/ft	= 0.67 ft	
Length of Pipe, ft	= 350 ft	
Chlorine Dose, mg/*L*	= 400 mg/*L*	
Hypochlorite, %	= 5.25%	

1. Calculate the volume of water in the pipe in gallons.

$$\text{Pipe Volume, gallons} = (0.785)(\text{Diameter, ft})^2(\text{Length, ft})(7.48\ \text{gal/cu ft})$$

$$= (0.785)(0.67\ \text{ft})^2(350\ \text{ft})(7.48\ \text{gal/cu ft})$$

$$= 923\ \text{gallons of Water}$$

2. Determine the pounds of chlorine needed.

$$\text{Chlorine, lbs} = (\text{Pipe Volume, M Gal})(\text{Chlorine Dose, mg}/L)(8.34\ \text{lbs/gal})$$

$$= (0.000923\ \text{M Gal})(400\ \text{mg}/L)(8.34\ \text{lbs/gal})$$

$$= 3.08\ \text{lbs Chlorine}$$

3. Calculate the gallons of 5.25-percent sodium hypochlorite solution needed.

$$\text{Sodium Hypochlorite Solution, gallons} = \frac{(\text{Chlorine, lbs})(100\%)}{(8.34\ \text{lbs/gal})(\text{Hypochlorite, }\%)}$$

$$= \frac{(3.08\ \text{lbs Chlorine})(100\%)}{(8.34\ \text{lbs/gal})(5.25\%)}$$

$$= 7.0\ \text{gallons}$$

Seven gallons of 5.25-percent solution of sodium hypochlorite should do the job.

5.702 Tanks

EXAMPLE 10

An existing service storage reservoir has been taken out of service for inspection, maintenance, and repairs. The reservoir needs to be disinfected before being placed back on line. The reservoir is 6 feet deep, 10 feet wide, and 25 feet long. An initial chlorine dose of 100 mg/*L* is expected to maintain a chlorine residual of over 50 mg/*L* during the 24-hour disinfection period. How many gallons of 5.25-percent sodium hypochlorite solution will be needed?

Known		Unknown
Tank Depth, ft	= 6 ft	5.25% Hypochlorite, gallons
Tank Width, ft	= 10 ft	
Tank Length, ft	= 25 ft	
Chlorine Dose, mg/*L*	= 100 mg/*L*	
Hypochlorite, %	= 5.25%	

1. Calculate the volume of water in the tank in gallons.

$$\text{Tank Volume, gallons} = (\text{Length, ft})(\text{Width, ft})(\text{Depth, ft})(7.48\ \text{gal/cu ft})$$

$$= (25\ \text{ft})(10\ \text{ft})(6\ \text{ft})(7.48\ \text{gal/cu ft})$$

$$= 11{,}220\ \text{gallons}$$

2. Determine the pounds of chlorine needed.

$$\text{Chlorine, lbs} = (\text{Vol Water, M Gal})(\text{Chlorine Dose, mg}/L)(8.34\ \text{lbs/gal})$$

$$= (0.01122\ \text{M Gal})(100\ \text{mg}/L)(8.34\ \text{lbs/gal})$$

$$= 9.36\ \text{lbs Chlorine}$$

3. Calculate the gallons of 5.25-percent sodium hypochlorite solution needed.

$$\text{Sodium Hypochlorite Solution, gallons} = \frac{(\text{Chlorine, lbs})(100\%)}{(8.34\ \text{lbs/gal})(\text{Hypochlorite, }\%)}$$

$$= \frac{(9.36\ \text{lbs})(100\%)}{(8.34\ \text{lbs/gal})(5.25\%)}$$

$$= 21.4\ \text{gallons}$$

Twenty-two gallons of 5.25-percent solution of sodium hypochlorite solution should do the job.

5.71 Disinfection of Water from Wells

5.710 Chlorine Dose

EXAMPLE 11

A chlorine demand test from a well water sample produced a result of 1.2 mg/*L*. The water supplier would like to maintain a chlorine residual of 0.2 mg/*L* throughout the system. What should be the chlorine dose in mg/*L* from either a chlorinator or hypochlorinator?

