



Water Treatment

Continuing Education from the
American Society of Plumbing Engineers

July 2013

ASPE.ORG/ReadLearnEarn

CEU 2013



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Many types of possible pathogenic organisms can be found in source water. These include dissolved gases, suspended matter, undesirable minerals, pollutants, and organic matter. These substances can be separated into two general categories: chemical and biological. They generally require different methods of remediation. No single filtration or treatment process satisfies all water-conditioning requirements.

Surface water may contain more of these contaminants than groundwater, but groundwater, while likely to contain less pathogens than surface water, may contain dissolved minerals and have undesirable tastes and odors. Water provided by public and private utilities is regarded to be potable, or adequately pure for human consumption so long as it meets the standards of the U.S. Environmental Protection Agency's Safe Drinking Water Act and the local health official. However, such water still might contain some levels of pathogens and other undesirable components. Even if the water quality would not cause a specific health threat to the general public, it may not be suitable for buildings such as hospitals and nursing homes that house populations that may be vulnerable. Moreover, it may not be pure enough for certain industrial, medical, or scientific purposes.

Impure water damages piping and equipment by scoring, scaling, and corroding. Under certain conditions, water containing particles in suspension erodes the piping and scores moving parts. Water containing dissolved acidic chemicals in sufficient quantities dissolves the metal surfaces with which it comes in contact. Pitted pipe and tank walls are common manifestations of the phenomenon called corrosion. Scaling occurs when calcium or magnesium compounds in the water (in a condition commonly known as water hardness) become separated from the water and adhere to the piping and equipment surfaces. This separation is usually induced by a rise in temperature because these minerals become less soluble as the temperature increases. In addition to restricting flow, scaling damages heat-transfer surfaces by decreasing heat-exchange capabilities. The result of this condition is the overheating of tubes, followed by failures and equipment damage.

Changing the chemical composition of the water by means of mechanical devices (filters, softeners, demineralizers, deionizers, and reverse osmosis) is called external treatment because such treatment is outside the equipment into which the water flows. Neutralizing the objectionable constituents

Table 10-1 Chemical Names, Common Names, and Formulas

Chemical Name	Common Name	Formula
Bicarbonate (ion)	—	HCO_3^-
Calcium (metal)	—	Ca^{2+}
Calcium bicarbonate	—	$\text{Ca}(\text{HCO}_3)_2$
Calcium carbonate	Chalk, limestone, marble	CaCO_3
Calcium hypochlorite	Bleaching powder, chloride of lime	$\text{Ca}(\text{ClO})_2$
Chlorine (gas)	—	Cl_2
Calcium sulfate	—	CaSO_4
Calcium sulfate	Plaster of paris	$\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$
Calcium sulfate	Gypsum	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$
Carbon	Graphite	C
Carbonate (ion)	—	CO_3^{2-}
Carbon dioxide	—	CO_2
Ferric oxide	Buraf ochre	Fe_2O_3
Ferrous carbonate	—	FeCO_3
Ferrous oxide	—	FeO
Hydrochloric acid	Muriatic acid	HCl
Hydrogen (ion)	—	H^+
Hydrogen (gas)	—	H_2
Hydrogen sulfide	—	H_2S
Iron (ferric ion)	—	Fe^{3+}
Iron (ferrous ion)	—	Fe^{2+}
Magnesium bicarbonate	—	$\text{Mg}(\text{HCO}_3)_2$
Magnesium carbonate	Magnesite	MgCO_3
Magnesium oxide	Magnesia	MgO
Magnesium sulfate	—	MgSO_4
Magnesium sulfate	Epsom salt	$\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$
Manganese (metal)	—	Mn
Methane	Marsh gas	CH_4
Nitrogen (gas)	—	N_2
Oxygen (gas)	—	O_2
Potassium (metal)	—	K
Potassium permanganate	Permanganate of potash	KMnO_4
Sodium (metal)	—	Na
Sodium bicarbonate	Baking soda, bicarbonate of soda	NaHCO_3
Sodium carbonate	Soda ash	Na_2CO_3
Sodium carbonate	Sal soda	$\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$
Sodium chloride	Salt	NaCl
Sodium hydroxide	Caustic soda, lye	NaOH
Sodium sulfate	Glauber's salt	$\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$
Sulfate (ion)	—	SO_4^{2-}
Sulfuric acid	Oil of vitrol	H_2SO_4
Water	—	H_2O

by adding chemicals to the water as it enters the equipment is referred to as internal treatment. Economic considerations usually govern the choice between the two methods. Sometimes it is necessary to apply more than one technology. For instance, a water softener may be required to treat domestic

water, but a reverse osmosis system may be needed before the water is sent to HVAC or medical equipment. Another example is the need for an iron prefilter to remove large iron particles to protect a reverse osmosis membrane, which would be damaged by the iron particles.

For reference, the chemical compounds commonly found in water treatment technologies are tabulated in Table 10-1. Table 10-2 identifies solutions to listed impurities and constituents found in water.

BASIC WATER TYPES

Following are the basic types of water. Keep in mind that these terms often have multiple meanings depending on the context or the discipline being used.

Raw Water

Raw water, or natural water, is found in the environment. Natural water is rainwater, groundwater, well water, surface water, or water in ponds, lakes, streams, etc. The composition of raw water varies. Often raw water contains significant contaminants in dissolved form such as particles, ions, and organisms.

Potable Water

Potable water as defined in the International Plumbing Code is water free from impurities present in amounts sufficient to cause disease or harmful physiological effects and conforming to the bacteriological and chemical quality requirements of the public health authority having jurisdiction. The U.S. EPA Safe Drinking Water Act defines the requirements for water to be classified as potable. Potable water is often filtered, chlorinated, and/or otherwise treated to meet these standards for drinking water.

Process Wastewater

Cooling tower water is classified as a process wastewater. Cooling tower water can scale and corrode. When left untreated, cooling tower water can encourage bacteria growth and the subsequent health risks. As with many process wastewaters, cooling tower water is monitored and controlled for pH, algae, and total dissolved solids.

Soft and Hard Water

Soft water contains less than 60 parts per million (ppm) of dissolved calcium or magnesium.

Hard water contains dissolved minerals such as calcium or magnesium in varying levels. As defined by the U.S. Geological Survey, water containing 61–120 ppm of dissolved minerals is considered moderately hard, and water containing 121–180 ppm of dissolved minerals is considered hard. Water containing greater than 181 ppm of dissolved minerals is considered very hard. (Note: pH and temperature affect the behavior of dissolved minerals and should be considered in the design of systems containing hard water.)

Deionized Water

Deionized water has been stripped of mineral ions such as cations from sodium, iron, calcium, and copper as well as anions of chloride and sulfate. However, the deionization process does not remove viruses, bacteria, or other organic molecules. Deionized water is specified in ranges of conductivity.

Distilled Water

Distilled water also meets the requirements of the local health department as well as the Safe Drinking Water Act. Distilling water involves removing the impurities by boiling and collecting the condensing steam into a clean container. Distilled water has many applications, and distillation is commonly the process used to provide bottled water for consumption.

Purified Water

Purified water meets the requirements of the local health department as well as the Safe Drinking Water Act. It is mechanically processed for laboratory or potable water use.

Pure water is a relative term used to describe water mostly free from particulate matter and dissolved gases that may exist in the potable water supply. Pure water is generally required in pharmacies, central supply rooms, laboratories, and laboratory glassware-washing facilities. The two basic types of pure water are high-purity water, which is free from minerals, dissolved gases, and most particulate matter, and biopure water, which is free from particulate matter, minerals, bacteria, pyrogens, organic matter, and most dissolved gases.

Water purity is most easily measured as specific resistance in ohm-centimeters ($\Omega\text{-cm}$) or expressed as parts per million of ionized salt (NaCl). The theoretical maximum specific resistance of pure water is 18.3 megaohm-centimeters ($M\Omega\text{-cm}$) at 25°C, a purity that is nearly impossible to produce, store, and distribute. It is important to note that the specific resistance of water is indicative only of the mineral content and in no way indicates the level of bacterial, pyrogenic, or organic contamination.

The four basic methods of producing pure water are distillation, demineralization, reverse osmosis, and filtration. Depending on the type of pure water required, one or more of the methods will be needed. Under certain conditions, a combination of methods may be required. These processes are explained in detail later in the chapter.

WATER CONDITIONS AND RECOMMENDED TREATMENTS

Turbidity

Turbidity is caused by suspended insoluble matter, including coarse particles that settle rapidly in standing water. Amounts range from almost zero in most groundwater and some surface supplies to 60,000 nephelometric turbidity units (NTU) in muddy, turbulent river water. Turbidity is objectionable for practically all water uses. The standard maximum for drinking water is 1 NTU (accepted by industry), which indicates quite good quality. Turbidity exceeding 1 NTU can cause health concerns.

Generally, if turbidity can be seen easily, it will clog pipes, damage valve seats, and cloud drinking water. For non-process water, if turbidity cannot be seen, it should present few or no problems.

Turbidity that is caused by suspended solids in the water may be removed from such water by coagulation, sedimentation, and/or filtration. In extreme cases, where a filter requires frequent cleaning due to excessive turbidity, it is recommended that engineers use coagulation and sedimenta-

tion upstream of the filter. Such a device can take the form of a basin through which the water can flow at low velocities to let the turbidity-causing particles settle naturally.

For applications where water demand is high and space is limited, a mechanical device such as a clarifier utilizing a chemical coagulant may be more practical. This device mixes the water with a coagulant (such as ferric sulfate) and slowly stirs the mixture in a large circular container. The coarse particles drop to the bottom of the container and are collected in a sludge pit, while the finer particles coagulate and also drop to the bottom of the container. The clarified water then leaves the device ready for use or further treatment, which may include various levels of filtration and disinfection.

The water provided by municipalities is usually low enough in turbidity and organic constituents to preclude the use of filters, clarifiers, or chlorinators. As always, however, there are exceptions to the rule. When dealing with health and safety or with the operating efficiency of machinery, engineers always must consider the occasional exception.

Hardness

The hardness of water is due mainly to the presence of calcium and magnesium cations. These salts, in order of their relative average abundance in water, are bicarbonates, sulfates, chlorides, and nitrates. They all produce scale.

Calcium salts are about twice as soluble as magnesium salts in natural water supplies. The presence of bicarbonates of calcium and magnesium produces a condition in the water called temporary hardness because these salts can be easily transformed into a calcium or magnesium precipitate plus carbon dioxide gas. The noncarbonic salts (sulfates, chlorides, and nitrates) constitute permanent hardness conditions.

Hardness is most commonly treated by the sodium-cycle ion exchange process, which exchanges the calcium and magnesium salts for very soluble sodium salts. Only calcium and magnesium (hardness ions) in the water are affected by the softening process, which produces water that is non-scale forming. If the oxygen or carbon dioxide content of the water is relatively high, the water may be considered aggressive.

The carbonic acid may be removed by aeration or degasification, and the remaining acids may be removed by neutralization, such as by blending hydrogen and sodium cation exchanger water. Another method of neutralizing the acid in water is by adding alkali. The advantage of the alkali neutralization method is that the cost of the sodium cation exchange softener is eliminated. However, the engineer may want to weigh the cost of chemicals against the cost of the sodium ion exchange unit.

Aeration and Deaeration

As hardness in water is objectionable because it forms scale, high oxygen and carbon dioxide contents are also objectionable because they corrode iron, zinc, brass, and several other metals.

Free carbon dioxide (CO₂) can be found in most natural water supplies. Surface waters have the lowest concentration, although some rivers may contain as much as 50 ppm. In groundwater, the CO₂ content varies from almost zero to concentrations so high that the carbon dioxide bubbles out when the pressure is released.

Carbon dioxide also forms when bicarbonates are destroyed by acids, coagulants, or high temperatures. The presence of CO₂ accelerates oxygen corrosion.

Table 10-2 Water Treatment—Impurities and Constituents, Possible Effects and Suggested Treatments

		Possible Effects ^a						Treatment								
		Scale	Corrosion	Sludge	Foamin	Priming	Embrittlement	None (Inert)	Setting, coagulation, filtration, evaporation	Setting, coagulation, filtration, evaporation, ion exchange	Softening by chemicals, ion exchange materials, evaporators	Softening by heaters, chemicals, ion exchange materials, evaporators	Neutralizing, followed by softening or evaporation	Evaporation and demineralization by ion-exchange material	De-aeration	Coagulation, filtration, evaporation
Constituents	Suspended solids	X		X	X	X			X							
	Silica — SiO ₂	X								X						
	Calcium carbonate — CaCO ₃	X									X					
	Calcium bicarbonate — Ca(HCO ₃) ₂	X										X				
	Calcium Sulfate — CaSO ₄	X	X								X					
	Calcium chloride — CaCl ₂	X									X					
	Magnesium carbonate — MgCO ₃	X									X					
	Magnesium bicarbonate — Mg(HCO ₃) ₂	X									X					
	Magnesium chloride — MgCl ₂	X	X								X					
	Free acids — HCl, H ₂ SO ₄		X										X			
	Sodium chloride — NaCl							X						X		
	Sodium carbonate — Na ₂ CO ₃					X	X	X						X		
	Sodium bicarbonate — NaHCO ₃					X	X	X						X		
	Carbonic acid — H ₂ CO ₃		X												X	
	Oxygen — O ₂		X												X	
	Grease and oil		X	X	X	X										X
	Organic matter and sewage		X	X	X	X										X

^a The possibility of the effects will increase proportionately to an increase in the water temperature.

Carbon dioxide can be removed from water by an aeration process. Aeration is simply a mechanical process that mixes the air and the water intimately. It can be done with spray nozzles, cascade aerators, pressure aerators, or forced draft units. When this aeration process is complete, the water is relatively free of CO₂ gas.

Water with a high oxygen content can be extremely corrosive at elevated temperatures. Oxygen (O₂) can be removed from the water by a deaeration process. Oxygen becomes less and less soluble as the water temperature increases; thus, it is removed easily from the water by bringing the water to its boiling point.

Pressure and vacuum deaerators are available. When it is necessary to heat the water, as in boilers, steam deaerators are used. Where the water is used for cooling or other purposes where heating is not desired, vacuum units may be employed.

With aerators and deaerators in tandem, water free of CO₂ and O₂ is produced.

Minerals

Pure water is never found in nature. Natural water contains a series of dissolved inorganic solids, which are largely mineral salts. These mineral salts are introduced into the natural water by a solvent action as the water passes through (or across) the various layers of the Earth. The types of mineral salts absorbed by natural water depend on the chemical content of the soil through which the natural water passes before it reaches the consumer. This may vary from area to area. Well water differs from river water, and river water differs from lake water. Two consumers separated by a few miles may have water supplies of very dissimilar characteristics. The concentrations and types of minerals in the same water supply even may vary with the changing seasons.

Many industries can benefit greatly by being supplied with high-grade pure water. These industries are finding that they must treat their natural water supplies in various ways to achieve this condition. The recommended type of water treatment depends on the chemical content of the water supply and the requirements of the particular industry. High-grade pure water typically results in greater economy of production and better products.

