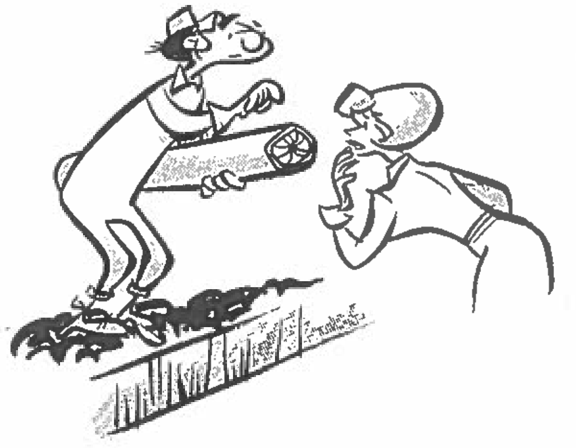
CHAPTER 4. SMALL WATER TREATMENT PLANTS

(Lesson 2 of 2 Lessons)

4.6 CORROSION CONTROL

Water is frequently corrosive to materials that it contacts, especially metal. Corrosion of metal is an *ELECTROCHEMICAL REACTION*[23] in which materials are dissolved into the water. This process of corrosion may work slowly but, over the extended periods of time involved in water systems, it can be very important. Pipelines, storage tanks, and other structures can be seriously damaged by corrosion. Corrosion can decrease the flow capacity of pipelines and significantly increase pumping costs. Also, the quality of water delivered to consumers can be seriously affected by corrosion in the system. Corrosion can cause the water to become discolored or turbid from suspended rust particles and the water may have an unpleasant taste. The water may also contain harmful concentrations of metals like copper, zinc, and lead. Therefore, corrosion control measures are well worthwhile because water system parts that have been damaged by corrosion are very expensive to replace or repair and corrosion can cause the water quality to become unacceptable to consumers.



There are two general methods often used to control corrosion. One method is to use construction materials that resist corrosion. For instance, iron or steel pipe can be lined with cement or coated with coal tar enamel to protect the pipe. A zinc galvanized coating can be applied to small iron plumbing pipes. Copper pipes resist corrosion in most cases and plastic pipes are completely free of corrosion.

The second method of controlling corrosion is to treat the water with chemicals to make it noncorrosive. The chemicals sometimes used include lime, soda ash, caustic soda, sodium silicate, and polyphosphates. Chemical treatment of the water is of limited effectiveness and should be considered only as a supplement to the use of materials that are naturally resistant to corrosion.

The corrosion control chemicals are usually dissolved in water and fed in a solution form. Lime and soda ash can also be fed in the dry granular or powder forms. The dosage of lime, soda ash, or caustic soda is set to adjust the pH of the treated water so a thin film of calcium carbonate is deposited on the pipe surface. This thin coating prevents corrosion of the pipe. Usually, the proper pH is in the range of 8.0 to 9.0.

One method to determine the proper pH is to calculate the Langelier Index, which takes into account the various factors affecting the corrosiveness of water. The formula and procedures to calculate the Langelier Index are given in *WATER TREATMENT PLANT OPERATION,* Volume I, Chapter 8, "Corrosion Control," in this series of operator training manuals. The dosage of silicate or phosphate is usually determined from past experience with similar types of water. Normally, a dosage of several milligrams per liter is necessary. Do not use phosphate compounds if the system has open reservoirs because the phosphate may encourage excessive algal growths.

Corrosion control chemicals are the last ones to be applied after all other treatment has been accomplished. The reason is that the pH required for successful coagulation and disinfection is much lower than the pH required to make the water noncorrosive. Also, a coating of calcium carbonate on the filter media should be avoided because it interferes with effective filtration. The operator must understand that any lime or soda ash applied with the alum to improve coagulation has a minimum impact in controlling corrosion. These materials are all consumed in the chemical reactions that occur during coagulation. Therefore, to make the water noncorrosive, additional lime, soda ash, or caustic soda must be added in the final stage of treatment.

The pH of the water is frequently used as a day-to-day indicator of the corrosive nature of the water. Water of a higher pH is normally less corrosive than water of a lower pH. However, because of the many factors that can affect corrosion, the pH measurement is not totally reliable. The best method of monitoring corrosion is to examine specimens of the actual pipeline material or the surface of the structure involved. This inspection is easy if sections of pipe can be removed periodically. Alternatively, small specimens of the pipeline material can be mounted in the flowing water and periodically removed for inspection.

Waters with a low pH are very aggressive and can dissolve concrete and asbestos cement pipe. Increasing the pH of the water by the use of chemicals can reduce the rate of deterioration of the materials.