Known		Unknown
Chlorine Demand, mg/*L*	= 1.2 mg/*L*	Chlorine Dose, mg/*L*
Chlorine Residual, mg/*L*	= 0.2 mg/*L*	

Calculate the chlorine dose in mg/*L*.

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

$$= 1.2\ \text{mg}/L + 0.2\ \text{mg}/L$$

$$= 1.4\ \text{mg}/L$$

NOTE: Be sure to check the chlorine residual regularly throughout the system. If the residual is low or there are coliforms present in the test results, then the residual should be increased.

5.711 Chlorinator

EXAMPLE 12

A deep well turbine pump is connected to a hydropneumatic tank. Under normal operating heads, the pump delivers 500 GPM. If the desired chlorine dosage is 3.5 mg/*L*, what should be the setting on the rotameter for the chlorinator (pounds of chlorine per 24 hours)?

Known		Unknown
Pump Flow, GPM	= 500 GPM	Rotameter Setting, lbs Chlorine/24 hours
Chlorine Dose, mg/*L*	= 3.5 mg/*L*	

1. Convert pump flow to million gallons per day (MGD).

$$\text{Flow, MGD} = \frac{(500\ \text{GPM})(60\ \text{min/hr})(24\ \text{hr/day})}{1{,}000{,}000/\text{Million}}$$

$$= 0.72\ \text{MGD}$$

2. Calculate the rotameter setting in pounds of chlorine per 24 hours.

$$\text{Rotameter Setting, lbs/day} = (\text{Flow, MGD})(\text{Dose, mg}/L)(8.34\text{ lbs/gal})$$
$$= (0.72\text{ MGD})(3.5\text{ mg}/L)(8.34\text{ lbs/gal})$$
$$= 21.0\text{ lbs Chlorine/day}$$
$$= 21.0\text{ lbs Chlorine/24 hours}$$

EXAMPLE 13

Using the results from Example 12 (a chlorinator setting of 21 lbs per 24 hours), how many pounds of chlorine would be used in one month if the pump hour meter shows the pump operates an average of 20 hours per day? The chlorinator operates only when the pump operates. How many 150-pound cylinders will be needed per month?

Known		Unknown
Chlorinator Setting, lbs/day	= 21 lbs/day	1. Chlorine Used, lbs/mo
Pump Operation, hr/day	= 20 hr/day	2. Cylinders Needed, no/mo
Chlorine Cylinders, lbs/cyl	= 150 lbs/cyl	

1. Calculate the chlorine used in pounds per month.

$$\text{Chlorine Used, lbs/mo} = \frac{(\text{Cl Setting, lbs/day})(\text{Operation, hr/day})(30\text{ days/mo})}{24\text{ hr/day}}$$
$$= \frac{(21\text{ lbs/day})(20\text{ hr/day})(30\text{ days/mo})}{24\text{ hr/day}}$$
$$= 525\text{ lbs/mo}$$

2. Determine the number of 150-pound cylinders needed per month.

$$\text{Cylinders Needed, no/mo} = \frac{\text{Chlorine Used, lbs/mo}}{\text{Chlorine Cylinders, lbs/cyl}}$$
$$= \frac{525\text{ lbs Cl/mo}}{150\text{ lbs Cl/cylinder}}$$
$$= 3.5\text{ Cylinders/month}$$

EXAMPLE 14

A deep well turbine pump delivers 400 GPM throughout a 24-hour period. The weight of chlorine in a 150-pound cylinder was 123 pounds at the start of the time period and 109 pounds at the end of the 24 hours. What was the chlorine dose rate in mg/*L*?

Known		Unknown
Pump Flow, GPM	= 400 GPM	Chlorine Dose, mg/*L*
Time Period, hr	= 24 hr	
Chlorine Wt at Start, lbs	= 123 lbs	
Chlorine Wt at End, lbs	= 109 lbs	

1. Convert flow of 400 GPM to MGD.

$$\text{Flow, MGD} = \frac{(400\text{ GPM})(60\text{ min/hr})(24\text{ hr/day})}{1{,}000{,}000/\text{Million}}$$
$$= 0.576\text{ MGD}$$