Before the advent of the demineralization process, the only method used to remove mineral salts from natural water was distillation. Demineralization has a practical advantage over distillation. The distillation process involves removing the natural water from the mineral salts (or the larger mass from the smaller mass). Demineralization is the reverse of distillation: it removes the mineral salts from the natural water. This renders demineralization the more economical method of purifying natural water in most cases. Many industries today are turning to demineralization as the answer to their water problems.

The stringent quality standards for makeup water for modern boilers are making demineralizers and reverse osmosis a must for these users. Modern plating practices also require the high-quality water that demineralization produces.

CHLORINATION

Chlorination of water is most commonly used to destroy organic (living) impurities. Organic impurities fall into two categories: pathogenic, which cause disease such as typhoid and cholera, and nonpathogenic, which cause algae and slime that clog pipes and valves, discolor water, and produce undesirable odors. These pathogenic and nonpathogenic organisms can be controlled safely by chlorine with scientifically engineered equipment to ensure constant and reliable applications. An intelligent choice of the treatment necessary cannot be made until a laboratory analysis of the water has determined its quality and the quantities of water to be used are known. If microorganisms are present in objectionable amounts, a chlorination system is required.

Chlorination traditionally has been used for the disinfection of drinking water. However, the initial investment required to properly chlorinate a potable water supply has, in many cases, restricted its use to the large water consumer or to cities, which have the adequate financial support and sufficient manpower to properly maintain the chlorination system. Another drawback to the use of chlorine as a disinfectant is that the transportation and handling of a gas chlorination system are potentially dangerous. When the safety procedures are followed, however, there are few problems than with either liquid or solid products.

Chemically, chlorine is the most reactive halogen and is known to combine with nitrogenous and organic compounds to form weak bactericidal compounds. Chlorine also combines with hydrocarbons to form potentially carcinogenic compounds (trihalomethanes).

When chlorine is added to the water, hypochlorous and hydrochloric acids are formed. Hydrochloric acid is neutralized by carbonates, which are naturally present in the water. The hypochlorous acid provides the disinfecting properties of chlorine solutions. Part of the hypochlorous acid is used quickly to kill (by the oxidation process) the bacteria in the water. The remaining acid keeps the water free of bacteria until it reaches the point of ultimate use.

This residual hypochlorous acid can take two forms. It may combine with the ammonia present in almost all waters to form a residual, or chloramine, that takes a relatively long time to kill the bacteria, but it is very stable. Thus, when a water system is large, it is sometimes desirable to keep a combined residual in the system to ensure safety from the treatment point to the farthest end use. If enough chlorine is added to the system, more hypochlorous acid than can combine with the ammonia in the water is present. The excess hypochlorous acid is called free residual. It is quite unstable, but it kills organic matter very quickly. Though the time it takes for this water to pass from the treatment plant to the point of ultimate use is short, only free residual can ensure that all bacteria will be killed. Maintaining an adequate free residual in the water is the only way to ensure that the water is safe. Its presence proves that enough chlorine was originally added to disinfect the water. If no residual is present, it is possible that not all of the bacteria in the water were killed; therefore, more chlorine must be added.

Chlorine gas or hypochlorite solutions can be readily and accurately added to the water at a constant rate or by

proportional feeding devices offered by a number of suppliers. Large municipal or industrial plants use chlorine gas because it is less expensive than hypochlorite solutions and convenient. Chlorinators, such as those shown in Figure 10-1, inject chlorine gas into the water system in quantities proportional to the water flow.

For the treatment of small water supplies, hypochlorite solutions sometimes are found to be more advantageous. In feeding hypochlorite solutions, small proportioning chemical pumps, such as the one illustrated in Figure 10-2, may be used to inject the hypochlorite solution directly into the pipelines or the reservoir tanks.

CLARIFICATION

Turbid water has insoluble matter suspended in it. As turbidity in the water increases, the water looks more clouded, is less potable, and is more likely to clog pipes and valves.

Particles that are heavier than the fluid in which they are suspended tend to settle due to gravity according to Stokes' law:

Equation 10-1

$$v = \frac{kd^2 (S_1 - S_2)}{z}$$

where

v = Settling velocity of the particle

k = Constant, usually 18.5

d = Diameter of the particle

S_1 = Density of the particle

S_2 = Density of the fluid

z = Viscosity of the fluid

From Equation 10-1, it can be seen that the settling velocity of the particle decreases as the density (S_2) and the viscosity (z) of the fluid increase. Because the density and viscosity of the water are functions of its temperature, it is readily understood why, for example, the rate of the particle settling in the water at a temperature of 32°F is only 43 percent of its settling rate at 86°F. Therefore, the removal of water turbidity by subsidence is most efficient in the summer.

Where the water turbidity is high, filtration alone may be impractical due to the excessive requirements for backwash and media replacement. Subsidence is an acceptable method for the clarification of water that permits the settling of suspended matter.

Although water flow in a horizontal plane does not seriously affect the particle's settling velocity, an upward flow in a vertical plane prevents particle settling. The design of settling basins should, therefore, keep such interferences to a minimum. For practical purposes, the limit for solids removal by subsidence is particles of 0.01 millimeter or larger in diameter. Smaller particles have such a low rate of settling that the time required is greater than can be allowed. Figure 10-3 shows a typical design of a settling basin. Obviously, when a large volume of water is being handled, the settling basin occupies a large amount of space. Also, it can present safety and vandalism problems if not properly protected.

Where space is limited, a more practical approach might be the use of a mechanical clarifier that employs chemical coagulants (see Figure 10-4). Such devices can be purchased

as packaged units with simple in-and-out connections. Many chemical coagulants currently are available, including aluminum sulfate, sodium aluminate, ammonium alum, ferric sulfate, and ferric chloride. Each coagulant works better than the others in certain types of water. However, no simple rules guide the engineer in the choice of the proper coagulant, coagulant dosages, or coagulant aids. Water analysis, water temperature, type of clarification equipment, load conditions, and end use of the treated water are some of the factors that influence the selection of the proper coagulant. A few tests conducted under actual operating conditions can assist the designer in achieving the best results.

Water leaves the settling basin on the mechanical clarifier at atmospheric pressure. Thus, the designer should bear in mind that the outputs must be pumped into the water distribution system.

FILTRATION

Filtration is the process of passing a fluid through a porous medium to physically remove suspended solids. Various types of filters are available, ranging from a back-washable filter to filter cartridge housing. Depending on the type of filter, a drain may be required.

Where a clarifier of the type described above precedes the filters, the heavier, coagulated particles are removed from the water, and only the smaller, lighter particles reach the filter bed. As the suspended particles lodge between the grains of the filter medium, flow is restricted. The coagulated particles build up on the surface of the filter bed. Penetration of the filter medium by the coagulated particles is achieved at the surface in the first device or 2 inches of the bed. This coagulated mat then acts as a fine filter for smaller particles. The normal water flow rate for most filters is 3 gallons per minute (gpm) per square foot of filter area. Recent design improvements in coagulation have enabled flow rates as high as 5 gpm to 6 gpm for gravity filters.

The filter medium should be selected to provide a top layer coarse enough to allow some penetration of the top few inches of the bed by the coagulated material. Where a clarifier employing a chemical coagulant is placed ahead of the filters, a separate coagulant feed should be used to form a mat on the filter bed surface. Alum commonly is used for this purpose at a rate of about 1/10 pound for each square foot of filter bed surface. This coagulant mat should be replaced after each backwash.

Filters are either gravity or pressure type.

Gravity Filters

As their name implies, the flow of water through gravity filters is achieved by gravity only.

The filter vessel may be rectangular or circular in configuration and made of steel or concrete. The filter most commonly used is the rectangular concrete unit illustrated in Figure 10-5. This unit has a very basic design. In its more sophisticated form, the gravity filter has storage wells for the clarified water, wash troughs for even collection of the backwash, and compressed air systems for agitation of the sand during backwash.

The advantages of the gravity filter over the pressure filter are that the filter sand can be easily inspected and the

application of a coagulant is usually more easily controlled. The disadvantages are the initial pressure loss, requiring pumping of the water to pressurize the distribution system, the additional space required for installation, and the possibility of outside bacterial contamination.

Pressure Filters

Pressure filters are more widely favored in industrial and commercial water-conditioning applications. These units have an advantage in that they may be placed in the line under pressure, eliminating the need to repump the water.

The design of the pressure filter is similar to that of a gravity filter with respect to the filter medium, gravel bed, underdrain system, and control devices. The filter vessel is usually a cylindrical steel tank.

Vertical pressure sand filters, such as the one shown in Figure 10-6, range in diameter from 1 foot to 10 feet with capacities from 210 gpm to 235 gpm at an average filter rate of 3 gpm per square foot.

Multimedia depth filters are replacing single-media pressure filters. The depth filter has four layers of filtration media, each of a different size and density. The media become finer and denser in the lower layers. Particles are trapped throughout the bed, not just in the top few inches, which allows a depth filter to run longer and use less backwash water.

Horizontal pressure sand filters, usually about 8 feet in diameter and 18 feet to 30 feet in length, have a water flow rate range of 218 gpm to 570 gpm. The industry trend in recent years has been back to the horizontal pressure sand filters, which provide the advantages of a vertical filter with a lower installed cost. When the filter tank is used in its horizontal position, a larger bed area can be obtained, thus increasing the flow rate available from a given tank size.

High-rate pressure filters, with filtration rates of 20 gpm per square foot, have proven to be very efficient in many

industrial applications. The design overcomes the basic problem of most sand and other single-medium filters, which provide a maximum filtering efficiency only in the top few inches of the filter bed. The high-rate depth filters work at a maximum efficiency throughout the entire filter bed.

As with any mechanical device, proper operation and maintenance are key to continued high operating efficiency. Chemical pretreatment often is used to enhance filter performance, particularly when the turbidity includes fine colloidal particles.

Backwashing

As the suspended particles removed from the water accumulate on the filter material, it should be cleaned to avoid any excessive pressure drops at the outlet and the carryover of turbidity. The need for cleaning, particularly in pressure filters, is easily determined through the use of pressure gauges, which indicate the inlet and outlet pressures. Generally, when the pressure drop exceeds 5 pounds per square inch (psi), backwashing is in order.

In this process (see Figure 10-7), the filtered water is passed upward through the filter at a relatively high flow rate of 10–20 gpm per square foot. The bed should expand at least 50 percent, as illustrated in Figure 10-8. This process keeps the grains of the filter medium close enough to rub each other clean, but it does not lift them so high that they are lost down the drain. Backwashing can be automated by employing pressure differential switches (electronically, hydraulically, or pneumatically) to activate the diaphragm or control valves that initiate the backwash cycle at a given pressure drop.

Some problems connected with filter beds are illustrated in Figures 10-9 through 10-11. Extremely turbid water or insufficient backwashing causes accumulations called mudballs (see Figure 10-9). If not removed, mudballs result

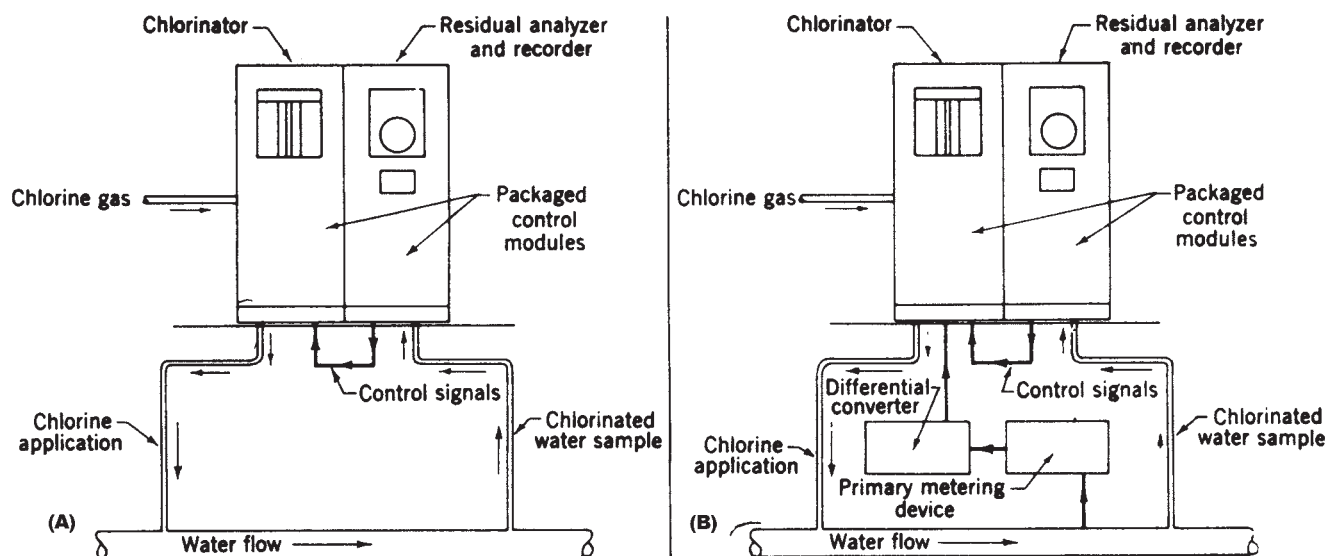


Figure 10-1 Automatic Chlorinators

Notes: The system illustrated in (A) maintains a given residual where the flow is constant or where it changes only gradually. The direct residual control is most effective on recirculated systems, such as condenser cooling water circuits and swimming pools. The desired residual is manually set at the analyzer. The flow is chlorinated until the residual reaches a set upper limit. The analyzer starts the chlorinator and keeps it operating until the residual again reaches the established upper limit. In (B) the compound loop controls the chlorinator output in accordance with two variables, the flow and the chlorine requirements. Two signals (one from the residual analyzer and another from the flow meter), when simultaneously applied to the chlorinator, will maintain a desired residual regardless of the changes in the flow rates or the chlorine requirements.

in uneven filtration and short filter runs and encourage fissures. When the filter bed surface becomes clogged with these deposits and simple backwashing does not remove them, the filter may need to be taken out of service and drained and the deposits removed by hand skimming, or the filter must be rebedded.

When fissures occur in the sand bed (see Figure 10-10), the cause usually can be traced to one or a combination of three items: the inlet water is not being distributed evenly or is entering at too high a velocity; backwash water is not being distributed evenly or is entering at too high a velocity; or mudballs have stopped the passage of water through certain areas and raised velocities in others. The filter must be drained and opened and the filter medium cleaned and reoriented.

Gravel upheaval (see Figure 10-11) usually is caused by violent backwash cycles during which water is distributed unevenly or velocities are too high. If not corrected, fissures are encouraged, or worse, filter media is allowed to pass into the distribution system where it may seriously damage valves and equipment as well as appear in potable water.

Diatomaceous Earth Filters

The use of diatomaceous earth as a water-filtering medium achieved prominence during the 1940s as a result of the need for a compact, lightweight, and portable filtering apparatus.

The water enters the filter vessel and is drawn through a porous supporting base that has been coated with diatomaceous earth. Filter cloths, porous stone tubes, wire screens, wire wound tubes, and porous paper filter pads are some of the support base materials most commonly used today. Figure 10-12 illustrates a typical leaf design filter.

Diatomaceous earth, or silica (SiO_4), is produced from mineral deposits formed by diatoms, or fossilized plants that are similar to algae. Deposits of diatoms have been found as much as 1,400 feet in thickness. Commercial filter aids are produced from the crude material by a milling process that separates the diatoms from one another. The finished product is in the form of a fine powder.

