

# WATER TREATMENT

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Raw water obtained from natural sources may not be completely satisfactory for domestic use. Surface water may contain disease organisms, suspended matter, or organic substances. Groundwater is less likely to contain pathogenic organisms than surface water, but it may contain undesirable tastes and odors or mineral impurities that limit its use or acceptability. Some of these objectionable characteristics may be tolerated temporarily, but suitable treatment should be used to raise the quality of the water to the highest possible level for long-term use. Even where a nearly ideal water source can be developed, it is still advisable to provide the treatment equipment necessary to ensure aesthetically and bacteriologically safe water at all times.

Some of the treatment processes that may be used by a water utility, depending on the characteristics of the water drawn from its ground or surface source, are as follows:

- Pretreatment
- Aeration
- Coagulation/flocculation
- Sedimentation
- Softening
- Filtration
- Adsorption
- Reverse osmosis
- Fluoridation
- Stabilization (corrosion control)
- Disinfection.

The order in which the processes are listed approximates the order in which they would typically be performed. However, some of the processes have overlapping

functions, and no utility would need to perform all of the processes. The one process that should be used by every utility is disinfection.

The following material gives a brief description of each of the treatment processes. Although it is only touched on in this discussion, it should be kept in mind that there is a complex interaction between the various processes in an operating treatment plant. The design and operation of such a plant requires expert attention to both water-quality goals and water-source characteristics. For any utility, and especially for a small utility investigating possible water sources, the question is not simply whether an objectionable characteristic can be treated, but whether treatment is economical as compared to the cost of developing a better source.

## PRETREATMENT

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Processes used to condition the water before it enters the main treatment processes are known as pretreatment. These may include screening, which removes large debris; microstraining, which removes algae or other small foreign matter that would clog filters; presedimentation, in which water is detained in a still reservoir for a period to allow large particles to settle out; and various chemical treatment methods to control organisms in the water source.

Surface waters may require screening, microstraining, presedimentation, and chemical pretreatment for algae and other nuisance organisms, depending on their quality. Groundwaters are usually screened through the well screen before entering the pump, and chemical pretreatment to control iron bacteria may be required.

### Controlling Aquatic Organisms in Surface Waters

Organisms known to produce tastes and odors and clog filters in surface water supplies include several species of algae, protozoa, and diatoms. Other nuisance organisms include copepods, whose eggs pass through filters; midge larvae or bloodworms; and snails and mollusks. These organisms vary in complexity and size. They are uncommon or absent in groundwater, but are common in surface waters. Some species of algae may cause gastrointestinal illness and allergic reactions; however, interference with water treatment processes and unpleasant taste, odor, and appearance constitute the chief complaints against aquatic organisms.

It is important to realize that aquatic plants and animals are normal and necessary inhabitants of a surface-water source. Overcontrol of such organisms can cause serious, long-term problems with the source's quality. Any chemical applied to control a problem with nuisance organisms must be used with caution, since excessive amounts of chemical may endanger other life systems in the environment. For example, sudden kill of heavy growths of algae may be followed by decomposition that depletes the oxygen content of the water. If oxygen depletion is excessive, a fish kill may result. Before initiating a chemical pretreatment program, advice should be sought from responsible environmental agencies.

**Algae.** Excessive growths of algae can usually be controlled by treating the water with copper sulfate (blue stone or blue vitriol) or, when feasible, by covering the reservoir unit to exclude sunlight. The particular control method or combination of methods is determined by assessing the probability for success and the costs involved for each case.

Copper sulfate has been used successfully for the control of algae since 1901. Temperature, pH, and alkalinity all affect its solubility in water. Consequently, the dosage required depends on the chemistry of the water treated and the susceptibility of the particular nuisance organism present to copper. Dosage rates of 1 oz (0.03 kg) of copper sulfate ( $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ ) for each 25 000 gal (95 000 L) of water have proven effective where the total alkalinity of the water does not exceed 40 mg/L. For more alkaline waters, the dosage can be increased to 5.5 lb of copper sulfate per acre (2.5 kg/ha)

of surface water treated regardless of depth. Copper sulfate is toxic to certain species of game fish, and this fact should be considered in calculating dosages for reservoirs where the game fish population is to be maintained.

The most practical method of application of copper sulfate for small ponds is either by spraying a solution on the water surface or by dragging a burlap bag filled with copper sulfate through the water. Rapid, uniform distribution of the chemical is important.

Frequency of treatment depends on temperature, amount of sunlight, and nutrients in the water. Systematic application of the calculated amount of chemical over the entire surface area ensures that serious algal blooms do not reappear. Several treatments per season are generally required. Treatments may be as frequent as twice a month during the growing season.

**Aquatic weeds.** Where excessive growth of aquatic weeds causes problems with filter clogging or tastes and odors, weed growth can generally be reduced to an acceptable level by physical methods such as harvesting, dewatering, dredging, shading, or lining. Biological control methods, where approved by the state department of game and fish, include the introduction of specific species of crayfish, snails, and fish. Where no other method is successful, chemical control with diquat or endothall may be used, but only with advice from the state health department. Both of these chemicals require a waiting period of up to 2 weeks before water treated with them can be used for drinking (state regulations should be consulted for exact recommendations).