2. Calculate the chlorine dose rate in mg/*L*.

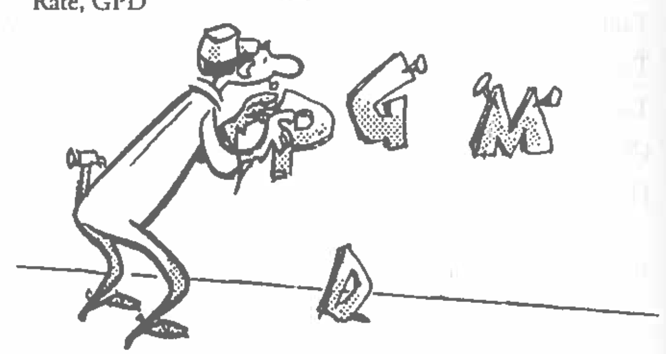
$$\text{Chlorine Dose, mg}/L = \frac{\text{Chlorine Used, lbs/day}}{(\text{Flow, MGD})(8.34\text{ lbs/gal})}$$
$$= \frac{(123\text{ lbs} - 109\text{ lbs})/1\text{ day}}{(0.576\text{ MGD})(8.34\text{ lbs/gal})}$$
$$= \frac{14\text{ lbs Chlorine/day}}{(0.576\text{ MGD})(8.34\text{ lbs/gal})}$$
$$= \frac{2.9\text{ lbs Chlorine}}{1\text{ M lbs Water}}$$
$$= 2.9\text{ mg}/L$$

5.712 Hypochlorinator

EXAMPLE 15

Water from a well is being treated with chlorine by a hypochlorinator. The well pump delivers water from the well at a pumping rate of 400 gallons per minute (GPM). The hypochlorinator pumps a 3-percent available hypochlorite solution and is set at a pumping rate of 50 gallons per day (GPD). When the well water combines with the hypochlorinator solution, what is the chlorine dose rate in milligrams per liter (mg/*L*)?

Known		Unknown
Well Pump Rate, GPM	= 400 GPM	Chlorine Dose, mg/*L*
Hypochlorite Solution, %	= 3%	
Hypochlorinator Pump Rate, GPD	= 50 GPD	



1. Convert the well pump rate from gallons per minute to million gallons per day.

$$\text{Well Pump Rate, MGD} = \frac{(\text{Well Pump Rate, GPM})(60\text{ min/hr})(24\text{ hr/day})}{1{,}000{,}000/\text{Million}}$$
$$= \frac{(400\text{ GPM})(60\text{ min/hr})(24\text{ hr/day})}{1{,}000{,}000/\text{Million}}$$
$$= 0.576\text{ MGD}$$

or $= 0.58\text{ MGD}$

2. Calculate the chlorine dose rate in pounds per day.

$$\text{Chlorine Dose, lbs/day} = \frac{(\text{Hypo Pump Rate, GPD})(\text{Hypo Sol, \%})(8.34\text{ lbs/gal})}{100\%}$$
$$= \frac{(50\text{ GPD})(3\%)(8.34\text{ lbs/gal})}{100\%}$$
$$= 12.5\text{ lbs/day}$$

3. Calculate the chlorine dose rate in mg/*L*.

$$\text{Chlorine Dose, mg}/L = \frac{\text{Chlorine Dose, lbs/day}}{(\text{Well Pump Rate, MGD})(8.34\text{ lbs/gal})}$$
$$= \frac{12.5\text{ lbs/day}}{(0.58\text{ MGD})(8.34\text{ lbs/gal})}$$
$$= 2.58\text{ mg}/L$$

EXAMPLE 16

Water pumped from a well is disinfected by a hypochlorinator. During a one-week time period, the water meter indicated that 1,098,000 gallons of water were pumped. A 2.0-percent sodium hypochlorite solution is stored in a 2.5-foot diameter plastic tank. During this one-week time period, the level of hypochlorite in the tank dropped 18 inches (1.5 ft). What was the chlorine dose in mg/*L*?