When diatomaceous earth forms a cake on the support base, a filter of approximately 10 percent solids and 90 percent voids is achieved. The openings in this filter are so small that even most bacteria are strained out of the water. However, the openings in the support base are not small enough initially to prevent the passage of individual diatomite particles. Some of these diatomite particles pass through the support base during the precoating operation. However, once the formation of the coating is complete, the interlocked mass of diatomite particles prevents any further passage of the particles.

Commercial diatomaceous earth is manufactured in a wide range of grades with differing filtration rates and differences in the clarity of the filtered water. The advantages of diatomaceous earth filters, as compared to pressure sand filters, are a considerable savings in the weight and required space, a higher degree of filtered water clarity and purity in the outgoing water, and no required coagulant use. One

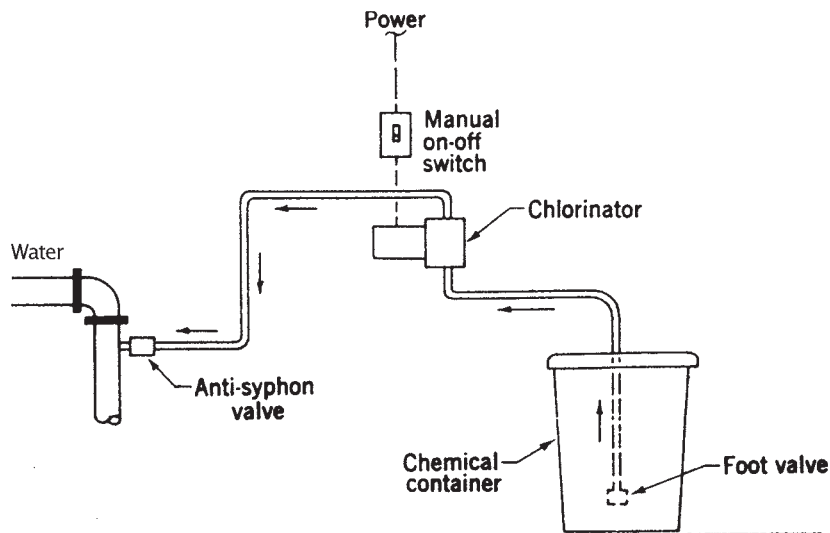


Figure 10-2 Manual Control Chlorinator

disadvantage is that only waters of relatively low turbidity can be used efficiently. It is not advisable to use these filters where incoming water turbidities exceed 100 ppm, since low-efficiency, short filter runs will result. Other disadvantages are that the initial and operating costs usually far exceed those of conventional sand filters and that the incidence of high pressure drop across the unit (as much as 25 to 50 psi) and intermittent flows cause the filter cake to detach from the support base.

DEMINERALIZATION

Sometimes called deionization, demineralization produces high-purity water that is free from minerals, most particulate matter, and dissolved gases. Depending on the equipment, the treated water can have a specific resistance of 50,000 Ω to nearly 18 M Ω . However, it can be contaminated with bacteria, pyrogens, and organics, as these can be produced inside the demineralizer itself. Demineralized water can be used in most laboratories, in laboratory glassware-washing facilities as a final rinse, and as pretreatment for still feed water.

The typical demineralizer apparatus consists of either a two-bed unit with a resistivity range of 50,000 Ω to 1 M Ω or a mixed-bed unit with a resistivity range of 1 M Ω to nearly 18 M Ω . The columns are of an inert material filled with a synthetic resin that removes the minerals by an ionization process. Since the unit runs on pressure, a storage tank is not required or recommended, as bacteria may grow in it. A demineralizer must be chemically regenerated periodically, during which time no pure water is being produced. If a continuous supply of water is needed, a backup unit should be considered, as the regeneration process takes several hours. An atmospheric, chemical-resistant drain is needed, and higher-pressure water is required for backwash during regeneration.

If deionized water is required in a small amount and the facility does not want to handle the regenerant chemicals and/or the regenerant wastewater, it may contract with a deionized water service provider to supply the facility with the quality and quantity of deionized water required. The service deionized water (SDI) provider furnishes the facility

with service deionized water exchange tanks to supply the quality, flow rate, and quantity of water required. When the tanks are exhausted, the SDI provider furnishes a new set of tanks. The SDI provider takes the exhausted tanks back to its facility for regeneration.

Ion Exchange

According to chemical theory, compounds such as mineral salts, acids, and bases break up into ions when they are dissolved in water. Ions are simply atoms, singly or in groups,

that carry an electric charge. They are of two types: cation, which is positively charged, and anion, which is negatively charged. For example, when dissolved in water, sodium chloride (NaCl) splits into the cation Na^+ and the anion Cl^- . Similarly, calcium sulfate (CaSO_4) in solution is present as the cation Ca^{2+} and the anion SO_4^{2-} . All mineral salts in water are in their ionic form.

Synthetic thermosetting plastic materials, known as ion exchange resins, have been developed to remove these objectionable ions from the solution and to produce very high-purity water. These resins are small beads (or granules) usually of phenolic, or polystyrene, plastics. They are insoluble in water, and their basic nature is not changed by the process of ion exchange. These beads (or granules) are very porous, and they have readily available ion exchange groups on all internal and external surfaces. The electrochemical action of these ion exchange groups draws one type of ion out of the solution and puts a different one in its place. These resins are of three types: cation exchanger, which exchanges one positive ion for another, anion exchanger, which exchanges one negative ion for another, and acid absorber, which absorbs complete acid groups on its surface.

A demineralizer consists of the required number of cation tanks and anion tanks (or, in the case of monobeds, combined tanks) with all of the necessary valves, pipes, and fittings required to perform the steps of the demineralization process for the cation resin, as well as an acid dilution tank material for the cation resin and an acid dilution tank, as sulfuric acid is too concentrated to be used directly. If hydrochloric acid is to be used as a cation regenerant, this mix tank is unnecessary since the acid is drawn in directly from the storage vessel. A mixing tank for soda ash or caustic soda, used in anion regeneration, is always provided.

Since calcium and magnesium in the raw regenerant water precipitate the hydroxide (or carbonate) salts in the anion bed, the anion resin must be regenerated with hardness-free water. This condition may be accomplished either with a water softener (which may be provided for this purpose) or by use of the effluent water from the cation unit to regenerate the anion resin. The use of a softener decreases the regeneration time considerably, as both units may be regenerated simultaneously rather than separately.

Provided with each unit is a straight reading volume meter, which indicates gallons per run as well as the total volume put through the unit. Also provided with each unit is a conductivity and resistivity indicator used to check the

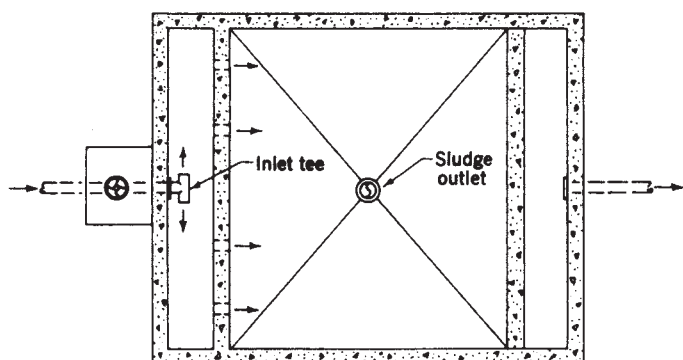
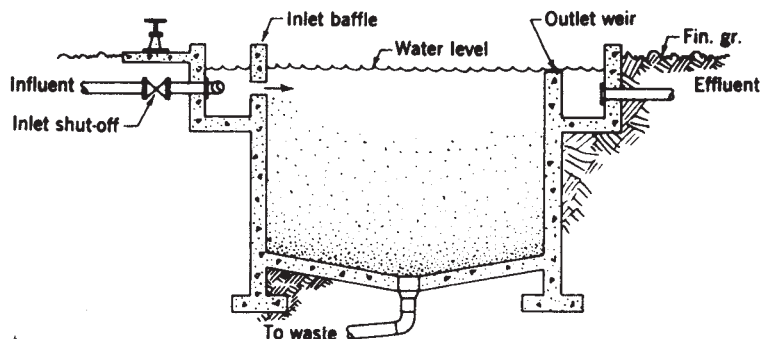
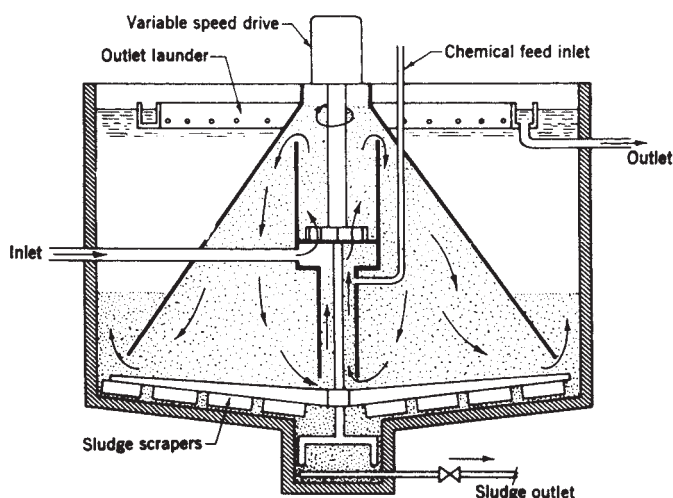


Figure 10-3 Settling Basin



Notes: The turbid water enters the central uptake mixed with the coagulant and is forced toward the bottom of the unit. Some water and the suspended precipitates enter the lower end of the uptake for recirculation and contact with the incoming chemicals and the water. New coagulation is encouraged by contact with these previously formed precipitates. The water then enters the outer settling section. The clarified water rises to the outlet flume above. The heavier particles settle and are moved along the bottom to the sludge pit.

Figure 10-4 Mechanical Clarifier

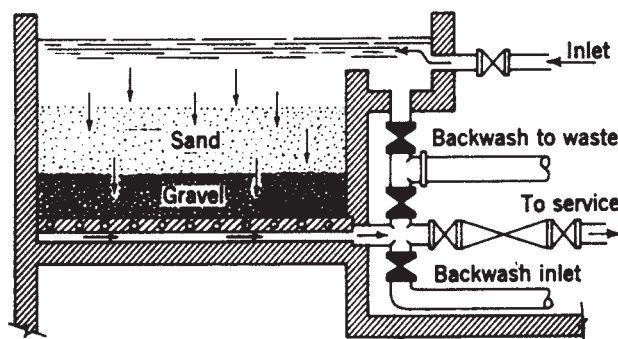


Figure 10-5 Rectangular Gravity Sand Filter

purity of the effluent water at all times. This instrument is essentially a meter for measuring the electrical resistance of the treated water leaving the unit. It consists of two principal parts: the conductivity cell, which is situated in the effluent line, and the instrument box to which the conductivity cell is connected.

The conductivity cell contains two electrodes across which an electric potential is applied. When these poles are immersed in the treated water, the resistance to the flow of the electricity between the two poles (which depends on the dissolved solids content of the water) is measured by a circuit in the instrument. The purity of the water may be checked by reading the meter. When the purity of the water is within the specific limits, the green light glows. When the water becomes too impure to use, the red light glows. In addition, a bell may be added that rings when the red light glows to provide an audible as well as a visible report that the unit needs regeneration. This contact also can close an effluent valve, shift operation to another unit if desired, or put the unit into regeneration.

Controls

Several types of controls are currently available to carry out the various steps of regeneration and return to service. The two most common arrangements follow:

- Type A: This consists of completely automatic, individual air- or hydraulic-operated diaphragm valves controlled by a sequence timer, and regeneration is initiated via a conductivity meter. This arrangement provides maximum flexibility in varying amounts and concentrations of regenerants, length of rinsing, and all other steps of the operating procedure. The diaphragm valves used are tight seating, offering maximum protection against leakage and thus contamination with minimal maintenance.
- Type B: This consists of manually operated individual valves. This system combines maximum flexibility and minimal maintenance with an economical first cost. It typically is used on larger installations.

Internal Arrangements

The internal arrangements of the vessels are similar for all types of controls. The internal arrangement used on medium to large units is shown in Figure 10-13. Smaller units have simpler arrangements since the distribution problems are less complex. The positive and thorough distribution of regenerants, rinse, and wash waters to achieve maximum efficiency provides economy and reliability.

Ion Exchange Water Softeners

A typical hydrogen-sodium ion exchange plant is shown in Figure 10-14. This process combines sodium-cycle ion exchange softening with hydrogen-cycle cation exchange.

The sodium ion exchange process is exactly the same as a standard ion exchange water softener. The hardness (calcium and magnesium) is replaced with sodium (non-scaling). The alkalinity (bicarbonates) and other anions remain as high as in the raw water.

The cation exchanger is exactly the same as the one used with demineralizers; therefore, its effluent contains carbonic acid, sulfuric acid, and hydrochloric acid. Sodium ion ex-

change units are operated in parallel, and their effluents are combined. Mineral acids in the hydrogen ion exchange effluent neutralize the bicarbonates in the sodium ion exchange effluent. The proportions of the two processes are varied to produce a blended effluent having the desired alkalinity. The

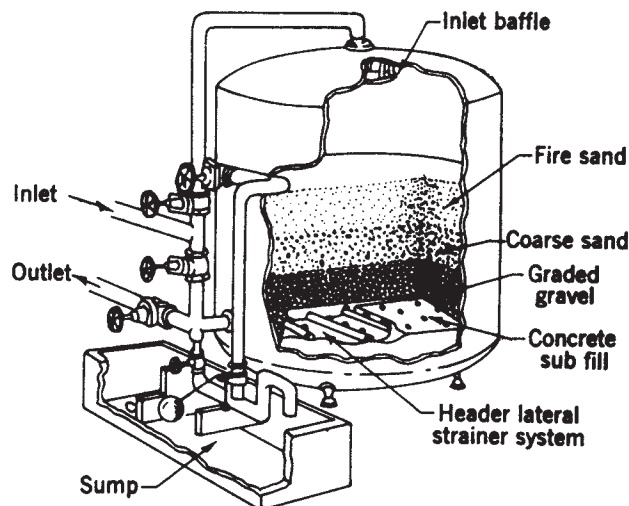


Figure 10-6 Vertical Pressure Sand Filter

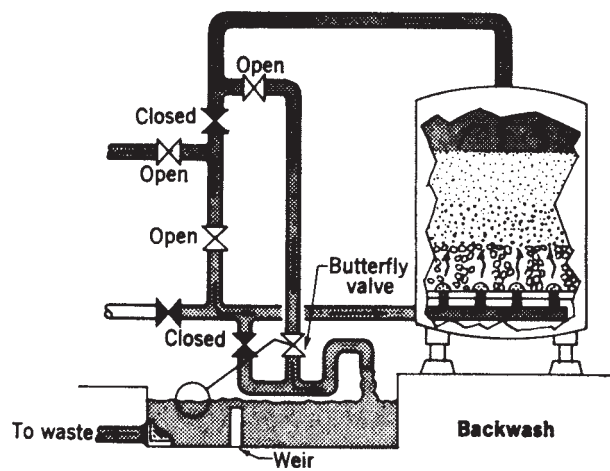


Figure 10-7 Backwashing

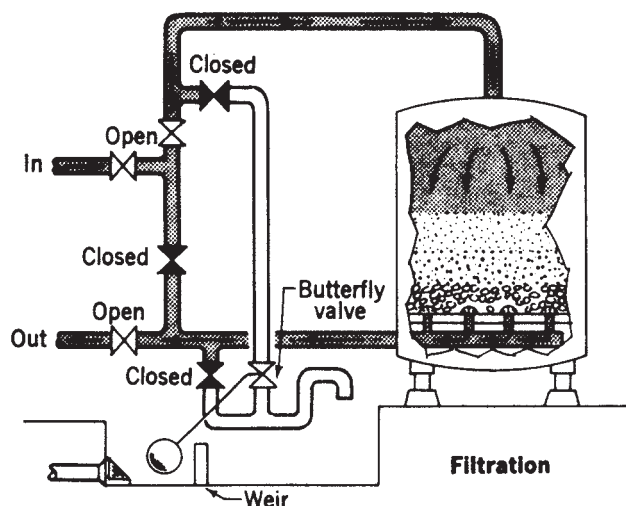


Figure 10-8 Filtration and Backsplash Cycles

carbon dioxide is removed by a degasifier. The effluent is soft, low in solids, and as alkaline as desired.