### Controlling Iron Bacteria

When dissolved iron and oxygen are present in the water, a group of organisms known as iron bacteria derive the energy they need for their life processes from the oxidation of the iron to its insoluble form. They accumulate within a slimy, rust-colored gelatinous mass, which coats submerged surfaces and indicates their presence. Although this problem may occur in surface waters having high iron content, it is especially prevalent with groundwater sources.

Iron bacteria can reduce the carrying capacity of water pipes by increasing frictional losses. The bacteria may impart an unpleasant taste and odor to the water; they may discolor and spot fabrics and plumbing fixtures; and they may clog pumps, well screens, valves, and meters. A detectable slime also builds up on any surface with which the water containing these organisms comes in contact. Iron bacteria may be concentrated in a specific location and may periodically break loose and appear at the faucet in the form of rust. Iron bacteria in wells also create an environment favorable to the growth of other organisms that can produce hydrogen sulfide, an explosive gas that gives water a strong rotten-egg taste and odor.

For groundwaters, the most effective solution to iron-bacteria problems is to eliminate the bacteria by injecting a hypochlorite solution into the well. However, successful penetration of the well by the hypochlorite may be difficult to achieve, and persistent problems may require repeated or even regular applications of hypochlorite. When pretreatment methods are unsuccessful, other treatment processes will be required to produce a water of acceptable quality. These may include aeration (to remove both iron and hydrogen sulfide gas), breakpoint chlorination, or a combination of processes designed to oxidize the iron and remove it by coagulation and filtration.

## AERATION

Aeration brings air into intimate contact with water. It can be used to oxidize dissolved iron or manganese, changing them into insoluble forms. A short period of storage may be needed to permit the insoluble material to settle, and in some cases the precipitated iron or manganese cannot be removed successfully except by filtration. Because of the time needed to oxidize manganese, waters with excessive manganese levels often require oxidation with some added chemical, such as chlorine.

Aeration also increases the oxygen content of water deficient in dissolved oxygen. Carbon dioxide and other gases that increase the corrosiveness of water can be eliminated largely by effective aeration; however, the increase in corrosion caused by increased oxygen may partially offset the advantage of the decrease in carbon dioxide. Finally, aeration can be used to remove odors from water.

Many methods for effective aeration are available, including spraying water into the air, allowing water to fall over a spillway in a turbulent stream, or distributing water in multiple streams or droplets through a series of perforated plates. Although aeration may be accomplished in an open system, adequate precautions should be taken to eliminate possible external contamination.

Insects such as the chironomus fly may lay eggs in the stagnant portion of an aerator tray. The egg develops into a small red worm, which is the larval stage of this insect. Proper encasement of the aerator prevents the development of this situation. Adequate screening will also provide protection from windblown debris. Whenever possible, a totally enclosed system should be provided.

## SEDIMENTATION AND COAGULATION/FLOCCULATION

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Sedimentation is a process of gravity settling and deposition of comparatively heavy suspended material in water. This settling action can be accomplished in a still pond or properly constructed tank or basin. At least 24 hours of detention time must be provided if a significant reduction in suspended matter is to be accomplished. The inlet to the tank should be positioned so that incoming water containing suspended matter is distributed uniformly across the entire width of the tank as the water flows to the outlet located at the tank's opposite end. Baffles are usually constructed to reduce high velocities and "short circuiting" (flow directly from tank inlet to outlet, without remaining in the tank long enough for settling to occur). Cleaning and repairing an installation can be simplified if a tank has two separated sections. The wall between the sections should be strong enough so that either section may be emptied and the other section used independently.

Sedimentation performed on raw water is effective in removing relatively large particles, but it cannot significantly reduce large concentrations of very small particles, which will remain suspended in the water even after many days of detention time. By performing coagulation/flocculation, many of these particles can be combined together into larger particles that will either settle out during further detention or be removed by filtration. Coagulation is achieved by adding a chemical such as alum (hydrated aluminum sulfate) to water. The chemical is first mixed vigorously with the turbid water (the coagulation step) and then the water is mixed gently (the flocculation step). The suspended particles combine with the chemical and each other to form floc particles, which then settle to the bottom of the sedimentation basin. The coagulation, flocculation, and sedimentation steps are conventionally performed in separate tanks or basins, but some combination units are available that perform all these steps, often in conjunction with the softening process.

Adjustment of pH may be required before the coagulation/flocculation process. Some color can be removed from water by using proper coagulation techniques. Competent engineering advice should be obtained on specific coagulation problems.

## SOFTENING

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Water softening is a process that removes minerals, primarily calcium and magnesium, that cause water hardness. Softening is used where scale from hard water is a problem. It may also be used to remove certain other undesirable water constituents, such as toxic metals. Water may be softened by either the lime-soda ash or the ion-exchange process, but both processes increase the sodium content of the water, a factor that should be

considered by people on low-sodium diets. Each softening process has advantages and limitations. Other methods can also be used to soften water, such as electrodialysis, distillation, freezing, and reverse osmosis. Although each of these processes can produce softened water, they are used only in unusual circumstances.