Known		Unknown
Water Treated, M Gal	= 1.098 M Gal	Chlorine Dose, mg/*L*
Hypochlorite, %	= 2.0%	
Hypochlorite Tank D, ft	= 2.5 ft	
Hypochorite Used, ft	= 1.5 ft	

1. Calculate the pounds of water disinfected.

$$\text{Water Treated, M lbs} = (\text{Water Treated, M Gal})(8.34\text{ lbs/gal})$$
$$= (1.098\text{ M Gal})(8.34\text{ lbs/gal})$$
$$= 9.16\text{ M lbs Water}$$

2. Calculate the volume of hypochlorite solution used in gallons.

$$\text{Hypochlorite, gal} = (0.785)(\text{Diameter, ft})^2(\text{Drop, ft})(7.48\text{ gal/cu ft})$$
$$= (0.785)(2.5\text{ ft})^2(1.5\text{ ft})(7.48\text{ gal/cu ft})$$
$$= 55.0\text{ gallons}$$

3. Determine the pounds of chlorine used to treat the water.

$$\text{Chlorine Used, lbs} = (\text{Hypochlorite, gal})\left(\frac{\text{Hypochlorite, \%}}{100\%}\right)(8.34\text{ lbs/gal})$$
$$= (55.0\text{ gal})\left(\frac{2.0\%}{100\%}\right)(8.34\text{ lbs/gal})$$
$$= 9.17\text{ lbs Chlorine}$$

4. Calculate the chlorine dose in mg/*L*.

$$\text{Chlorine Dose, mg}/L = \frac{\text{Chlorine Used, lbs}}{\text{Water Treated, Million lbs}}$$
$$= \frac{9.17\text{ lbs Chlorine}}{9.16\text{ M lbs Water}}$$
$$= \frac{1.0\text{ lb Chlorine}}{1\text{ M lbs Water}}$$
$$= 1.0\text{ mg}/L$$

EXAMPLE 17

Estimate the required concentration of a hypochlorite solution (%) if a pump delivers 600 GPM from a well. The hypochlorinator can deliver a maximum of 120 GPD and the desired chlorine dose is 1.8 mg/*L*.

Known		Unknown
Well Pump Rate, GPM	= 600 GPM	Hypochlorite Strength, %
Hypochlorinator Pump Rate, GPD	= 120 GPD	
Chlorine Dose, mg/*L*	= 1.8 mg/*L*	

1. Calculate the flow of water treated in million gallons per day.

$$\text{Water Treated, M Gal/day} = \frac{(\text{Well Pump Rate, GPM})(60\text{ min/hr})(24\text{ hr/day})}{1{,}000{,}000/\text{Million}}$$
$$= \frac{(600\text{ GPM})(60\text{ min/hr})(24\text{ hr/day})}{1{,}000{,}000/\text{Million}}$$
$$= 0.864\text{ MGD}$$

2. Determine the pounds of chlorine required per day.

$$\text{Chlorine Required, lbs/day} = (\text{Water Treated, MGD})(\text{Chlor Dose, mg}/L)(8.34\text{ lbs/gal})$$
$$= (0.864\text{ MGD})(1.8\text{ mg}/L)(8.34\text{ lbs/gal})$$
$$= 13.0\text{ lbs Chlorine/day}$$

3. Calculate the hypochlorite solution strength as a percent.

$$\text{Hypochlorite Strength, \%} = \frac{(\text{Chlorine Required, lbs/day})(100\%)}{(\text{Hypochlorinator Pump Rate, GPD})(8.34\text{ lbs/gal})}$$
$$= \frac{(13.0\text{ lbs/day})(100\%)}{(120\text{ GPD})(8.34\text{ lbs/gal})}$$
$$= 1.3\%$$

EXAMPLE 18

A hypochlorite solution for a hypochlorinator is being prepared in a 55-gallon drum. If 10 gallons of 5-percent hypochlorite is added to the drum, how much water should be added to the drum to produce a 1.3-percent hypochlorite solution?