In the sodium ion exchange softener plus acid addition process (see Figure 10-15), the acid directly neutralizes the bicarbonate's alkalinity to produce a soft, low-alkaline water. The carbon dioxide produced is removed by a degasifier. The chief disadvantages of this process are that the total dissolved solids are not reduced and control of the process is difficult.

In a sodium ion exchange softener plus chloride dealkalizer process, water passes first through the sodium ion exchange softener, which removes the hardness, and then through a chloride dealkalizer, which is an ion exchanger that operates in the chloride cycle. The bicarbonates and sulfates are replaced by chlorides. The resin is regenerated with sodium chloride (common salt). The equipment is the same as that for sodium ion softeners. This process produces soft, low-alkaline water. Total dissolved solids are not reduced, but the chloride level is increased. The chief advantages of this process are the elimination of acid and the extreme simplicity of the operation. No blending or proportioning is required.

In some cases, the anion resin can be regenerated with salt and caustic soda to improve capacity and reduce the leakage of carbon dioxide.

WATER SOFTENING

Water softening is required for practically all commercial and industrial building water usage. Generally speaking, almost any building supplied with water having a hardness of 3.5 grains per gallon (gpg) or more should have a water softener. This is true even if the only usage of the water other than for domestic purposes is for heating because the principal threat to water heater life and performance is hard water. Approximately 85 percent of the water supplies in the United States have hardness values above the 3.5 gpg level.

However, it is not good practice to specify a water softener to supply the heating equipment only and disregard the softening needs for the balance of the cold water usage in the building. A typical example of this condition is a college dormitory. Many fixtures and appliances in a dormitory in addition to the hot water heater require soft water, including the piping itself, flush valve toilets, shower stalls, basins, and laundry rooms. Many fixtures and appliances that use a blend of hot and cold water experience scale buildup and staining, even when the hot water is softened.

One of the most common reasons for installing water softening equipment is to prevent hardness scale buildup in piping systems, valves, and other plumbing fixtures. Scale builds up continually and at a faster rate as the temperature increases. The graph in Figure 10-16 illustrates the degree of scale deposit and the rate increase as the temperature of the water is elevated on water having a hardness of 10 gpg. For water of 20-gpg hardness, scale deposit values can be multiplied by two. Although the rate of scale deposit is higher as the temperature increases, significant scale buildup occurs with cold water. Thus, the cold water scale, while taking a longer period to build up, is nevertheless significant.

Water Softener Selection

The factors the designer should consider in sizing water softeners include the following: flow rate, softener capacity,

frequency of regeneration, single versus multiple systems, space requirements, cost, and operating efficiency.

Flow Rate

After determining the total flow rate requirements for the building, including all equipment, the engineer can consider the size of the water softener. The unit selected should not restrict the water flow rate beyond the pressure loss that the building can withstand, based on the pressures available at the source and the minimum pressure needed throughout the entire system. A water softener that meets both flow rate and pressure drop requirements should be selected.

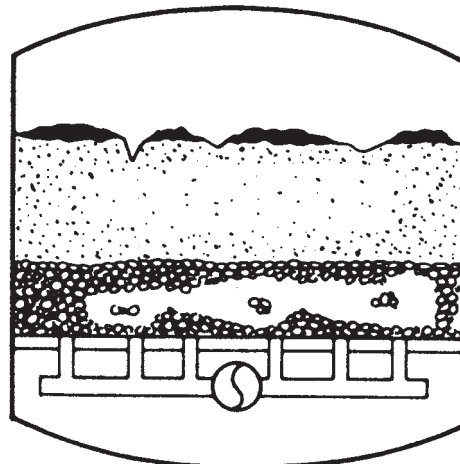


Figure 10-9 Mudballs

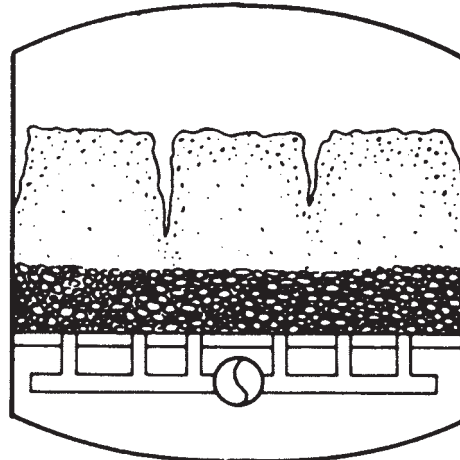


Figure 10-10 Fissures

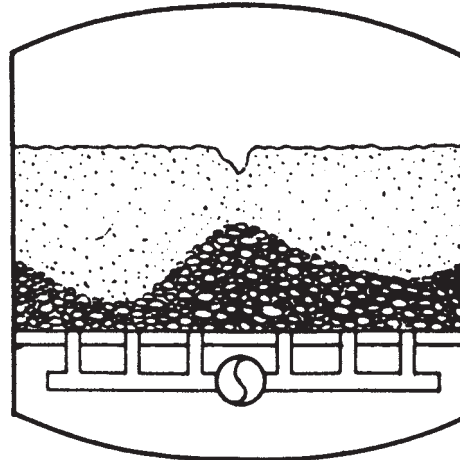


Figure 10-11 Gravel Upheaval

The softener system also should be capable of providing the design flow rates within the desired pressure drop. This means not only that the pipe and valve sizes must be adequate, but also that the water softener tank and its mineral must be capable of handling the flows while providing the soft water. The water softener design should be based on hydraulic and chemical criteria.

Good design practices for general use dictate that service flow rates through the water softener be approximately 1–5 gpm per cubic foot with mineral bed depths of 30 inches or more. Based on these accepted practices, the water softener is generally able to handle peak flows for short periods.

Standard softener units are designed for a pressure differential of approximately 15 psi, the most common differential acceptable for building design. Thus, for general usage, a water softener may be selected from a manufacturer's catalog. The engineer should give more detailed consideration to the selection of a water softener where especially low pressure losses are needed. Many equipment manufacturers offer complete pressure drop curves for their equipment, allowing the selection of components to fit any flow pressure drop conditions desired.

Fixture Count Flow Rate Estimating Guide for Water Softeners

This guide is for estimating average and maximum flow rate requirements (in gallons per minute) for both private and public buildings and is based on fixture flow rates and probability of use. It is to be used when actual continuous and peak flow rates are not known.

The average rates may be used when line pressure less the conditioner pressure drop is at least 30 psi at the highest point of use in the building. The maximum rates are equal to the fixture count figures commonly used to size water lines and are applicable especially in low water pressure areas where pressure drop is critical.

- Count and list each type of fixture used intermittently. Multiply the total of each type by its private or public unit weight. Private or public unit weights must be determined by the use of the fixture. For example, lavatories in an apartment house are private. Lavatories in a restaurant are public. Add the products of each type of fixture to determine the total fixture count weight.
- From the intermittent flow rate chart, select the total fixture count, or the next highest fixture count, determined in step 1.
- Add to the flow rate determined in step 2 any continuously used flow rates in gallons per minute. These additional requirements may include commercial dishwashers, garbage disposals that run continually, boiler makeup water, or swimming pool makeup water. In some cases, these additional requirements are seasonal and used separately. For example, if boilers are shut down during the summer, use the additional requirement of the boiler or the air-conditioning system, whichever is greater.

Example 10-1

For example, the flow rate for a 10-unit apartment building can be estimated as follows. In addition to the fixtures

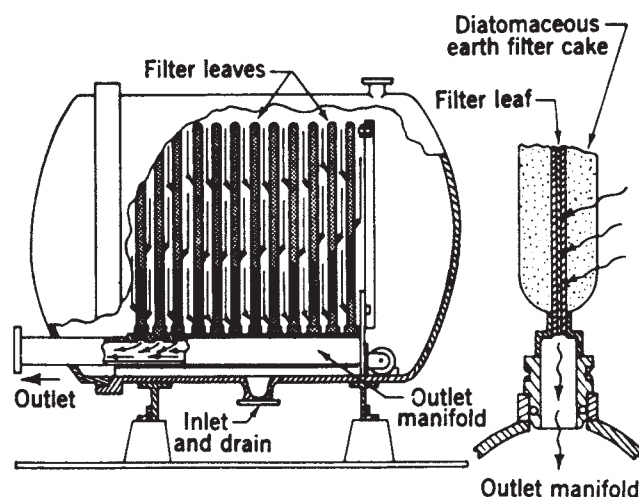


Figure 10-12 Leaf Design, Diatomaceous Earth Filter

listed, the building has one air-conditioner with 5-gpm makeup. (Refer to the local code for the specific water supply load values used in the area.)

Fixtures	Unit Weight	Total Weight
10 kitchen sinks	× 2	= 20
10 bathtub/showers	× 2	= 20
10 lavatories	× 1	= 10
10 tank-type toilets	× 3	= 30
3 washing machines	× 2	= 6
Total		= 86

For a total of 86 fixture units, the corresponding flow rate is 31 gpm. Add 31 gpm to 5 gpm for the air-conditioner: $31 + 5 = 36$ gpm. Select the smallest unit that has a continuous flow rate of 36 gpm.

- Select the smallest water conditioner with a continuous flow rate that is equal to or greater than the total flow rate requirement in step 3.

The line pressure less the pressure drop of the selected unit must be at least 30 psi to handle the peak flow rate periods. If it is less than 30 psi, repeat step 2 using the maximum column on the intermittent flow rate chart and add the additional requirements of step 3. Select a water conditioner with a continuous flow rate that is equal to or greater than the new total flow rate requirement.

When the maximum figures are used, the line pressure less the conditioner pressure drop must be 20 psi minimum

Note: When water conditioners are installed in series, such as an iron filter in a water softener, the 30-psi and 20-psi minimum pressures must be maintained after both units. Select combinations of conditioners with a total pressure drop, when subtracted from the line pressure, of 30 psi minimum when using the average figures or 20 psi when using the maximum figures.

Where measurements of water consumption are not possible—for instance, where water meter records are not available—the information in Table 10-3 can be used to estimate the amount of water consumed in several establishments. (Note: For more accurate figures, take meter readings during average or peak periods—a week or a month. Water bills may be used to determine daily water consumption.) If manually operated equipment is desired, longer periods between regenerations may be desired to reduce the attention that an operator must give to the water softener. Thus, larger-capacity units must be selected.

Softener Capacity

Once the size of the water softener is selected based on flow rate and pressure drop, the designer should consider the length of the service run. For each standard-size water softener, a nominal quantity of softening mineral is used. This amount is based on the recommended depth of the mineral (normally 30–36 inches) and the proper free-board space above the mineral (the space required for the proper expansion of the mineral during backwashing). Thus, from the unit initially selected, a standard capacity is known.

The capacity of a water softener is its total hardness exchange ability, generally expressed in terms of grains exchange. The normal capacity of available softening mineral (resins) is 20,000–30,000 grains for each cubic foot of mineral. Thus, the total capacity for the water softener is obtained by multiplying this value by the number of cubic feet of mineral in the water softener. The hardness of the raw water must be ascertained. By dividing the water hardness (grains per gallon), expressed as CaCO_3 equivalent, into the total softener capacity (grains), the designer can determine the number of gallons of soft water that the unit will produce before requiring regeneration.

Knowing (or estimating) the total gallons of water used per day indicates the frequency of regeneration. Most often, it is best to have a slight reserve capacity to accommodate any small increases in water usage.

Softening is not really a form of water purification since the function of a softener is to remove only the hardness (calcium and magnesium) from the water and substitute, by ion exchange, the softer element of sodium. Softeners frequently are used in hard water areas as pretreatment to distillation to simplify maintenance. They are often necessary as a pretreatment to deionizers and reverse osmosis, depending on the analysis of the feed water and the type of deionizer.

The following steps should be taken prior to selecting a water softener.

1. Perform a water analysis by analyzing the water with a portable test kit, obtaining a water analysis from the local authorities, or sending a water sample to a qualified water testing lab.
2. Determine the water consumption using sizing charts or consumption figures from water bills or by taking water meter readings.
3. Determine continuous and peak flow rates using the fixture count flow rate estimating guide to determine the required flow rate, obtaining flow rate figures for

the equipment to be serviced, or by taking water meter readings during peak periods of water consumption.

4. Determine the water pressure by installing a pressure gauge. If there is a well supply, check the pump's start and stop settings.
5. Determine the capacity: gallons per day $\times$ grains per gallon = grains per day.
6. Select the smallest unit that can handle the maximum capacity required between regenerations with a low salt dosage. Avoid sizing equipment with the high dosage unless there is reason to do so, such as a high-pressure boiler.

Example 10-2

For example, the capacity required is 300,000 grains. What size unit should be selected?

A 300,000-grain unit will produce this capacity when regenerated with 150 pounds of salt.

A 450,000-grain unit will produce this capacity when regenerated with 60 pounds of salt.

The 450,000-grain unit is the better selection to remove 300,000 grains. The salt consumption will be 75 pounds per regeneration as opposed to 150 pounds for the smaller unit, a 50 percent salt consumption savings. It should be noted that while a salt savings is realized in using the lower salting rate on the larger unit, hardness leakage will increase. If minimum hardness leakage is required, such as for boiler feed water, the maximum salting rate (15 pounds per cubic foot) should be used.