### Lime-Soda Ash Softening

In the lime-soda ash process, lime and soda ash are added to the water and react with various salts of calcium and magnesium to form two insoluble precipitates, calcium carbonate and magnesium hydroxide. These precipitates are then removed by sedimentation and filtration processes. Most larger treatment plants that use softening select the lime-soda ash process. With some modifications, the process can also remove turbidity and color; therefore, it should be considered when softening surface water.

Caustic soda (sodium hydroxide—NaOH) can be used in place of lime and soda ash to remove carbonate and noncarbonate hardness. Disposal of the sludge that results from sedimentation after softening is a major problem with softening, and the major advantage of caustic soda is that it produces less sludge than lime and soda ash. However, since caustic soda is more expensive and increases the amount of total dissolved solids in the treated water, it is not used as widely as lime and soda ash. Because caustic soda is a relatively hazardous chemical that requires trained operators for safe handling, it may not be an appropriate choice for small systems with part-time personnel.

### Ion-exchange Softening

The ion-exchange method removes hardness ions by exchanging or replacing them with sodium ions, which do not contribute to hardness. In this softening process, ion-exchange materials, such as polystyrene resins, are placed in an ion-exchange unit through which unsoftened water is passed. As the name indicates, ion-exchange involves the exchange of one ion for another. In this case, calcium and magnesium ions attach to the resin, which releases sodium ions in exchange. With use, the ion-exchange resins become saturated with calcium and magnesium ions, and have no more sodium ions available to exchange. The resins are then regenerated by passing brine (a salt-water solution) through the ion-exchange unit.

The ion-exchange process is used in household softeners and is favored in smaller municipal water treatment plants using groundwater supplies. When a large percentage of water hardness is in noncarbonate form, the ion-exchange softening process is used because the chemical costs of removing noncarbonates are lower with the ion-exchange process than with the lime-soda ash process. The ion-exchange process can be adapted to treat surface waters, but pretreatment is normally required before the water enters the ion-exchange unit.

## FILTRATION

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Filtration is the process of removing suspended matter from water as it passes through beds of porous material. The degree of removal depends on the character and size of the individual grains of filter media, the depth of the media, and the size and quantity of the suspended matter. The effectiveness of filtration is monitored by measurement of turbidity—a light-scattering property of particles suspended in water. If a water source is highly turbid, much of the turbidity can first be removed by coagulation/flocculation and sedimentation.

A protected reservoir is helpful in producing a reasonably clear raw water, which will reduce the load placed on the filters. A filter must produce water of low turbidity if adequate disinfection is to be accomplished. Since bacteria can travel long distances

through granular materials, filters should not be relied on to produce bacteriologically safe water, even though they may greatly improve water quality. Groundwaters seldom require filtration, but most surface water sources must be filtered before disinfection.

Types of filters that may be used include:

- Slow-sand gravity filters
- Rapid-sand and high-rate gravity filters
- Pressure filters.

### Slow-Sand Gravity Filters

In a slow-sand filter, water passes slowly down through beds of fine sand at rates averaging 0.05 gpm/sq ft (0.03 mm/s) of filter area. Properly constructed slow-sand filters require a minimum of maintenance and can be used by small water systems where water does not have excessively high or variable turbidity. The filter is cleaned by removing approximately 1 in. (25 mm) of sand from the surface of the filter and either discarding it or stockpiling it for subsequent washing and reuse. This removal will necessitate the periodic addition of new or washed sand. The length of time between cleanings will vary, depending on the turbidity of the water. Filter runs of one to several weeks are common.

### Rapid-Sand and High-Rate Gravity Filters

Rapid-sand and high-rate filters are the two systems most commonly used by large municipalities. In these installations, water moves down through a filter bed of sand (rapid-sand filters) or sand and anthracite coal (high-rate filters) supported by a layer of gravel. Filtration rates range from 2 to 8 gpm/sq ft (1.3 to 3.2 mm/s), so relatively small filter plants can provide water for a large city. The filters are cleaned every 12 to 36 hours by backwashing—forcing clean water through the filter from the bottom up. The filter can run unattended for several hours, but backwashing and regular maintenance require a trained operator. For most surface waters, coagulation/flocculation is required before rapid-sand or high-rate filtration.

### Pressure Filters

In pressure filters, water is pumped through a filter medium under high pressure. The filter medium may be sand (or sand and anthracite coal) or it may be diatomaceous earth (DE), the skeletal remains of small, single-celled organisms called diatoms. The cleaning and operating procedures for pressure filters using sand or anthracite coal are similar to those for rapid-sand and high-rate gravity filters. DE filters are also cleaned by backwashing every few hours, but the backwash removes the diatomaceous-earth filter medium along with the solids that have been filtered out of the water. Fresh filter medium must then be applied to the filter, a procedure known as precoating, before the next filter run can begin. Additional DE filter medium is continuously added to the water entering the filter in order to maintain the filter surface. (The cost of continuously replenishing the DE medium may make DE filters uneconomical for larger utilities.)

Several types of pressure filters are available that backwash automatically and operate with only periodic attention. Such units are particularly appropriate for small utilities.

## ADSORPTION

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Adsorption is used primarily to remove organic materials. It can also be used to remove organic ions of fluoride and arsenic. In the adsorption process, water is brought into contact with a material to which specific types of molecules will adhere. Since the

molecules adhere only to the surface of the adsorbent material, a large surface area is required. This requirement is met by using porous adsorbent materials, which can provide a large surface area within a relatively small volume. The type of adsorbent material used depends on the contaminant to be removed. For adsorption of organics, the material used is generally either powdered activated carbon (PAC) or granular activated carbon (GAC).