For additional information on corrosion control, see *WATER TREATMENT PLANT OPERATION,* Volume I, Chapter 8, "Corrosion Control," in this series of operator training manuals.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 276.

4.6A List the two general methods of controlling corrosion.

4.6B What is the best method of monitoring corrosion in a water main?

4.7 SOLIDS-CONTACT CLARIFICATION

by J. T. Monscvitz

4.70 Process Description

Solids-contact units were first used in the Midwest as a means of handling the large amounts of sludge generated by water softening processes. It quickly became clear that this compact, single-unit process could also be used to remove turbidity from drinking water.

Solids-contact clarifiers (Figures 4.19 and 4.20) go by several names that may be used interchangeably: solids-contact clarifiers, upflow clarifiers, reactivators, and precipitators. The basic principles of operation are all the same, even though various manufacturers use different terms to describe how the mechanisms remove solids from water. The settled materials from coagulation or settling are referred to as "sludge" and "slurry" refers to the suspended floc clumps in the clarifier. Sometimes, the terms sludge and slurry are used interchangeably.

The internal mechanism consists of three distinct unit processes that function in the same way as any conventional coagulation-flocculation-sedimentation process chain. Sludge produced by the unit is recycled through the process to act as a coagulant aid, thereby increasing the efficiency of the processes of coagulation, flocculation, and sedimentation. This is the same principle that has been used successfully for many years in the operation of separate coagulation, flocculation, and sedimentation processes.

The advantages of using a solids-contact clarifier over operating the same three processes separately are significant, but are sometimes offset by disadvantages. For example, capital and maintenance costs are greatly reduced because the entire chain of processes is accomplished in a single tank. At the same time, though, operation of the single-unit processes requires a higher level of operator knowledge and skill. The operator must have a thorough understanding of how these processes operate and be able to imagine how all of these processes can occur in a small chamber or clarifier at the same time. Operators often have trouble visualizing what is happening in an upflow clarifier and become discouraged or upset when routine problems associated with solids-contact units occur.

A tremendous advantage in the use of the solids-contact units is the ability to adjust the volume of slurry (sludge blanket). By proper operational control, the operator can increase or decrease the volume of slurry in the clarifier as needed to cope with certain problems. During periods of severe taste and odor problems, for example, the operator can increase the sludge level and add activated carbon. The *ABSORPTIVE*[24] characteristics of activated carbon make it highly effective in treating taste and odor problems. Similarly, when coagulation fails because of increased algal activities, the operator can take advantage of the slurry accumulation to carry the plant through the severe periods of the day when the chemicals will fail to react properly because of changes in the pH, alkalinity, carbonate, and dissolved oxygen. In the conventional plant, the operator cannot respond to this type of breakdown in the coagulation process as well as the operator of a solids-contact unit can. Once algal activities have been determined to be causing the problem (readily checked by pH and DO), the operator can increase the amount of slurry available during good periods of the day and remove it during periods when the coagulation process is not functioning well. By skillfully making these slurry level adjustments, the operator can maintain a high-quality effluent from the solids-contact unit.

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[23] *Electrochemical Reaction.* Chemical changes produced by electricity (electrolysis) or the production of electricity by chemical changes (galvanic action). In corrosion, a chemical reaction is accompanied by the flow of electrons through a metallic path. The electron flow may come from an external source and cause the reaction, such as electrolysis caused by a DC (direct current) electric railway, or the electron flow may be caused by a chemical reaction, as in the galvanic action of a flashlight dry cell.

[24] *Absorption* (ab-SORP-shun). The taking in or soaking up of one substance into the body of another by molecular or chemical action (as tree roots absorb dissolved nutrients in the soil).