7. Determine if the unit selected will deliver the required flow rate.

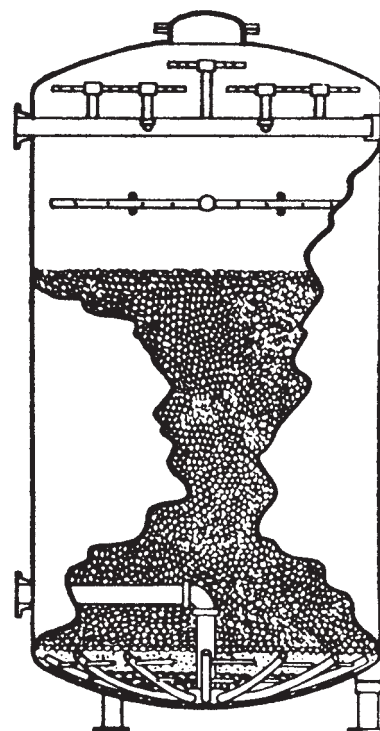


Figure 10-13 Ion Exchange Vessel—Internal Arrangement

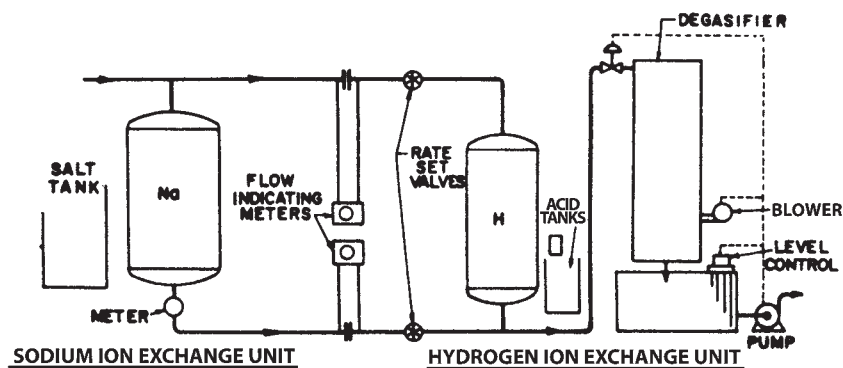


Figure 10-14 Hydrogen-Sodium Ion Exchange Plant

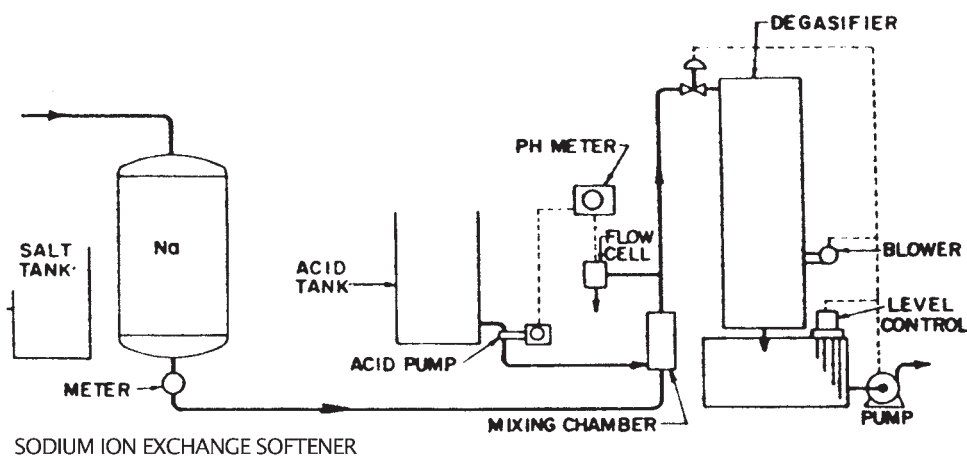


Figure 10-15 Sodium Cycle Softener Plus Acid Addition

- a. When sizing to a continuous flow rate, subtract the pressure drop from the line pressure. At least 30 psi should be left for the working pressure.
- b. When sizing to a peak flow rate, subtract the pressure drop from the line pressure. At least 20 psi should be left for the working pressure.

If one of those options results in less than the minimum allowable working pressure, select a larger model that has a higher flow rate. The water softener requires a dynamic pressure of 35 psi to draw brine.

8. Compare the dimensions of the unit selected with the space available for installation.
9. Make sure both the softener and the brine tank will fit through all doors and hallways to the installation area. If not, a twin unit or smaller brine tank may be used.
10. Make sure a drain is available that will handle the backwash flow rate of the unit selected. Refer to the specification sheet for backwash flow rates.

Single or Multiple Systems

A single-unit softener will bypass the hard water during periods of regeneration (normally 1.5 hours). This is the danger with a single-unit softener. If soft water requirements are critical and adequate soft water storage is not available, a twin or duplex water softener will be needed.

Space Needs

Many times a softener system is selected without much concern for space needs. Generally, sufficient floor space is available, although this factor should not be overlooked for storage. More commonly overlooked is the actual height of the softener tank and the additional height required (24 inches) for access through the top manhole opening for loading the unit. If height in the room is critical, the upper manhole can be located on the upper side shell of the softener tank (if so specified).

Severe room height restrictions normally require specifying a large-diameter, squat softener tank with the same specified quantity of softening mineral. Further consideration must be given to the floor space around the equipment, particularly around the salt tanks, for loading purposes and accessibility for servicing the unit.

Where water softeners are installed in existing buildings, the door openings should be checked for passage of the softener equipment to the final loading.

Cost

Technical advances in the water-softening industry and increasing labor costs are, for the most part, responsible for the fact that almost all equipment produced is operated automatically. For budget-estimating purposes, automatic water-softening costs range from \$15 to \$40 per 1,000 grains of exchange capacity, depending on the degree of sophistication. This estimate is based on the total capacity of all units.

Operating Efficiency

Most water softeners are alike in terms of their operation. Their basic operating cost is the salt consumption. Practically all use a high-capacity, resinous mineral. The mineral can exchange 30,000 grains of hardness per cubic foot of mineral when regenerated with 15 pounds of salt, which is the nominal standard rating currently used in the industry.

As salt is the basic commodity that affects the operating cost, it is the only area where reduced costs may be considered. Fortunately, the softening mineral can be regenerated at different salt levels, yielding actual cost savings on the salt consumption. As indicated, with a 15-pound salt level, 30,000 gains per cubic foot can be obtained. With a salt dosage of 10 pounds or 6 pounds, a resulting capacity yield of 25,000 gains per cubic foot or 20,000 gains per cubic foot respectively is obtained.

Thus, approximately a 40 percent salt rating can be effected at the lower salt level. The lower salt levels can be used effectively on general applications, resulting in lower operating costs. However, where very high-quality soft water

is required in an area where very hard water exists, this approach is not recommended.

Sizing

Figure 10-17 can be used to develop the data required to size the basic softening equipment. The final selection of a system for specification should be made using this information. In many cases, the importance of the water-softening equipment justifies calling on manufacturers' representatives for their recommendations. Their specialized knowledge can help in the design of a reliable, economical water softener system. Figure 10-18 provides a step-by-step procedure for selecting the water softener equipment.

Salt Recycling Systems

To increase the efficiency of the water softener in terms of salt consumption and water usage during the regeneration cycle, one option to consider is the use of a salt recycling system. It is essentially a hardware modification available for both new and existing water softeners that immediately reduces the amount of salt needed to regenerate a softener by 25 percent, without any loss of resin capacity or treated water quality. It works best with water softener equipment that utilizes a nested diaphragm valve configuration as seen in Figure 10-19. It is not recommended for water softeners that utilize a top-mounted, multi-port motorized control valve.

The salt recycling process adds a brine reclaim step to the regeneration process after the brine draw has occurred. During brine reclaim, used dilute brine flow is diverted from the drain and routed back to the brinemaker tank where it is stored and resaturated for later use, thereby saving both salt and water. The salt savings occur because the make-up water to the brinemaker contains approximately 25 percent of the salt needed for the next regeneration. Therefore, only 75 percent of "new" salt is dissolved for the next regeneration. Water savings occur because the recycled brine is not discharged to drain but is used to make up the brine solution for the next regeneration. The effective salt dosage for the water softener is unchanged; therefore, the 25 percent salt savings can be realized in softener systems that use both maximum and minimum salt dosages.

The hardware package consists of a diverter valve (see Figure 10-19) in the drain line that routes the recycled brine to the brinemaker tank and a modified control system that incorporates the extra brine reclaim step.

Salt Storage Options

A few options for salt storage are available. Salt blocks and bags of salt, or beads, may not be suitable for large systems in which dozens or even hundreds of pounds may be needed on a daily basis. These

systems may require bulk salt storage and delivery systems, consisting of an aboveground storage tank that is loaded directly from salt trucks. The salt then is conveyed through piping to the brine tank. This system may be wet or dry.

Underground storage tanks almost always require the salt to be premixed with water in the storage tank. It then can be piped to the brine tank as a brine solution and mixed down to the desired concentration levels.

DISTILLATION

Distillation produces biopure water that is free from particulate matter, minerals, organics, bacteria, pyrogens, and most dissolved gases and has a minimum specific resistance of 300,000 Ω -cm. Until recent advances in the industry, the use of distilled water was limited to hospitals and some pharmaceutical applications. Now, in hospitals, schools with science departments, laboratories, and industries other than pharmaceuticals, distilled water is vital to many operational functions. When used in healthcare facilities, biopure water is needed in the pharmacy, central supply room, and any other area where patient contact may occur. Biopure water also may be desired in specific laboratories at the owner's request and as a final rinse in a laboratory glassware washer.

The Distillation Process

The typical water distillation system consists of an evaporator section, internal baffle system, water-cooled condenser, and storage tank. The heat sources, in order of preference

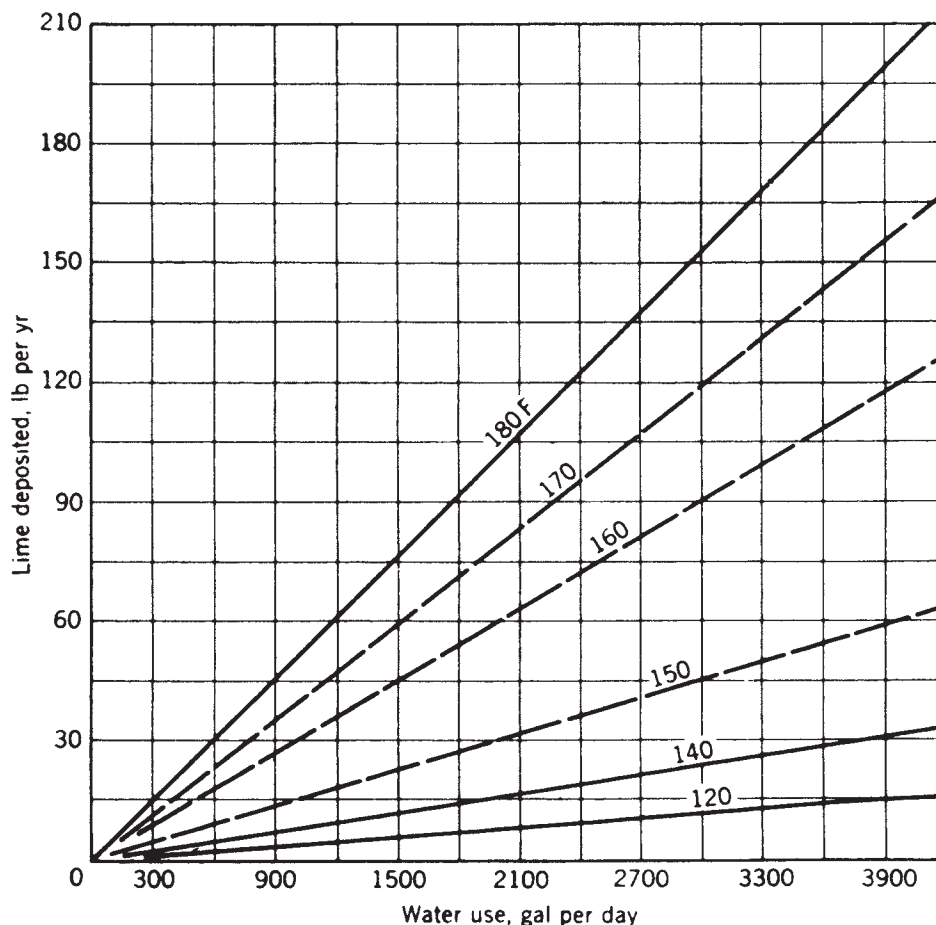


Figure 10-16 Lime Deposited from Water of 10 Grains Hardness as a Function of Water Use and Temperature

based on economy and maintenance, are steam, electricity, and gas. (Gas is not a good choice.) The still may be operated manually or automatically. The distilled water may be distributed from the tank by gravity or by a pump. A drain is required. On stills larger than 50 gallons per hour (gph), a cooling tower should be considered for the condenser water.

The principles of distillation are quite simple. The water passes through two phase changes, from liquid to gas and back to liquid (see Figure 10-20). All the substances that are not volatile remain behind in the boiler and are removed either continuously or intermittently. Water droplets are prevented from coming up with the water vapor by proper design of the still, which takes into account the linear velocity, and by use of an appropriate system of baffles.

Although distillation removes nonvolatile substances sufficiently, the volatile substances in the feed water cause more problems. These, mainly carbon dioxide, which are already present in the feed water or are formed by the decomposition of bicarbonates, can be removed by keeping the distillate at a relatively high temperature because carbon dioxide is less soluble at high temperatures. Ammonia (NH_3) is much more soluble in water than carbon dioxide, and its tendency to redissolve is much higher as well. Moreover, the ionization constant of ammonium hydroxide (NH_4OH) is much greater than that of carbonic acid (H_2CO_3), which means that equal amounts of ammonia and carbon dioxide show different conductivities (that for ammonia is much higher than that for carbon dioxide).

The purity of the distillate is usually measured with a conductivity meter, and a resistivity of $1 \text{ M}\Omega$ —or a conductivity of $1 \text{ microsiemen } (\mu\text{S})$ —is equivalent to approximately 0.5 ppm of sodium chloride. Most of the conductivity is accounted for by the presence of carbon dioxide (and ammonia) and not by dissolved solids. The question arises: Which is preferred, $1 \text{ M}\Omega$ resistivity or a maximum concentration of dissolved solids? It is quite possible that a distillate with a resistivity of $500,000 \Omega$ (a conductivity of $2 \mu\text{S}$) contains fewer dissolved solids than a distillate with a resistivity of $1,000,000 \Omega$ ($1 \mu\text{S}$).

A problem in distillation can be scale formation. Scale forms either by the decomposition of soluble products of insoluble substances or because the solubility limit of a substance is reached during the concentration. Solutions to this problem include the following:

- A careful system of maintenance, with descaling at regular intervals
- Softening of the feed water, that is, removing all calcium and magnesium ions. However, this does not remove the silica, which then may form a hard, dense scale that is very difficult to remove.
- Removal of the alkalinity (bicarbonates). When originally present, sulfate and silica still form a harder scale than a carbonate scale.
- Removal of all or most of the dissolved substances. This can be done by demineralization with ion exchangers or by reverse osmosis.

It may sound foolish to remove the impurities from the water before distilling the water. However, keep in mind that distillation is the only process that produces water guaran-

teed to be free of bacteria, viruses, and pyrogens. It may pay to have pretreatment before a still to cut down on maintenance (descaling), downtime, and energy consumption and to have better efficiency, capacity, and quality. Pretreatment may require a higher initial investment, but the supplier who has the experience and technology in all water treatment systems can give unbiased advice—that is, to offer a systems approach instead of pushing only one method.

Distilled water is often called hungry water. This refers to the fact that distilled water absorbs in solution much of the matter, in any phase, with which it comes in contact. It becomes important, therefore, to select a practical material for the production, storage, and distribution of distilled water.