Powdered activated carbon can be fed into water in dry form or as a carbon-and-water slurry. The addition is performed early in the treatment process, and the PAC is later removed, along with the adsorbed organics, by coagulation, sedimentation, and filtration. Small treatment plants and plants that use adsorption only for periodic taste and odor problems typically use a dry-feed PAC system.

Granular activated carbon is commonly used when adsorption is needed continuously. The GAC is used like a filter media, either as a replacement for sand in the regular filter bed or in a special, filter-like tank called a contactor. After a few months to a few years, the GAC bed loses its ability to adsorb and must be replaced (or, in large installations, reactivated).

## REVERSE OSMOSIS AND ELECTRODIALYSIS

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Several recently developed processes use semipermeable membranes to remove undesirable constituents from water. Membrane separation processes currently in use by utilities include reverse osmosis, membrane filtration, ultrafiltration, and electrodialysis. Both reverse osmosis and electrodialysis can be used to produce potable water from sea water or groundwater having a high concentration of dissolved solids, and both processes can be used to remove a fairly broad range of chemicals. However, power costs for the operation of the membrane processes are relatively high, and some water characteristics can cause membrane fouling.

### Reverse Osmosis

In a reverse-osmosis unit, a pump forces water through a specially designed plastic membrane at extremely high pressure, often greater than 300 psig (2100 kPa). The water passes molecule by molecule through openings in the molecular structure of the membrane, leaving a high percentage of the contaminating chemicals behind. The contaminants removed remain in the water on the inlet (high-pressure) side of the membrane; they are not deposited on the membrane itself. The efficiency of removal for a given chemical depends on the characteristics of the membrane.

Most waters require some pretreatment before reverse osmosis, usually filtration and sometimes softening and/or chemical additions, to prevent fouling of the membrane. Commercial package treatment units using reverse osmosis are available that provide the necessary pretreatment. Such units may operate with minimal attention; however, the necessary periodic maintenance and chemical additions require that the operator have some training, which should be provided by the manufacturer of the RO unit.

### Electrodialysis

Like reverse osmosis, electrodialysis separates chemicals from water by the use of semipermeable membranes. However, instead of using pumps and high pressure to force water through the membrane, the electrodialysis unit is equipped with electrodes that pull negatively and positively charged atoms out of the water through selective membranes. Since only charged atoms (ions) are removed, electrodialysis does not remove as wide a range of constituents as reverse osmosis. The process has been used most widely for desalination of brackish water.

## FLUORIDATION

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Fluoridation is used to maintain fluoride concentrations in drinking water at levels known to reduce tooth decay in children. The level must be closely controlled; too low a concentration will have no effect, and too high a concentration can cause mottling and pitting of the teeth. The optimum concentration varies with the average annual air temperature, since children will drink more water in hot weather. Precise recommendations are available from the state health department.

Three chemicals are available for fluoridating water: sodium fluoride (available in powder or crystalline form), hydrofluosilicic acid (a corrosive liquid), and sodium silicofluoride (a crystalline or granular material). All fluoride stock chemicals require care in handling, since both solid and liquid forms can be irritating or even toxic in the concentrations found in a treatment plant.

The fluoride compound used may be fed into the water with a dry feeder or with a solution feeder. Solution feeders are usually simpler. Where dry compounds are used, they must be mixed into a solution before being fed with a solution feeder; this involves regular measuring and handling of the chemicals. The mixing step can be simplified by using a saturator, a bed of sodium fluoride crystals through which water is slowly pumped. The water dissolves the crystals until it reaches a concentration level of 4-percent sodium fluoride, at which point no more crystals will dissolve. This 4-percent stock solution can then be used in a liquid feeder.

## STABILIZATION (CORROSION CONTROL)

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Corrosion control is important in maintaining the structural strength and water-tight integrity of the distribution system and in ensuring that treated water does not pick up trace quantities of hazardous metals from distribution and home pipelines. Whenever corrosion is minimized there is an appreciable reduction in the maintenance and possible replacement of water pipes, water heaters, and other metallic appurtenances of the system.

Corrosion is an electrochemical reaction in which metal deteriorates or is destroyed when in contact with environmental elements such as air, water, or soil. Whenever this reaction occurs, electric current flows from the corroding portion of the metal toward the electrolyte or conductor of electricity, such as water or soil. The point at which current flows from the metal into the electrolyte is called the anode and the point at which current flows away from the electrolyte is called the cathode. Any characteristic of the water that tends to allow or increase the rate of this electrical current will increase the rate of corrosion. The important characteristics of a water that affect its corrosiveness include the following:

- *Acidity.* A measure of the water's ability to neutralize alkaline materials. Water with acidity or low alkalinity (a measure of the concentration of alkaline materials) tends to be corrosive.
- *Conductivity.* A measure of the amount of dissolved mineral salts. An increase in conductivity promotes flow of electrical current and increases the rate of corrosion.
- *Oxygen content.* The amount of oxygen dissolved in water. The amount dissolved promotes corrosion by destroying the thin protective hydrogen film that is present on the surface of metals immersed in water.
- *Carbon dioxide.* Forms carbonic acid, which tends to attack metallic surfaces.
- *Water temperatures.* The corrosion rate increases with water temperature.