Known		Unknown
Drum Capacity, gal	= 55 gal	Water Added, gal
Hypochlorite, gal	= 10 gal	
Actual Hypo, %	= 5%	
Desired Hypo, %	= 1.3%	

or

$$\text{Desired Hypo, \%} = \frac{(\text{Hypo, gal})(\text{Actual Hypo, \%})}{\text{Hypo, gal} + \text{Water Added, gal}}$$

Rearrange the terms in the equation.

$$(\text{Desired Hypo, \%})(\text{Hypo, gal} + \text{Water Added, gal}) = (\text{Hypo, gal})(\text{Actual Hypo, \%})$$

$$(\text{Desired Hypo, \%})(\text{Hypo, gal}) + (\text{Desired Hypo, \%})(\text{Water Added, gal}) = (\text{Hypo, gal})(\text{Actual Hypo, \%})$$

$$(\text{Desired Hypo, \%})(\text{Water Added, gal}) = (\text{Hypo, gal})(\text{Actual Hypo, \%}) - (\text{Desired Hypo, \%})(\text{Hypo, gal})$$

Calculate the volume of water to be added in gallons.

$$\text{Water Added, gal} = \frac{(\text{Hypo, gal})(\text{Actual Hypo, \%}) - (\text{Desired Hypo, \%})(\text{Hypo,gal})}{\text{Desired Hypo, \%}}$$

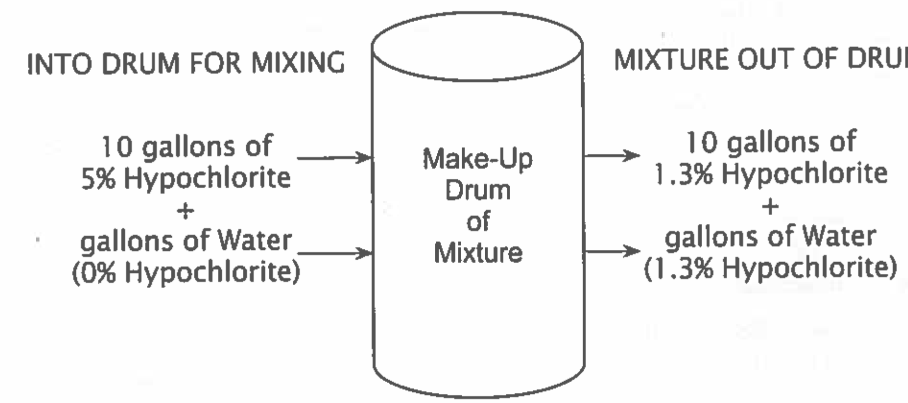
$$= \frac{(10\text{ gal})(5\ \%) - (1.3\%)(10\text{ gal})}{1.3\%}$$

$$= \frac{50 - 13}{1.3}$$

$= 28.5$ gallons of Water (Add 28.5 gallons of water to the 10 gallons of 5 percent hypochlorite in the drum.)

This problem also may be solved by using the mixture formula:

Pounds or Gallons (Kilograms or Liters) In = Pounds or Gallons (Kilograms or Liters) Out



$$(\text{Hypo In})(\%\text{ Chemical}) + (\text{Water In})(\%\text{ Chemical}) = (\text{Hypo Out})(\%\text{ Chemical}) + (\text{Water Out})(\%\text{ Chemical})$$

$$\left(\frac{\text{Hypo In,}}{\text{gal}}\right)(\text{Actual Hypo, \%}) + \left(\frac{\text{Water In,}}{\text{gal}}\right)(\text{Actual Hypo, \%}) = \left(\frac{\text{Hypo Out,}}{\text{gal}}\right)(\text{Desired Hypo, \%}) + \left(\frac{\text{Water Out,}}{\text{gal}}\right)(\text{Desired Hypo, \%})$$

$$(10\text{ gal})(5\%) + (\text{Water In, gal})(0\%) = (10\text{ gal})(1.3\%) + (\text{Water Out, gal})(1.3\%)$$

(Divide both sides of the equation by 100% to eliminate percents.)

$$\frac{(10\text{ gal})(5\%)}{100\%} + \frac{(\text{Water In, gal})(0\%)}{100\%} = \frac{(10\text{ gal})(1.3\%)}{100\%} + \frac{(\text{Water Out, gal})(1.3\%)}{100\%}$$

$$0.50\text{ gal} + 0\text{ gal} = 0.13\text{ gal} + (\text{Water Out, gal})(0.013)$$

$$0.50\text{ gal} = 0.13\text{ gal} + (\text{Water Out, gal})(0.013)$$

(Subtract 0.13 gallons from both sides of the equation.)