Table 10-3 Water Consumption Guide

Apartments	
One-bedroom units	1.75 people/apartment
Two-bedroom units	Three people/apartment
Three-bedroom units	Five people/apartment
Full line	60 gpd/person
Hot only	25 gpd/person
One bath	1.5 gpm/apartment
Two baths	2.5 gpm/apartment
Barber shops	75 gpm/chair
Beauty shops	300 gpd/person
Bowling alleys	75 gpd/lane
Factories (not including process waters)	
With showers	35 gpd/person/shift
Without showers	25 gpd/person/shift
Farm animals	
Dairy cow	35 gpd
Beef cow	12 gpd
Hog	4 gpd
Horse	12 gpd
Sheep	2 gpd
Chickens	10 gpd/100 birds
Turkeys	18 gpd/100 birds
Hospitals	225 gpd/bed (Estimate air-conditioning and laundry separately.)
Motels (Estimate the restaurant, bar, air-conditioning, swimming pool, and laundry facilities separately, and add these to the room gallonage for total consumption.)	
Full line	100 gpd/room
Hot only	40 gpd/room
Mobile home courts	Estimate 3.75 people/home, and estimate 60 gpd/person. (Outside water for sprinkling, washing cars, etc., should be bypassed.)
Restaurants	
Total (full line)	8 gal/meal
Food preparation (hot and cold)	3 gal/meal
Food preparation (hot only)	1.5 gal/meal
Cocktail bar	2 gal/person
Rest homes	175 gpd/bed (Estimate laundry separately.)
Schools	
Full line	20 gpd/student
Hot only	8 gpd/student
Trailer parks	100 gpd/space

Years of experience and research have shown that pure tin is the most practical material for the production, storage, and distribution of distilled water due to its inert characteristic. It is the least soluble. (Other materials, such as gold, silver, and platinum, have equal or superior qualities but are not considered for obvious reasons.) A secondary but almost equal advantage of tin is its relatively low porosity, which virtually eliminates the possibility of particle entrapment and growth in pores. In a good water still, therefore, all of the surfaces that come in contact with the pure vapors and distillate should be heavily coated with pure tin. Likewise, the storage tank should be heavily coated or lined with pure tin on all interior surfaces. Tinned stills and storage tanks are not significantly more expensive than glass ones in all but the smallest sizes.

Titanium is being strongly considered as a promising material for distillation equipment. Although some stills have been made of titanium, it is more expensive than tin and has not yet been proven superior.

Distillation Equipment Applications and Selection

In the construction of buildings requiring distilled water, the selection of the appropriate equipment is usually the responsibility of the plumbing engineer. Before the proper equipment can be selected, the following factors should be considered:

- The quantity of distilled water that will be required per day (or per week) by each department
- The purity requirements of each department
- The space available for the equipment
- The availability of power

Regarding the first two items, the engineer should obtain the anticipated quantity and purity requirements from all department heads who require distilled water.

In this section, it is assumed that less than 1,000 gallons per day (gpd) of distilled water is re-

quired. The single-effect still operated at atmospheric pressure is generally the most practical and widely used. For the consumption of larger quantities of distilled water, consideration may be given to other types of stills (such as the multiple-effect and vapor-compression stills). These stills have advantages and disadvantages that should be studied when conditions warrant.

Centralized vs. Decentralized Systems

The choice between central distillation equipment and individual stills in each department is a matter of economics. In the case of central distillation, the factors to consider are the distances involved in piping the water to the various departments—hence, the cost of the appropriate piping and, possibly, the pumping requirements. The original and maintenance costs of multiple individual stills can be high. In the majority of installations, the use of one or two large, centrally located stills with piped distribution systems has proven more practical and economical than a number of small, individual stills.

Stills

While a well-designed still can produce pure distilled water for most purposes, the distilled water to be used by a hospital for intravenous injections or by a pharmaceutical company manufacturing a product for intravenous injections must be free of pyrogens (large organic molecules that cause individuals to go into shock). For such uses, a still with special baffles to produce pyrogen-free distilled water must be specified.

Other types of stills are designed to meet various purity requirements. The recommendations of the manufacturer should be obtained to specify the proper type of still for a specific application.

Due to the amount of heat required in the operation to change the water into steam, it is impractical to make large-capacity, electrically heated and gas-heated stills. All stills larger than 10 gph, therefore, should be heated by steam. For each gallon per hour of a still's rated capacity, steam-heated stills require approximately 1/3 boiler horsepower, electrically

date _____

Project name _____

Location _____

Type of facility _____

What is water being used for? _____

Water analysis: (express in gr./ gal. or ppm as CaCO₃)

Total hardness _____

Sodium _____

Total dissolved solids _____

Sodium to hardness ratio _____

Iron _____

Flow rate (gpm) peak _____ Normal _____ Average _____

Allowable pressure loss _____ System inlet pressure _____

Operating hours/day _____ Gallons/day _____

Influent header pipe size _____

Electrical characteristics _____

Type of operation _____

Special requirement or options (ASME, lining, accessories) _____

Space limitation L _____ W _____ H _____

Figure 10-17 Water Softener Survey Data

Project name _____ Date _____
 Location _____

Step 1. Operating conditions
 A. Operating hours per day _____
 B. Can regeneration take place once each day? Yes _____ No _____
 C. If "B" is No, state days between regenerations _____
 D. Is a twin unit required? Yes _____ No _____
 E. Type of operation:
 Time clock _____ Alarm meter _____ Auto reset meter _____
 F. Allowable pressure loss _____ psi.

Step 2. Flow rate (gpm) _____ (peak, average, continuous)

Step 3. Water usage per day:
 _____ × 60 min./hr. × _____ GPM = _____
 Operating hr/day Average flow rate gal/day

Step 4. Required exchange capacity:
 _____ × _____ = _____
 Gal/day water usage Water hardness (gr/gal) Required exchange capacity (gr/day)

Step 5. Select resin capacity & salt dosage per cu ft.:
 (_____) 32,000 gr @ 15# (_____) 29,000 gr @ 10# (_____) 21,000 gr @ 6#

Step 6. One day of operation per regeneration (step no. 1-B)
 _____ ÷ _____ = _____
 Required exch. cap (gr/day) Resin cap (gr/ft³) Required resin (ft³/day)
 Note: If more than one day between regenerations is required, use step no. 7 instead of step no. 6.

Step 7. More than one day of operation per regeneration (step no. 1-B)
 Cubic feet of resin required:
 _____ × _____ ÷ _____ = _____
 Required exch. cap. (gr/day) Number of days/regen. Resin cap. (gr/ft³) Resin required (ft³)

Step 8. Salt consumption per regeneration:
 _____ × _____ = _____
 Required resin (ft³/regen.) Salt dosage (lb/ft³) Salt regeneration (lb)

Step 9. System selection:
 (If auto-reset operation is desired, refer to step no. 10.)
 A. Select from the manufacturer's specification table, a single unit that meets the flow rate (step no. 2).
 B. Check that selected unit meets the allowable pressure loss at the flow rate (step no. 1-F).
 C. If a single unit will not meet both steps no. 9-A and 9-B, then a multiple unit is required (refer to step no. 10).
 D. Check that selected unit contains the required cubic feet of resin (step no. 6 or 7).
 E. If single unit will not meet step no. 9-D, then a multiple unit is required. (refer to step no. 10).
 F. Select a standard system that meets, or exceeds by no more than 10%, step nos. 9-A, 9-B, and 9-D. If a good balance is not available, refer to step no. 10.
 G. Check that brine-tank salt storage is sufficient to provide a minimum of two regenerations before requiring refill (step no. 8).

Step 10. Multiple systems:
 The following procedure should be followed for a twin unit.
 A. Select either auto-reset meter initiation or time clock to start regeneration. Refer to the appropriate subtitle.
 Auto-reset meter-initiated regeneration.
 B. Select, from the specification table, a tank size that meets the *flow rate* (step no. 2) and the *allowable pressure loss* (step no. 1-F). Each tank in the system must meet these conditions.
 C. Divide the required cu. ft. of resin (step no. 6 or 7) by two to determine the required cubic feet of resin contained in the tanks selected in step no. 10-B. Select a tank large enough to match the required cu. ft. resin/tank.
 D. Check that the brine tank salt storage is sufficient to provide a minimum of four regenerations per tank.
 Time clock regeneration
 E. Divide the *flow rate* (step no. 2) by 2 to determine the *flow rate per tank*. Select a tank size that meets this flow rate. (Both tanks will be on line during the operating period.)
 F. Check that the tank selected meets the *allowable pressure loss* (step no. 1-F) at the *flow rate per tank*.
 G. Follow step no. 10-C to determine the required cubic feet of resin per tank.
 H. Follow step no. 10-D to determine the brine tank to be used.

Step 11. Using this data, select a standard system from the softener specifications that most closely matches all the data. If none is available, a detailed specification should be developed which will allow the manufacturer to match the system requirements.

Step 12. Select options such as ASME code tanks, lining, and materials of construction, as required.

Figure 10-18 Water Softener Sizing Procedure

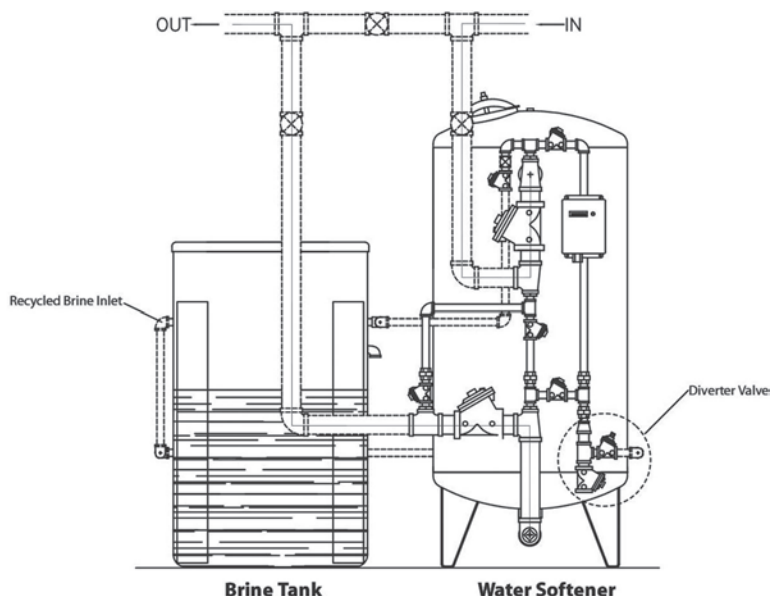


Figure 10-19 Water Softener with Salt Recycling System

heated stills need 2,600 watts, and gas-fired stills need 14,000 British thermal units per hour.

The still must be well designed and baffled to effect an efficient vapor separation without the possibility of carryover of the contaminants and to ensure optimum removal of the volatile impurities. It is equally important that the materials used in construction of the still, storage reservoir, and all components coming in contact with the distilled water do not react with the distilled water.

Distribution Systems

Cost can be a significant factor in the distribution system, particularly if it is extensive. The distribution system can consist of 316 stainless steel, CPVC Schedule 80, and polyvinylidene fluoride (PVDF). The fittings should be of the same material.

The purity requirements should be considered and a careful investigation made of the properties and characteristics of the materials being considered. Many plastics have a relatively porous surface, which can harbor organic and inorganic contaminants. With some metals, at least trace quantities may be imparted to the distilled water.

Storage Reservoir

The storage reservoir used for distilled water should be made of a material that is suited for the application and sealed with a tight cover so that contaminants from the atmosphere cannot enter the system. As the distilled water is withdrawn from the storage tank, air must enter the system to replace it. To prevent airborne contamination, an efficient filter should be installed on the storage tank so that all air entering the tank may be filtered free of dust, mist, bacteria, and submicron particulate matter, as well as carbon dioxide.

Figure 10-21 illustrates a typical air filter. This air filter (both hydrophilic and hydrophobic) removes gases and airborne particles down to $0.2\ \mu$. Purified air leaves at the bottom. The rectangular chamber is a replaceable filter

cartridge. A and B are intake breather valves, and C is an exhaust valve.

As a further safeguard against any possible contamination of the distilled water by biological impurities, an ultraviolet light can be attached to the inside of the cover (not very effective) and/or immersed in the distilled water (also not very effective) or in the flow stream to effectively maintain its sterility. Ultraviolet lighting should be given strong consideration for hospital and pharmaceutical installations, as well as for any other applications where sterility is important.

Example 10-3

Assume that a total of 400 gpd of distilled water is required by all departments. A fully automatic still and storage tank combination should be used in this application. Fully automatic controls stop the still when the storage tank is full and start the still when the level in the storage tank reaches a predetermined low level. In addition, the evaporator is flushed out each time it stops. A 30-gph still (with a 300-gallon storage tank) produces more than the desired 400 gpd. Because the still operates on a 24-hour basis, as the storage tank calls for distilled water (even if no distilled water is used during the night), 300 gallons are on hand to start each day. As water is withdrawn from the storage tank, the still starts and replenishes the storage tank at a rate of 30 gph.

In this example, the storage tank volume, in gallons, is 10 times the rated capacity of the still. This is a good rule of thumb for a fully automatic still and storage tank combination. A closer study of the pattern of the anticipated demands may reveal unusual patterns, which may justify a larger ratio.

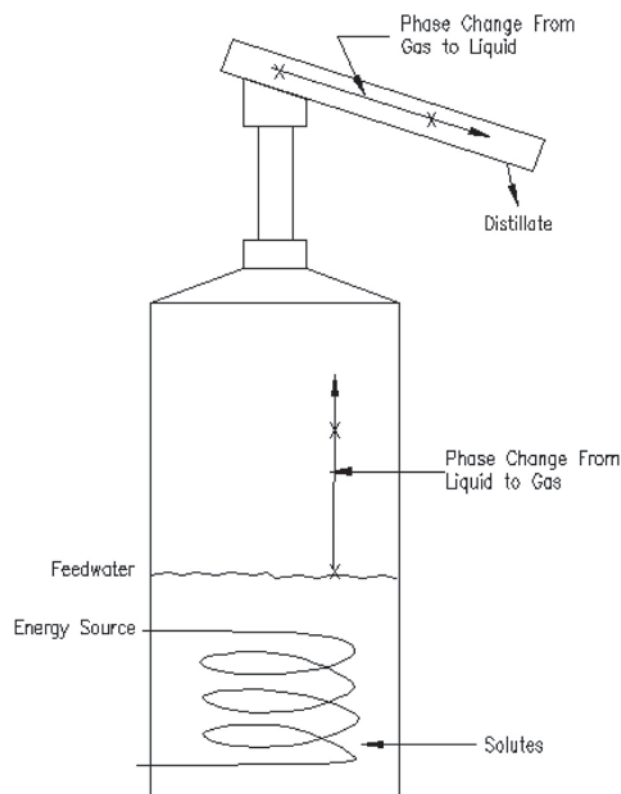


Figure 10-20 Distillation

Purity Monitor

One frequently used accessory is the automatic purity monitor. This device tests the purity of the distilled water coming from the still with a temperature-compensated conductivity cell. This cell is wired to a resistivity meter that is set at a predetermined standard of distilled water commensurate with the capability of the still. If for any reason the purity of the distilled water is below the set standard, the substandard water does not enter the storage tank and is automatically diverted to waste. At the same time, a signal alerts personnel that the still is producing substandard water so an investigation may be made as to the cause. Simple wiring may be used to make the alarm signal visual or audible at any remote location, such as the plant engineer's office. The advantages of this automatic purity monitor are obvious, particularly ahead of large storage tanks (as one slug of bad water can ruin a whole tank).