When corrosion is caused by water's acidity, it can often be controlled by neutralizing the acidity with a soda ash solution, which is fed into the water with a liquid-chemical



feeder. Another method of controlling corrosion is to feed small amounts of health-department approved, commercially available film-forming materials, such as polyphosphates or silicates, which coat and protect pipe interior surfaces. Other methods of corrosion control include installation of dielectric or insulating unions at problem locations in the distribution system, reduction of velocities and pressures, removal of oxygen or acid constituents, and lining or use of noncorrosible materials for distribution lines.

Corrosion and scale are related problems. The essential effect of corrosion is to destroy metal; scale, on the other hand, tends to clog open sections and line surfaces with deposits. A thin coating of calcium carbonate scale, however, may help to protect pipes from corrosion.

## DISINFECTION

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The most important water treatment process is disinfection, the destruction of all disease-causing bacteria and other harmful organisms that may be present in water. Disinfection is usually the last treatment process performed, since water must be low in turbidity for the process to be effective. After disinfection, water must be kept in tanks or other storage facilities that will prevent recontamination.

The methods available for disinfection of drinking water fall into the three general categories of heat treatment, radiation treatment, and chemical treatment. Heat treatment (boiling water for at least 5 min, longer at high altitudes) is an effective way to disinfect household drinking water when a local health agency has issued a "boil order" because of temporarily unsafe water. The energy costs for boiling water are too high to make it economically feasible for regular use. Disinfection with radiation, using ultraviolet light, also requires too much energy to be generally useful for a utility. The most common means of disinfection in the United States is chemical treatment, primarily with chlorine and chlorine compounds. Chemicals used less frequently include bromine, iodine (not recommended for utilities serving permanent populations), and ozone.

Disinfection of water with chlorine involves the addition of pure chlorine or a chlorine-releasing compound. A period of time is necessary after chlorine addition to allow disinfection to take place, and the chlorine concentration must be such as to ensure that disinfection will be completed before the water reaches the first user in the system. A slight residual chlorine concentration, remaining in the water as it passes through the distribution system, is desirable to prevent the regrowth of organisms after the water leaves the treatment plant. In systems where a chlorine residual is maintained, the absence of residual in a given area of the distribution system can indicate the possibility of a cross connection to a sewer or other nonpotable line. The ability to provide this residual is one of the primary factors in favor of using chlorination instead of some other means of disinfection.

Operation of an installed chlorination system requires a certain amount of training in operating, safety, and testing procedures. Publications and training programs designed for operators of chlorination systems are available through state health departments and the American Water Works Association. The remainder of this section gives a brief overview of chlorination chemistry, equipment, and operating procedures.

### Chlorination Chemistry

The chemical reactions occurring when chlorine is added to water are relatively complex and not always intuitively obvious. For example, in many cases a chlorine taste and odor in finished water is caused by the application of too little chlorine and can be corrected by increasing the chlorine dosage. Some of the more important chemical

concepts relating to chlorination can be introduced by defining terminology and noting the major factors affecting dosages.

**Chlorination terminology.** The following terms are used to describe the chemistry of the chlorination process.

- *Chlorine concentration.* The concentration of chlorine in water is expressed in milligrams per litre (mg/L). One mg/L is equivalent to 1 mg of chlorine in 1 L of water. For water, the terms parts per million (ppm) and mg/L indicate essentially equivalent concentrations.
- *Chlorine feed or dosage.* Chlorine dosage is the concentration of disinfectant, measured in mg/L, that is fed into the water system by feeder or automatic dosing apparatus. Since some of the chlorine combines with other compounds in the water, the chlorine dosage must usually be greater than the concentration of chlorine needed for adequate disinfection.
- *Chlorine demand.* Chlorine demand is a measure of the amount of chlorine fed into the water that combines with the impurities and, therefore, may not be available for disinfection action. Impurities that increase chlorine demand include organic materials and certain reducing materials such as hydrogen sulfide, ferrous iron, and nitrites.
- *Combined available chlorine residual.* In addition to organic materials that exert a chlorine demand, chlorine can combine with ammonia or other nitrogen compounds present in water to form chlorine compounds that have some disinfectant properties. These chlorine compounds are called combined available chlorine residual. ("Available" indicates they are available to act as a disinfectant.)
- *Free available chlorine residual.* The uncombined chlorine that remains in the water after any combined residual has formed is called free available chlorine residual. This is the most effective disinfectant form of chlorine.
- *Total available chlorine residual.* The total concentration of chlorine compound available to act as disinfectants, including both free and combined chlorine residuals, is called total available chlorine residual.
- *Chlorine contact time.* Contact time elapses between the time when chlorine is added to the water and the time when that particular water is used. The contact required for chlorine to act as an effective disinfectant varies from 30 min to 1 or 2 hours, depending on the concentration of the chlorine residual.