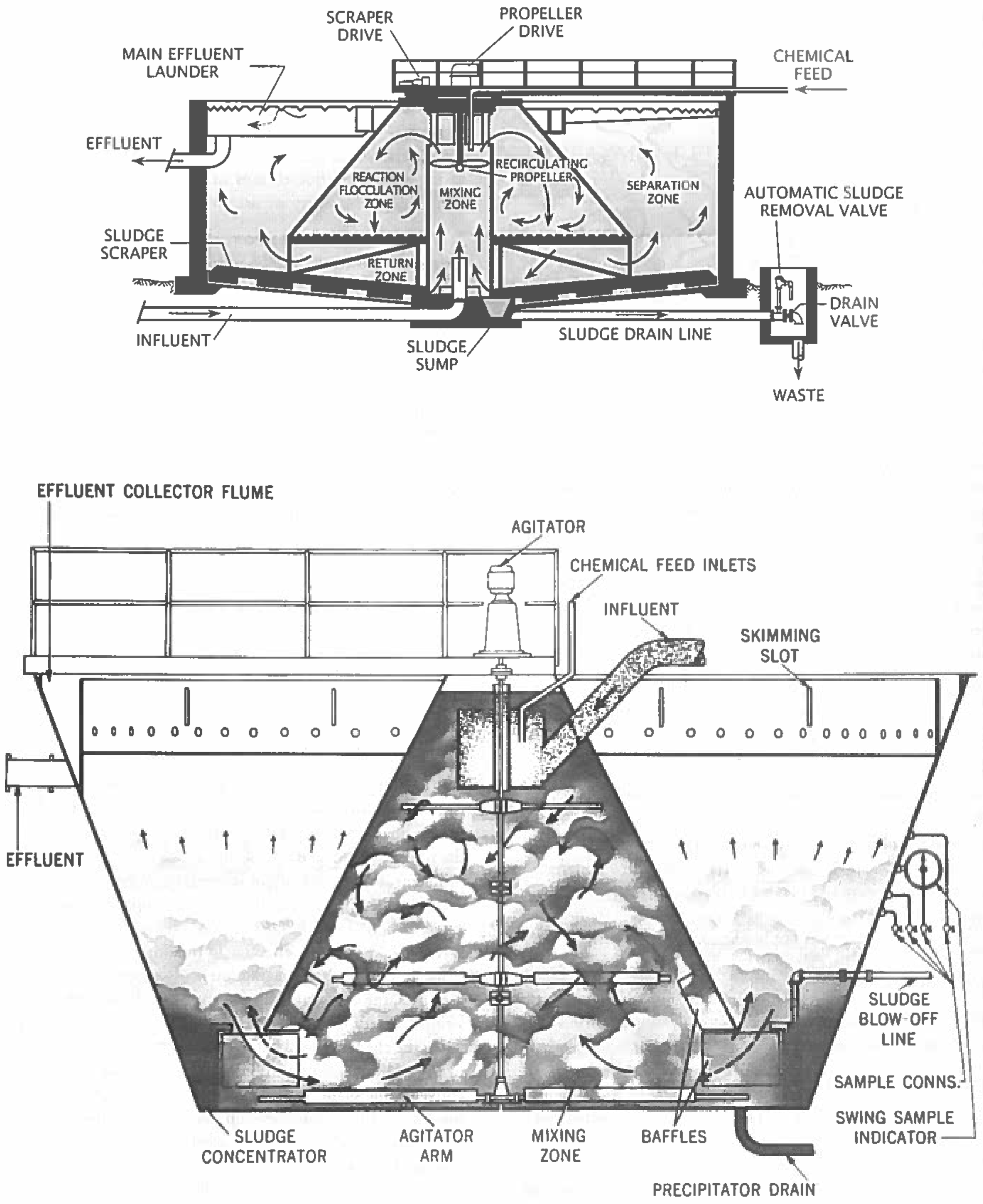

Fig. 4.19 Solids-contact clarifiers
(Adapted from Permutit Company)