$$\begin{array}{r} 0.50\text{ gal} \\ -0.13\text{ gal} \\ \hline 0.37\text{ gal} \end{array} = \begin{array}{r} 0.13\text{ gal} + (\text{Water Out, gal})(0.013) \\ -0.13\text{ gal} \qquad\qquad\qquad \\ \hline 0\text{ gal} + (\text{Water Out, gal})(0.013) \end{array}$$

$$0.37\text{ gal} = (\text{Water Out, gal})(0.013)$$

(Divide both sides of the equation by 0.013.)

$$\frac{0.37\text{ gal}}{0.013} = \frac{(\text{Water Out, gal})(0.013)}{0.013}$$

$$28.4615\text{ gal} = \text{Water Out, gal}$$

$$28.5\text{ gal} = \text{Water Out, gal}$$

QUESTIONS

Write your answers in a notebook and then compare your answers with those on pages 351 and 352.

5.7A A section of 12-inch water main has been repaired and a 400-foot section of pipe needs to be disinfected. An initial chlorine dose of 450 mg/*L* is expected to maintain a chlorine residual of over 300 mg/*L* during the 3-hour disinfection period. How many gallons of 5-percent sodium hypochlorite solution will be needed?

5.7B Estimate the chlorine demand in milligrams per liter of a water that is dosed at 2.0 mg/*L*. The chlorine residual is 0.2 mg/*L* after a 30-minute contact period.

5.7C What should be the setting on a chlorinator (in pounds of chlorine per 24 hours) if a pump usually delivers 600 GPM and the desired chlorine dosage is 4.0 mg/*L*?

5.7D Water from a well is being treated with chlorine by a hypochlorinator. The well pump delivers water from the well at a pumping rate of 400 gallons per minute (GPM). The hypochlorinator pumps a 2-percent available hypochlorite solution and is set at a pumping rate of 60 gallons per day (GPD). When the well water combines with the hypochlorinator solution, what is the chlorine dose rate in milligrams per liter (mg/*L*)?

5.8 ARITHMETIC ASSIGNMENT

Turn to the Appendix, "How to Solve Small Water System Arithmetic Problems," at the back of this manual and read Section A.9, "Steps in Solving Problems." Also work the example problems and check the arithmetic using a pocket calculator.

In Section A.13, "Typical Small Water System Problems (English System)," read and work the problems in Section A.134, Disinfection.

5.9 ADDITIONAL READING

1. *NEW YORK MANUAL,* Chapter 10,* "Chlorination."
2. *TEXAS MANUAL,* Chapter 10,* "Disinfection of Water."
3. *CHLORINE MANUAL,* Sixth Edition. Obtain from the Chlorine Institute, Inc., Bookstore, PO Box 1020, Sewickley, PA 15143-1020. Pamphlet 1. Price to members, $28.00; nonmembers, $70.00; plus $6.95 shipping and handling.

The following *AWWA STANDARDS FOR DISINFECTION* are available from American Water Works Association (AWWA), Bookstore, 6666 West Quincy Avenue, Denver, CO 80235:

4. *AWWA STANDARD FOR DISINFECTING WATER MAINS,* C651-05. Order No. 43651. Price to members, $46.50; nonmembers, $68.50; price includes cost of shipping and handling.
5. *AWWA STANDARD FOR DISINFECTION OF WATER-STORAGE FACILITIES,* C652-02. Order No. 43652. Price to members, $46.50; nonmembers, $68.50; price includes cost of shipping and handling.
6. *AWWA STANDARD FOR DISINFECTION OF WATER TREATMENT PLANTS,* C653-03. Order No. 43653. Price to members, $46.50; nonmembers, $68.50; price includes cost of shipping and handling.
7. *AWWA STANDARD FOR DISINFECTION OF WELLS,* C654-03. Order No. 43654. Price to members, $46.50; nonmembers, $68.50; price includes cost of shipping and handling.

* Depends on edition.

5.10 ACKNOWLEDGMENT

Malcolm P. Dalton, General Manager, and James F. Brace, Staff Assistant, Navajo Tribal Utility Authority, provided many helpful contributions to all aspects of safety throughout this entire manual.

End of Lesson 2 of 2 Lessons on DISINFECTION

Please answer the discussion and review questions next.