**Factors affecting chlorine dosage.** It has already been noted that waters with high turbidity cannot be adequately disinfected. The particles of turbidity inhibit disinfection in two ways: they provide "hiding places" for bacteria where chlorine cannot reach and they increase the chlorine demand. For water that has been adequately coagulated and filtered to reduce turbidity, the primary factors that determine the disinfectant efficiency of chlorine are as follows:

- *Chlorine concentration.* The higher the concentration, the more effective the disinfection and the faster the disinfection rate.
- *Type of chlorine residual.* Free chlorine is a much more effective disinfectant than combined chlorine.
- *Contact time between the organism and chlorine.* The longer the contact time, the more effective the disinfection.
- *Temperature of the water in which contact is made.* The higher the temperature, the more effective the disinfection.
- *The pH of the water in which contact is made.* The lower the pH, the more effective the disinfection.

Each of the above factors must be considered in determining the chlorine dosage to be fed into the water. As a general rule, the chlorine dosage should be large enough to satisfy the chlorine demand and provide a free available chlorine residual of 0.4 mg/L after a chlorine contact time of 30 min before the water reaches the first user beyond the point of chlorine application. Water can usually be properly disinfected if a minimum contact time of 30 min is ensured. It is also desirable to maintain a detectable free chlorine residual at distant points in the distribution system. Bacteriological (coliform) testing may indicate the need for a higher dosage or longer contact time.

Superchlorination-dechlorination is used to overcome the problem of insufficient contact time in certain water systems. In this method, chlorine is added to the water in relatively large concentrations (superchlorination) to provide a minimum free available chlorine residual of 3.0 mg/L for a minimum contact period of 5 min. The excess chlorine is then removed (dechlorination) to eliminate objectionable chlorine tastes.

### Chlorination Chemicals and Equipment

**Chlorination chemicals.** Three forms of chlorine are available for use in the disinfection of water: (1) pure chlorine gas (actually shipped and stored as a liquid in pressurized containers); (2) calcium hypochlorite, sold as a granular powder or in tablet form; and (3) sodium hypochlorite, a high-strength form of liquid bleach. Large utilities use gaseous chlorine almost exclusively, because of its economy. The operation of a gas chlorination system is fairly complicated, however, and special safety equipment is required in case of chlorine gas leaks. Smaller utilities commonly select systems using calcium hypochlorite or sodium hypochlorite, because of their relative simplicity and somewhat less stringent safety requirements.

*Calcium hypochlorite.* Calcium hypochlorite is commercially available as a granular, soluble powder or in tablet form. Calcium hypochlorite in these forms is classed as a high-test hypochlorite and contains approximately 65-percent available chlorine by weight. It is sold packed in cans or drums, and it will not deteriorate if properly stored and handled.

Calcium hypochlorite must be stored and handled with care to avoid contact between it and organic matter such as wood, cloth, or petroleum products. The reaction between calcium hypochlorite and organics can generate enough heat to cause a fire or even an explosion. Measuring containers, dippers, and mixing tanks used with the chemical should never be used for any other purpose.

To prepare a disinfectant solution that will be fed into the water, calcium hypochlorite is mixed with water to form a stock solution. (The powder should always be added to the water; adding water to the powder can generate sudden heat and cause a spattering of caustic solution.) Fresh stock solutions should be prepared frequently because the container used for preparation, storage, or distribution of the chlorine solution may not be resistant to corrosion or to light, which produces a photochemical reaction that reduces the strength of chlorine solutions. Colored glass, plastic, crockery, or rubber-lined metal containers are suitable for solution storage.

*Sodium hypochlorite.* Sodium hypochlorite is available through chemical or swimming pool equipment suppliers. The most common type sodium hypochlorite solution is household chlorine bleach, which has a strength of approximately 5-percent available chlorine by weight. Other sodium hypochlorite solutions vary in strength from 3- to 15-percent available chlorine by weight. They have a shelf life of 60 to 90 days when stored in a cool, dark place. The commercial-strength solutions may be diluted with potable water to obtain the desired solution strength to be fed into the system.

There is no fire hazard with sodium hypochlorite, and handling is simplified where the solution is fed at commercial strength. The liquid is quite corrosive, however, and should be handled with care and kept away from equipment that could be damaged by corrosion.

*Chlorine gas.* Systems using chlorine gas purchase the gas in pressurized cylinders that actually contain liquid chlorine. The gas fills the space above the level of liquid in the cylinder and is drawn off and fed into the water with precision metering devices.

Chlorine gas, if accidentally released into the air, is irritating to the eyes, nasal membranes, and respiratory tract. A few breaths of the gas can be fatal at concentrations as low as 0.1 percent in air by volume. A self-contained breathing apparatus (similar to a scuba tank with a special face mask)\* should be readily available in case leaks need to be repaired, and specially designed handling equipment and tools should be used to move and connect the pressure cylinders. The chlorination storage and operating facilities should be located in a secure building with power ventilation designed to evacuate the air near the floor, where chlorine gas will settle. Any personnel assigned to operate the chlorination system will need training in operating and emergency procedures.

**Chlorination equipment.** The equipment required for a chlorination system depends on the type of chemical used. Both calcium and sodium hypochlorite systems use hypochlorite solution feeders (hypochlorinators) to meter the liquid stock solution into water. Calcium hypochlorite also requires mixing and storage tanks for making up the stock solution from powder. Gas chlorination systems require a different type of chlorine feed system, as well as specialized equipment for handling and safety.