Feed Water

Pretreated Feed Water

In the conventional or basic operation of a still, potable water is used to condense the pure vapors from the evaporator and is heated. Part of this preheated water enters the evaporator as feed water, while the greater part goes to the drain. A well-designed still has the intrinsic features to retard the formation of scale in the evaporator. These features include frequent, automatic flushing and a bleeder valve that continuously deconcentrates the buildup of impurities in the evaporator.

As a further aid in reducing the maintenance of a still in areas having exceptionally hard water, it is often desirable (but not essential) to demineralize (with a deionizer or re-

verse osmosis), soften, or otherwise pretreat the feed water. Demineralizing the feed water practically eliminates the need to clean the evaporator. For this purpose, the demineralizing process is relatively expensive; however, it does contribute to a higher purity of distilled water.

Because water softening is less expensive than the demineralizing process, it is used more often as a method of pretreatment. It does not have the advantages of demineralized water—eliminating cleaning and contributing to a higher purity—but it does eliminate hard scale formation in the evaporator.

When any kind of pretreated feed water is used, an adequate preheater (for pretreated water) and a float feeder valve should be specified by the designer. With these devices, the raw water is used only as cooling water for the condenser, and the pretreated feed water is piped separately to the still, eliminating the waste of the pretreated water. When the float feeder valve is used on any still equipped with an automatic drain, an automatic shutoff valve to the float feeder valve also should be specified so the supply of pretreated water stops at the same time the drain valve opens. Specifications prepared by the designer should describe the type of pretreated water to be used.

Condensate as Feed Water

Another method of reducing maintenance on a steam-heated still is to use the condensed boiler steam as feed water. Here again, the raw water is used only as condenser cooling water. The condensate from the steam trap is cooled and then passed through an ion exchange cartridge and an organic removal filter. These cartridges remove any traces of scale-forming salts, ionized amines, odor, or taste impurities present in the original condensate, as well as organics that may be given off by the ion exchange cartridge.

This type of system commonly is referred to as the feedback purifier. This design contributes to a higher purity of distillate and virtually eliminates the need to clean the still (since scale-forming hardness has been eliminated from the feed water).

It is important for the engineer to determine the characteristics of the steam condensate when considering the feedback purifier system. If amines are used as the treatment for the boiler feed water in an excessive amount, this method should not be used. However, most condensates are satisfactory for this purpose.

Distribution Pressure

Whenever possible, it is best to locate the still and the storage tank where gravity can be employed to provide an adequate pressure to operate the distribution system. When this condition is not possible, centrifugal pumps of the appropriate size must be used. Along with the circulation pump, an orificed bypass back to the storage tank should be installed so the pump can be operated continuously, maintaining adequate pressure in the distribution system. Then the distilled water is available in any outlet all the time. The bypass relieves the pressure on the circulating pump when the water is not being drawn at its outlets.

A low water cutoff also should be installed on the storage tank to shut off the pump if the storage tank runs dry. This

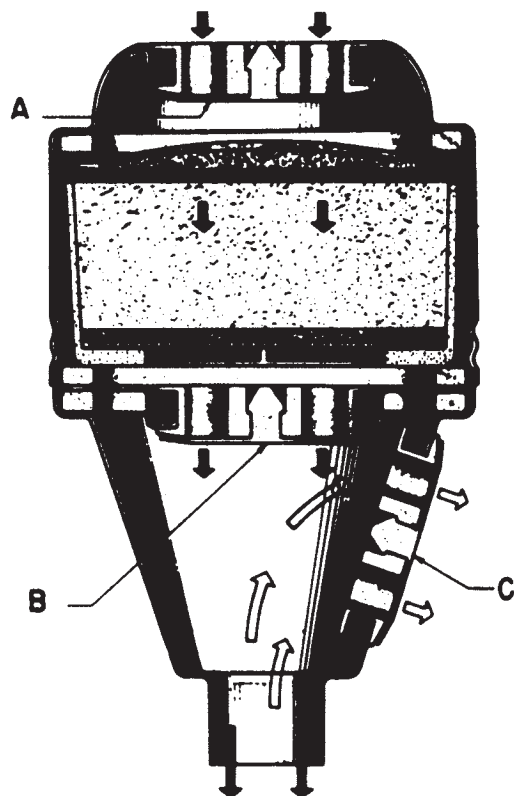


Figure 10-21 Typical Air Filter

pump arrangement is simple in construction, efficient to operate, and less expensive than a pressurized tank.

SPECIALIZED WATER TREATMENT

Ozone Treatment

Ozone is a compound in which three atoms of oxygen are combined to form the ozone molecule O_3 . It is a strong, naturally occurring, oxidizing, and disinfecting agent. The unstable ozone (O_3) compound can be generated by the exposure of oxygen molecules to ultraviolet radiation or high-energy electrical discharge in manufactured ozone generators.

Ozone can react with any oxidizable substance, such as certain forms of inorganic materials like iron and manganese, many organic materials, and microorganisms. In an oxidation reaction, energy is transferred from the ozone molecule, leaving a stable oxygen (O_2) and a highly reactive oxygen atom (O_1). The molecule being oxidized then bonds with the loose oxygen atom, creating an oxidized product or a derivation of the substance. Bacterial cells and viruses are literally split apart (lysed) or inactivated through oxidation of their DNA and RNA chains by ozone in water and wastewater treatment applications. Ozone is the most powerful oxidizer that can be safely used in water treatment.

Ozone frequently is used to treat wastewater and as a disinfectant and oxidant for bottled water, ultrapure waters, swimming pools, spas, breweries, aquariums, cooling towers, and many other applications. Ozone is not able to produce a stable residual in a distribution system. However, ozone can lower the chlorine demand and thus the amount of chlorine required and the chlorinated by-products.

Ozone systems can be big enough to serve central plants or municipalities. Figure 10-22 shows an example of a large-scale system. Figure 10-23 shows a simplified plan view of such a system.

Ultraviolet Light Treatment

Ultraviolet light is electromagnetic radiation, or radiant energy, traveling in the form of waves. A short-range (UVC) wavelength is considered a germicidal UV. When ultraviolet light of a sufficient energy level is absorbed into matter, it causes a chemical or physical change. In the case of microorganisms, ultraviolet light is absorbed to a level that is just enough to physically break the bonds in DNA to prevent life reproduction. Therefore, ultraviolet light is a mechanism capable of disinfecting water. The most widely used source of this light is low-pressure mercury vapor lamps emitting a 254-nanometer (nm) wavelength. However, 185 nm can be used for both disinfection and total oxidizable carbon reduction. The dosage required to destroy microorganisms is the product of light intensity and exposure time. The exposure requirements for different microorganisms are well documented by the EPA. Ultraviolet bulbs are

considered to provide 8,000 hours of continuous use and to not degrade to more than 55 percent of their initial output.

When ultraviolet equipment is sized, the flow rate and quality of the incoming water must be taken into consideration. It is generally necessary to filter the water before the ultraviolet equipment. Sometimes it may be necessary to filter downstream of the ultraviolet equipment with 0.2- μ absolute filter cartridges to remove dead bacteria and cell fragments.

Ultraviolet equipment often is used in drinking water, beverage water, pharmaceutical, ultra-pure rinse water, and other disinfection applications.

To validate effectiveness in drinking water systems, the methods described in the U.S. EPA's *Ultraviolet Disinfection Guidance Manual* is typically used. For wastewater systems, the National Water Research Institute's *Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse* is typically used, specifically in wastewater reclamation applications.

Reverse Osmosis

Reverse osmosis produces a high-purity water that does not have the high resistivity of demineralized water and is not biopure. Under certain conditions, it can offer economic advantages over demineralized water. In areas that have high mineral content, it can be used as a pretreatment for a demineralizer or still when large quantities of water are needed.

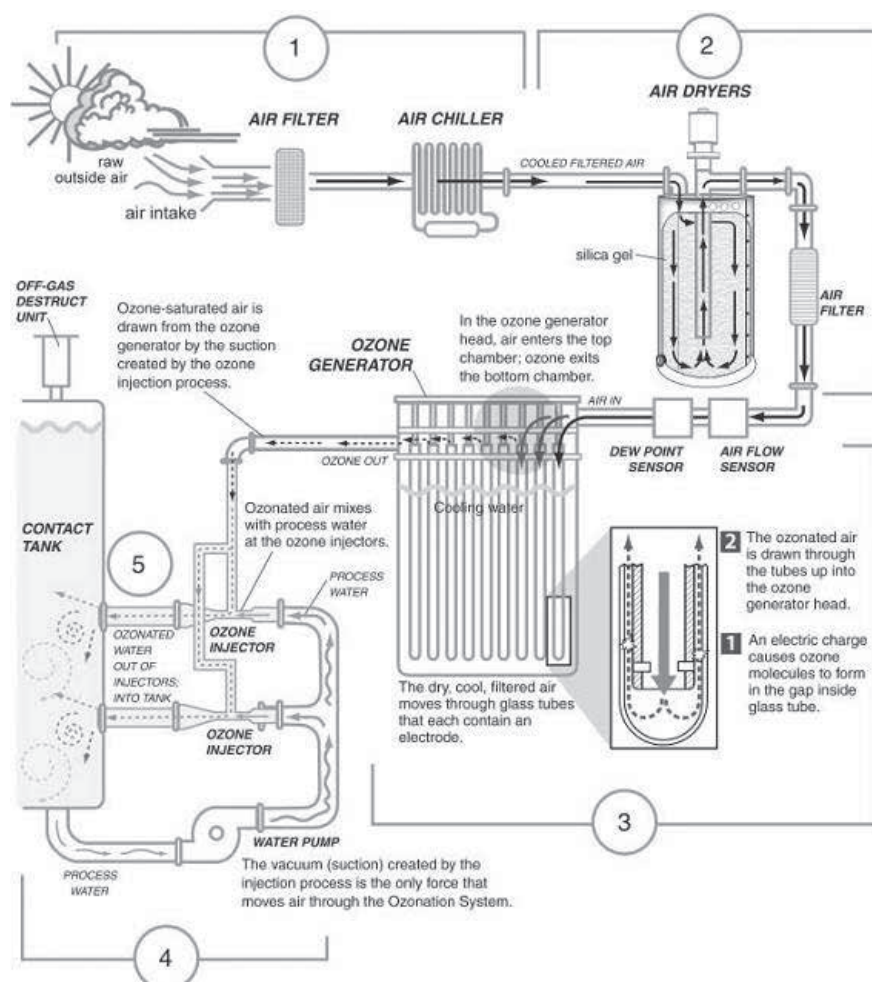


Figure 10-22 Schematic Diagram of a Large-Scale Ozone System

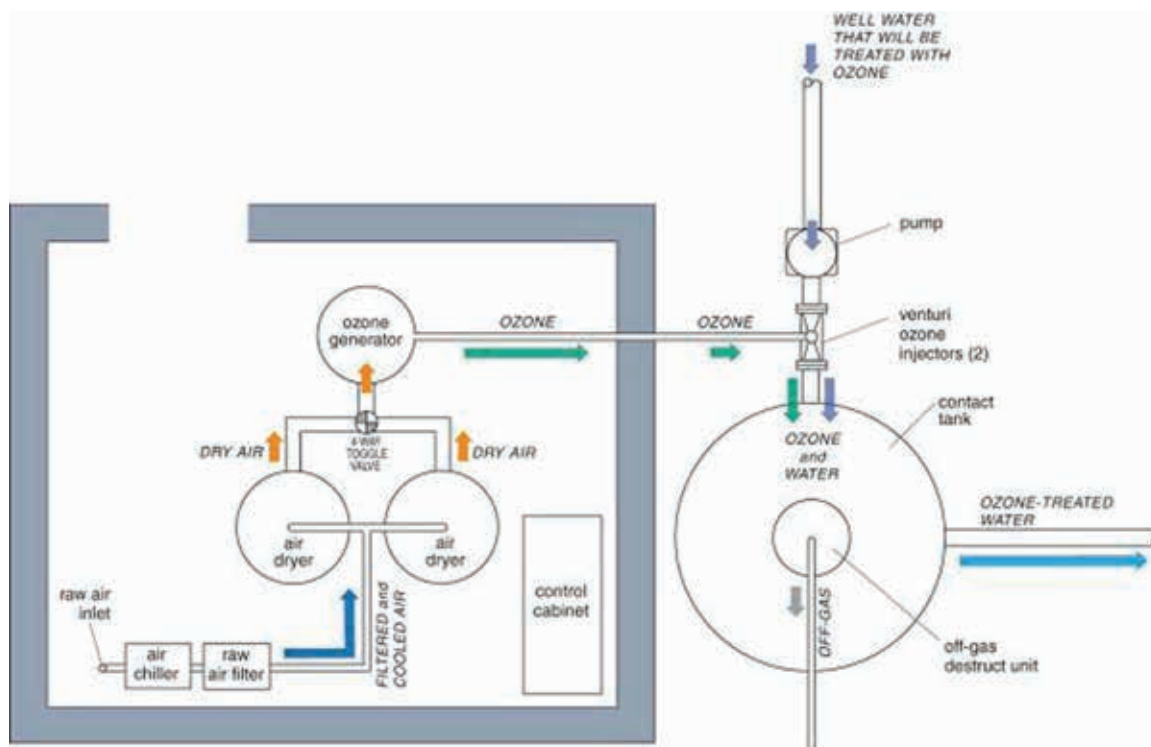


Figure 10-23 Simplified Plan View of Ozone System

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Reverse osmosis is used primarily in industrial applications and in some hospitals and laboratories for specific tasks. It also is used by some municipalities and end users for the removal of dissolved components or salts.

Several types of reverse osmosis units are available. Basically, they consist of a semipermeable membrane, and water is forced through the membrane under high pressure. A drain and storage tank are required with this system.

RO is a relatively simple concept. When equal volumes of water are separated by a semipermeable membrane, osmosis occurs as pure water permeates the membrane to dilute the more concentrated solution (see Figure 10-24). The amount of physical pressure required to equalize the two volumes after equilibrium has been reached is called the osmotic pressure. If physical pressure is applied in excess of the osmotic pressure, reverse osmosis (see Figure 10-25) occurs as water passes back through the membrane, leaving contaminants such as dissolved salts, organics, and colloidal solids concentrated upstream. In practice, the concentrate is diverted to drain, thus rejecting contaminants from the system altogether. The continuous flushing process of the membrane prevents a phenomenon known as concentration polarization, which is a buildup of the polarized molecules on the membrane surface that further restricts flow in a short period.

For dependable long-term performance, RO equipment for large-volume applications should be of all stainless steel fittings and bowls. Such a system should use solid-state controls (with simple indicator lights and gauges) plus a conductivity meter that reads the tap and permeates water quality. High-pressure relief devices and low-pressure switches protect the membrane and the pump from any prefilter blockage and accidental feed water shutoff. A water-saver device that

completely shuts off water flow when the storage tank is full but allows an hourly washing of the membrane is essential.