*Hypochlorinators.* Types of hypochlorinators available include positive displacement feeders, aspirator feeders, suction feeders, and tablet hypochlorinators. A positive displacement hypochlorinator uses a piston or diaphragm pump to inject the chlorine solution. This type of equipment, which is adjustable during operation, can be designed to give reliable and accurate feed rates. Stopping and starting the hypochlorinator can be synchronized with the pumping unit. The positive displacement hypochlorinator can be used with any water system; however, it is especially desirable in systems with low, fluctuating water pressure.

The aspirator feeder type of hypochlorinator operates on a simple hydraulic principle that employs the use of the vacuum created when water flows either through a venturi tube or perpendicular to a nozzle. The vacuum that is created draws the chlorine solution from a container into the chlorinator unit where it is mixed with water passing through the unit, and the solution is then injected into the water system. In most cases, the water inlet line to the chlorinator is connected to receive water from the discharge side of the water pump, with the chlorine solution being injected back into the suction side of the same pump. The chlorinator operates only when the pump operates. Solution flow rate is regulated by a control valve, though pressure variations may cause changes in the feed rate.

One type of suction feed hypochlorinator consists of a single line that runs from the chlorine solution container through the chlorinator unit and connects to the suction side of the pump. The chlorine solution is pulled from the container by suction created by the operating water pump. Another type of suction feeder operates on the siphon principle, with chlorine solution being introduced directly into the well. This type of feeder also consists of a single line, but the line terminates in the well below the water surface instead of at the influent side of the water pump. When the pump is operating, the chlorinator is activated so that a valve is opened and the chlorine solution is passed into the well. In each of these units, the solution flow rate is regulated by a control valve, and the chlorinator operates only when the pump operates. The pump circuit should be connected to a liquid level control so that the water supply pump operation is interrupted when the chlorine solution is exhausted.

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\*The self-contained breathing apparatus, commonly called an air pack, should be of a type approved by the National Institute of Occupational Safety and Health (NIOSH) for use near chlorine-gas leaks. The less-expensive canister type of gas mask, which does not include an air-supply tank, is designed only for very brief use in allowing personnel to leave a chlorine-contaminated atmosphere in an emergency. This type of mask should never be used for protection during leak repairs, and some jurisdictions have prohibited its use with chlorine under any circumstances.

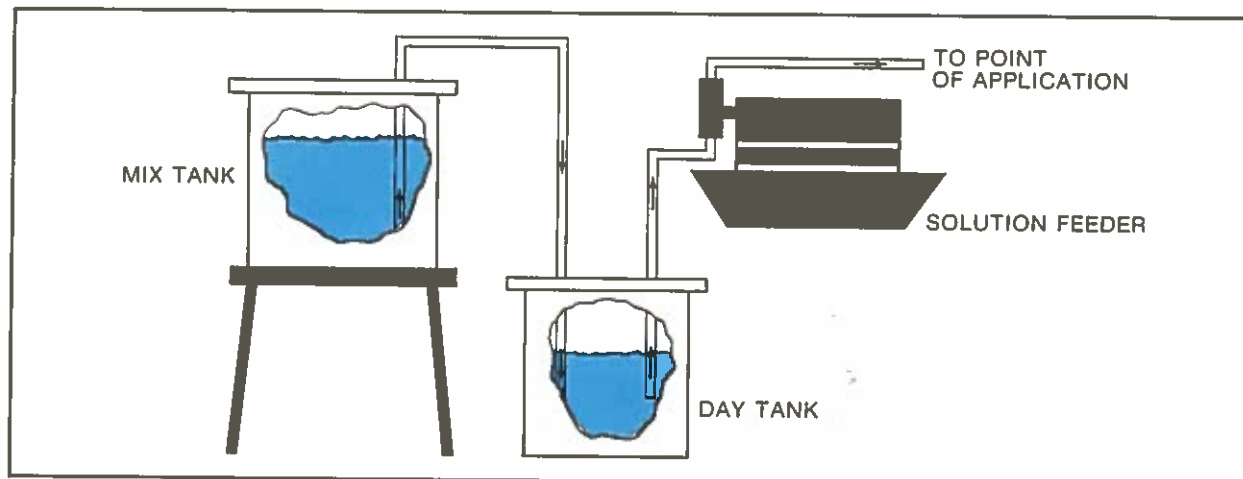


Figure 5-1 Hypochlorinator Equipment

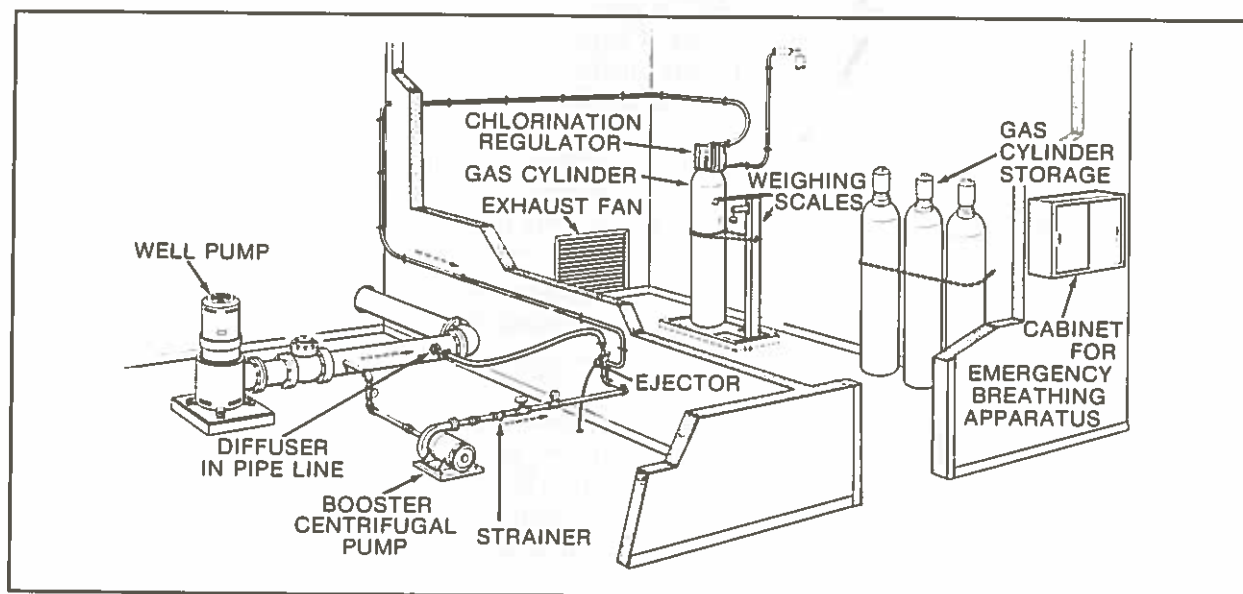


Figure 5-2 Typical Gas Chlorinator Deep Well Installation Showing Booster Pump

Hypochlorite solutions are mixed in a mixing tank, then transferred to a day tank from which the solution is fed into the water (Figure 5-1). Sensing units that can be placed in hypochlorite solution feed containers to sound a warning alarm when the solution goes below a predetermined level are commercially available. The unit can also be connected to the pump, which will automatically shut off the pump and activate a warning bell. This signals the operator to refill the solution container and take necessary steps to ensure proper disinfection.

*Gas chlorinators.* Where gas is used for chlorination, a precision gas chlorinator is used to regulate gas pressure and meter the chlorine evenly into the water. The dosage control may be varied manually or it may be controlled by a sophisticated automatic system. Scales may be used to weigh gas cylinders in use to monitor the amount of chlorine remaining. Systems using gas also require several major pieces of special safety equipment, including chlorine detectors (which sound an alarm in case of a leak), self-contained breathing apparatus, and emergency repair kits (Figure 5-2).

## Chlorination Monitoring

Residual chlorine in water can be measured as a chlorine compound (combined available chlorine residual), as free chlorine (free available chlorine residual), and as both combined and free available chlorine (total available chlorine residual).

The amount of chlorine remaining in the water (chlorine residual) can be determined by several methods. A relatively simple test called the DPD colorimetric test is commonly used. The test may be done under field conditions, using pill reagents that are placed in a special test tube. The presence of free chlorine residual produces a violet color that can be compared with a color standard to determine the quantity present. The kits, complete with all necessary equipment, can be obtained from firms that specialize in the manufacture of water-testing equipment and materials. A combination DPD and pH kit is also available. State and county water supply agencies can provide the names of kits they consider acceptable.

Wherever chlorination is required for disinfection, chlorine residual should be tested for at least daily. More information on the DPD test is included in *Introduction to Water Quality Analyses* (Water Supply Operations, Volume 4, American Water Works Association, Denver, Colo., 1982).

Adequate chlorination monitoring also depends on the maintenance of accurate operating records of the chlorination process. The records should serve as an indicator that proper chlorination is being accomplished and as a guide in improving operations. The records should show the amount of water treated, amount of chlorine used, setting of the chlorinator, time and location of tests, and results of chlorine residual determinations. This information should be kept current and posted near the chlorinator.

## PLANT MAINTENANCE

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A maintenance routine should be developed so that equipment is checked on a regular schedule. Almost all equipment will have daily, weekly, monthly, semiannual, and annual maintenance requirements, which must be followed to ensure trouble-free operation. Multiple copies of the manufacturer's instruction and maintenance manual should be available for each piece of plant equipment. A general inspection of the treatment facility should be performed daily. The disinfection equipment should be checked to be sure that it is operating satisfactorily. When chlorine disinfection is practiced, the chlorinator and chlorine supply should be checked and the water supply should be checked daily for its chlorine residual. Water may become turbid after heavy rainfall and the quality may change. Increases in the amount of chlorine and coagulants used will then be required. The performance of the filter should be watched closely. When water becomes turbid or the available quantity of water decreases, the filter should be cleaned.

**Protection from freezing.** Protection from freezing must be provided unless the plant is not operated and is drained during freezing weather. In general, the filter and pumphouse should be located in a building that can be heated in winter. The need for heat can be eliminated if the pump room and filter can be placed underground on a hillside. Gravity drainage from the pump room must be possible to prevent flooding. In any case, the filter and pumphouse must be easily accessible for maintenance and operation.