Three types of semipermeable membranes are manufactured from organic substances: tubular membrane, cellulose-acetate sheet membrane, and polyamide-hollow fiber membrane. They may be used for similar applications, assuming that the proper pretreatment for each is furnished. In properly designed and maintained systems, RO membranes may last two or three years.

RO Membranes

The current technology of RO developed rapidly as one specific application of the larger technology of synthetic membranes. Several code requirements had to be met before these membranes could be considered practical or economical for water purification processes.

First, the membrane had to be selective—that is, it had to be capable of rejecting contaminants and yet still be highly permeable to water. This condition meant that it had to have a consistent polymeric structure with a pore size in the range of the smallest contaminant molecules possible.

Second, the membrane had to be capable of sustained high flux rates to be economical and practical in water applications. This condition meant that the membrane had to be thin and yet durable enough for long-term use.

Developments in membrane technology led to a membrane with a thin skin (approximately 0.05μ) cast on top of a porous support structure (100μ thick). This resulted in high flux rates, selectivity, and structural strength. The resulting RO membrane proved to be highly resistant to chemical and microbial degradation. It also could maintain the required water quality and flow rates under a sustained high pressure. Such a membrane could be incorporated into a system with

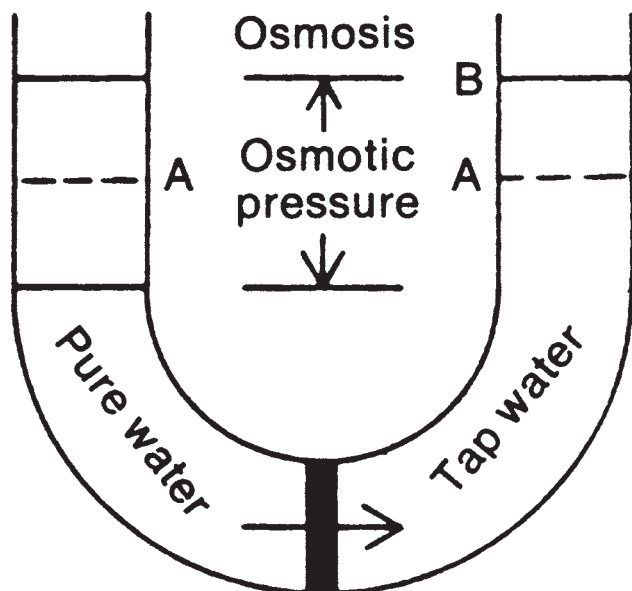


Figure 10-24 Osmosis

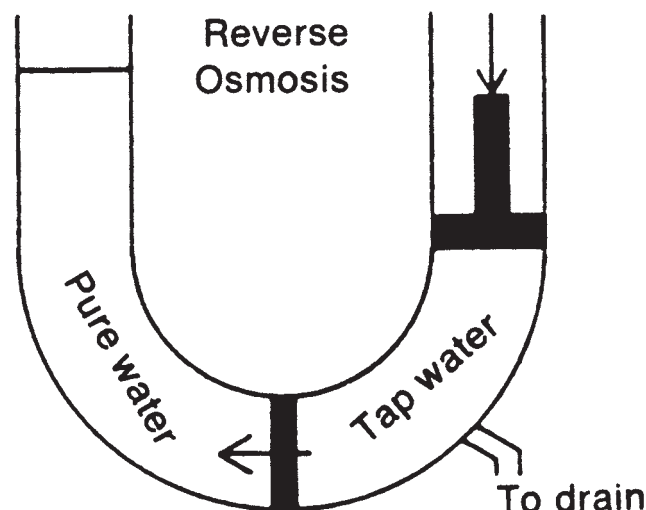


Figure 10-25 Reverse Osmosis

relatively low capital, equipment, and operating costs. These attributes were combined successfully, and the resulting membrane achieved a flow rate of 20 gallons per square foot per day at 800 psi with 95 percent removal of salt.

RO Water Quality

The term high purity often is applied to a type of water that may be exceptionally free of one class of contaminant and yet may contain large amounts of another. The key, of course, is the application involved. One useful distinction is between reagent-grade water and laboratory-grade water. Reagent-grade water means that all classes of contaminants have been removed from the water. Several nationally recognized standards for reagent-grade water are published by ASTM and the College of American Pathologists (CAP). The minimum resistivity for reagent-grade water is 10 MΩ-cm at 25°C. The production of reagent-grade water always requires more than one stage of treatment. It should be produced at the point of use to minimize (or eliminate) transportation and storage, which invariably degrade the reagent water purity. A system for producing reagent-grade water might, for example, use the RO process to produce laboratory-grade water, plus a combination of activated carbon, deionization, and 0.20-μ membrane filtration. Only the laboratory-grade water would be accumulated and stored. The reagent water would be produced at high flow rates as needed, thus eliminating the need to store it.

Laboratory-grade water is less rigorously defined, but it still refers to water from which one or more types of contaminants have been removed. This definition should be distinguished from other processes that exchange one contaminant for another, such as water softening (in which calcium and magnesium salts are removed

by exchanging them with sodium salts). The reverse osmosis, deionization, and distillation processes are all capable of producing laboratory-grade water.

The quality of the laboratory-grade water produced by several methods of central-system water production is shown in Table 10-4. The RO and distillation processes remove more than 99 percent of all bacteria, pyrogens, colloidal matter, and organics above molecular weight 200. These methods remove the dissolved inorganic material, such as multivalent ions, calcium, magnesium, carbonates, and heavy metals to the level of 98 percent, while monovalent ions, such as sodium, potassium, and chloride, are removed to the level of 90 percent to 94 percent by RO and 97 percent by distillation.

Large-scale deionization processes achieve similar levels of inorganic ion removal, but they do not remove bacteria,

Table 10-4 Comparison of Laboratory-Grade Water Quality Produced by Centralized Systems

Contaminant	Tap, Typical	Reverse Osmosis		Distilled		Deionized	
		Actual	Percent Removal	Actual	Percent Removal	Actual	Percent Removal
Microorganism/ mL	100	1	>99	1	>99	1000 ^a	none
Particles 5 μm/mL	10,000	1	>99	200	>97	10,000	none
Pyrogens	Variable	—	>99	—	>99	Variable	none
Dissolved organics ppm	12	1	>95	1	>95	12 ^b	none
Dissolved inorganics ppm CaCO ₃	170	1–17	>90–98	1–8	>95–99	1–8	>95–99
Monovalent ions ^c	—	—	>90	—	>97	—	>97
Multivalent ions ^d	—	—	>97	—	>97	—	>97
Conductivity, μS, 25°C	333	2–40	—	2–10	—	2–10	—
Specific resistance MΩ/cm, 25°C	0.003	0.025–0.5	—	0.1–0.5	—	0.1–0.5	—
Silicates ppm	1	0.1	>90	0.1	>90	0.1	>90
Heavy metals ppm	1	0.1	>97	0.1	>97	0.1	>90
pH	7.5	6.8	—	4–7.5	—	7.0	—

^a Bacteria often multiply in large deionizing (D.I.) resin beds used directly on tap water.

^b Large D.I. resin beds also contribute organics from the resin beds.

^c Monovalent ions: Singly charged ions such as Na⁺, K⁺, Cl[−]

^d Multivalent ions: Multiply charged ions such as Ca²⁺, Mg²⁺, CO₃^{2−}, SO₄^{2−}

pyrogens, particles, and organics. Bacteria, in fact, can multiply on the resins, resulting in an increase in biological contaminants over normal tap water.

It should be stressed that the degrees of water purity shown in Table 10-4 are obtainable only from well-cleaned equipment that is performing to its original specifications. Maintaining this condition for the deionization process means that the resins must be replaced (or regenerated) regularly and that the internal components of the still must be thoroughly cleaned. If a still is not properly and regularly cleaned, the residual contaminants can cause the pH value of the end product water to fall as low as 4. Reverse osmosis is the only one of the methods that uses a reject stream to continuously remove the residual contaminants. Regularly scheduled prefilter changes and system maintenance are, of course, necessary to maintain the desired water quality.

Applications for RO

The quality and cost of RO water make RO a strong competitor for distillation and deionization in many applications. Table 10-5 compares the three methods of water purification for several research and industrial applications.

Frequently, the user needs both laboratory-grade and reagent-grade waters to meet a wide range of needs. Figure 10-26 shows two ways of approaching this situation. Alternative A consists of a central RO system from which the water is piped to a point-of-use polishing system to be upgraded to reagent-grade water. This approach utilizes the economics of a large central RO system while ensuring the highest reagent-grade purity at those use points that require it. Alternative B employs smaller point-of-use RO systems with point-of-use polishing, which eliminates lengthy distribution piping, a potential source of recontamination. Both alternatives include a final polishing by activated carbon, mixed-bed deionization, and 0.2- μ membrane filtration. In each case,

laboratory-grade water is readily available directly from the RO system. Moreover, the transportation and storage of the reagent-grade water are avoided.

Nanofiltration

Nanofiltration (NF) is a cross-flow membrane filtration system that removes particles in approximately the 300–1,000 molecular weight range, rejecting selected ionic salts and most organics. Nanofiltration rejects the dissociated inorganic salts that are polyvalent, such as calcium, magnesium, and sulfate, while passing monovalent salts, such as sodium and chloride. Therefore, nanofiltration often is called a softening membrane system. Nanofiltration operates at low feed pressures. The equipment is similar to that for reverse osmosis.

Ultrafiltration

Ultrafiltration (UF) is a membrane filtration system that separates liquids and solids. This separation process is used in industry and research to purify and concentrate macromolecular solutions, especially protein solutions. It provides filtration in the range of 0.0015 μ to 0.1 μ , or approximately 1,000–100,000 molecular weight. Ultrafiltration in an industrial application often is used to separate oil and water as in cutting solutions, mop water, and coolants.

Copper-Silver Ionization

Copper-silver ionization is not a filtration system, but a method of injecting positive ions into the water stream. The positive cations attach to the negative anions of organic pathogens, destroying their cell structures. It is used to eliminate *Legionella* and other waterborne organisms; thus, these systems are used extensively in hospitals and healthcare centers. Figure 10-27 shows the basic system components.

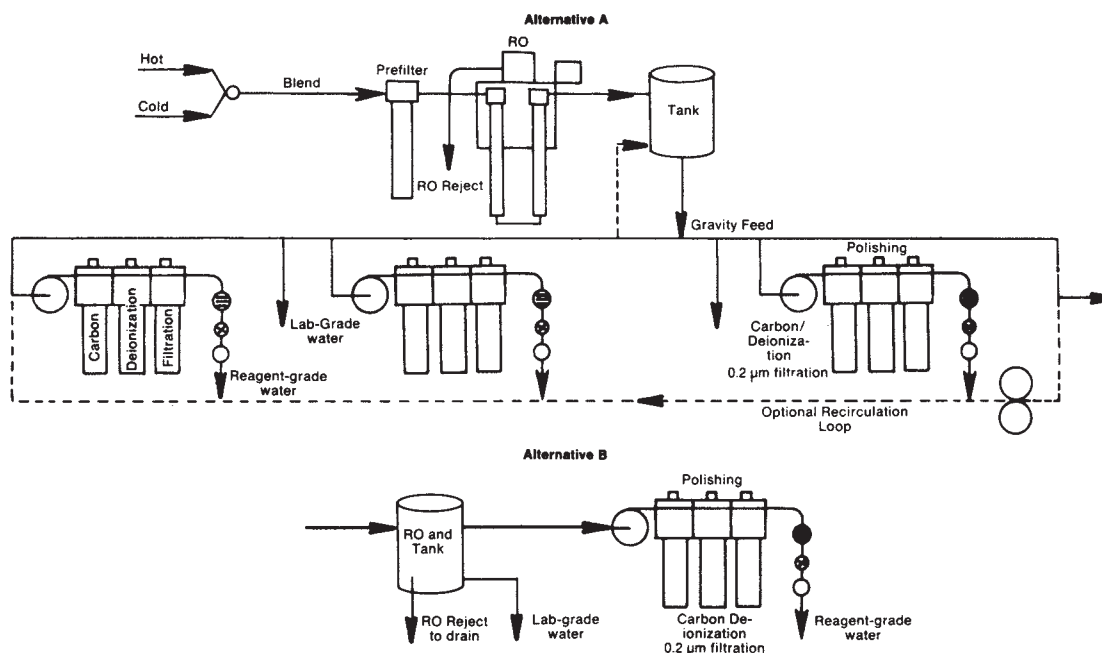


Figure 10-26 Approaches to Providing Laboratory-Grade and Reagent-Grade Water: (A) RO Water Purified Centrally and Transported by Pipe to Points of Use Then Polished, (B) RO System Coupled with Deionization System Totally at the Point of Use, Eliminating Piping

Table 10-5 Applications of Purified Water

Water Use	Method of Purification		
	RO	Distilled	Deionized
General process use	Yes	Yes	Yes
General lab use (buffers, chemical mfg.)	Yes	Yes	Yes (except for pyrogens, bacteria, and organics)
Dishwasher final rinse	Yes	Yes	Yes
Critical lab use (reagents, tissue culture, etc.)	Post-treatment necessary		
USP XXIII water for injection	Yes (must meet purified water standard)	Yes	No
Hemodialysis	Yes	No	Yes (except for pyrogens, bacteria, and organics)

**Figure 10-27 Silver Ionization Unit and Control Panel**

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Expiration date: Continuing education credit will be given for this examination through **June 30, 2014**.

CE Questions — "Water Treatment" (CEU 201)

1. **High-purity water is free from _____.**
 - a. minerals
 - b. bacteria
 - c. pyrogens
 - d. all of the above
2. **Distillation is the reverse of _____.**
 - a. deaeration
 - b. demineralization
 - c. filtration
 - d. reverse osmosis
3. **What is formed when chlorine is added to water?**
 - a. hypochlorous acid
 - b. hydrochloric acid
 - c. sulfuric acid
 - d. both a and b
4. **What is the normal water flow rate for most filters?**
 - a. 2 gpm
 - b. 3 gpm
 - c. 5 gpm
 - d. 6 gpm
5. **Which of the following is a problem connected with filter beds?**
 - a. fissures
 - b. gravel upheaval
 - c. mudballs
 - d. all of the above
6. **Demineralization removes which of the following?**
 - a. pyrogens
 - b. bacteria
 - c. dissolved gases
 - d. organic matter
7. **To size a water softener, you must consider _____.**
 - a. frequency of regeneration
 - b. space requirements
 - c. flow rate
 - d. all of the above
8. **Standard water softener units are designed for a pressure differential of approximately _____.**
 - a. 10 psi
 - b. 15 psi
 - c. 20 psi
 - d. 25 psi
9. **Distillation removes which of the following?**
 - a. particulate matter
 - b. pyrogens
 - c. bacteria
 - d. all of the above
10. **Reverse osmosis equipment for large-volume applications should be made of what material for long-term dependability?**
 - a. copper
 - b. stainless steel
 - c. PVC
 - d. glass
11. **Which of the following is capable of producing laboratory-grade water?**
 - a. reverse osmosis
 - b. deionization
 - c. distillation
 - d. all of the above
12. **Which of the following is used to eliminate Legionella?**
 - a. copper-silver ionization
 - b. nanofiltration
 - c. ultrafiltration
 - d. distillation