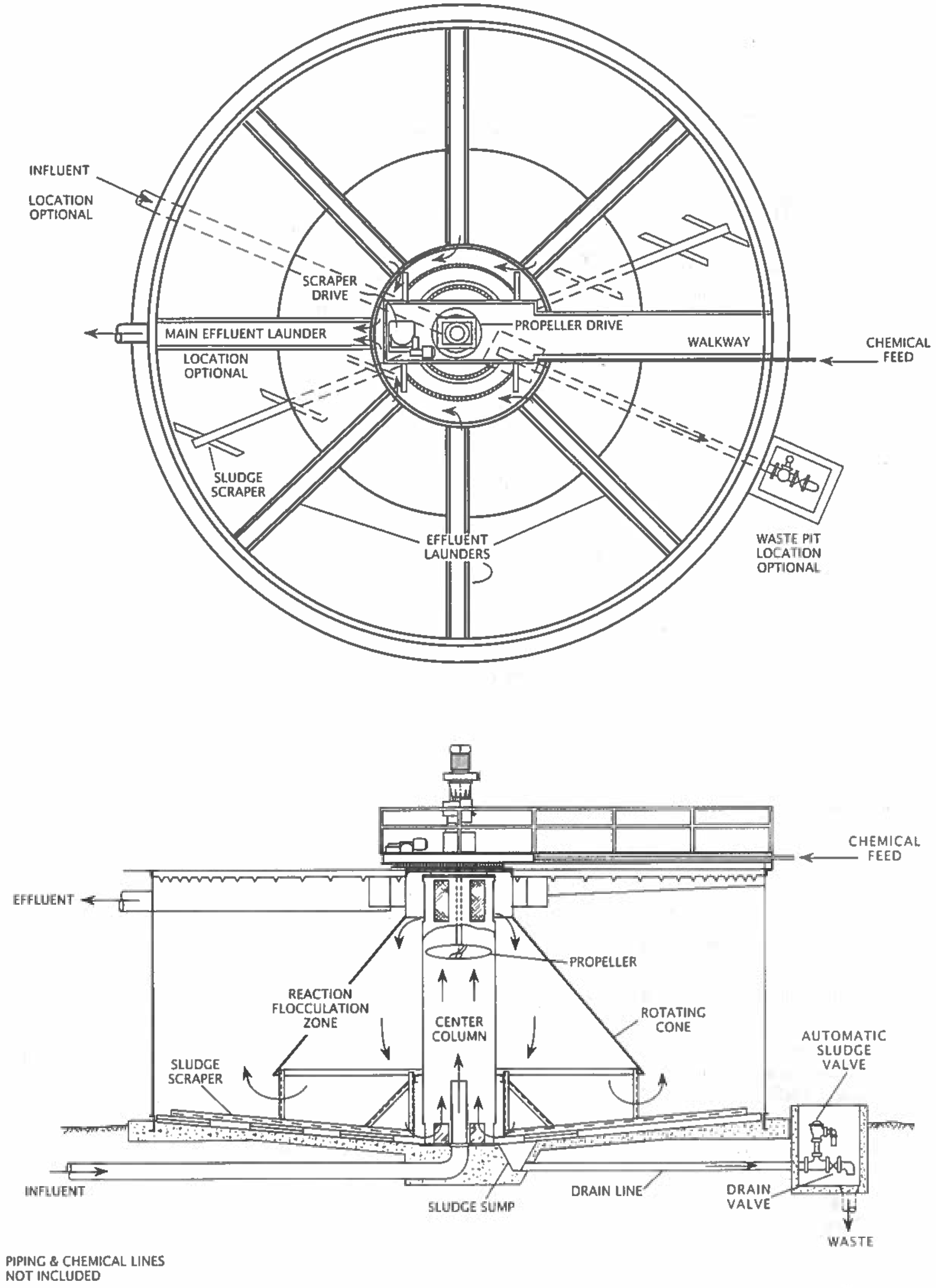

Fig. 4.20 Plan and section views of a solids-contact clarifier
(Permission of General Filter)

The most serious limitation of solids-contact units is their instability during rapid changes in flow (throughput), turbidity level, and temperature. The solids-contact unit is most unstable during rapid changes in the flow rate. The operator should identify and keep in mind the design flow for which the unit was constructed. For easier use, convert the design flow to an *OVERFLOW RATE.*[25] This rate may be expressed as the rise rate in inches per minute or feet per minute (centimeters per minute). For each rise rate there will be an optimum (best) slurry level to be maintained within the unit. A rising flow rate will increase the depth of the slurry without increasing its volume or density. Conversely, a decrease in flow rate will reduce the level of slurry without changing its volume.

Sampling taps can be installed to enable the operator to monitor changes in slurry depth or concentration. The level of the slurry can be identified by placing sampling taps at various depths along the wall of the solids-contact reactor. The taps should penetrate the wall and extend into the slurry zone. It is often necessary to modify existing sampling taps or install additional sampling pipes to accomplish this.

By observing and measuring slurry depths at frequent intervals, the operator can easily monitor the rise or fall of the slurry levels; this will enable the operator to promptly make appropriate adjustments in the recirculation device or more tightly control the rate of change in the flow rate. This method of operational control is relatively effective in a gravity flow system when the water demands are moderate and the flow rate can be changed slowly. However, operational control in pressure systems is more difficult. Responding to rapid changes in demand or placing pumps into service at full capacity can easily upset an upflow clarifier immediately. In this case, the operator can witness the crisis occurring by observing the sampling taps but be next to helpless to respond. The slurry will rise very rapidly in the settling zone, approach the overflow weirs, and spill onto the filters in a total breakdown of the plant process.

Solids-contact clarifiers are also sensitive to severe changes in the turbidity of incoming raw water. The operator must be alert to changes in turbidity and must take immediate action. With experience, the operator will learn to accurately forecast when the turbidity may arrive at the reaction zone and will cope with the problem by increasing the chemical dosage prior to the arrival of excess turbidity. Early application of an increased chemical dosage puts the unit in a mode in which the turbidity can be handled successfully. The control of slurry and its influence on operational control during turbidity changes is discussed in greater detail later in this section.

The third factor that exerts a major influence on operation of a solids-contact unit is temperature. Changes in water temperature will cause changes in the density of the water; changes in density influence the particle settling rate. In extremely cold water, consider using polymers, activated silica, powdered calcium carbonate, or some other weighting agent to aid sedimentation without affecting coagulation. Simple heating by the sun on the wall of the tank or on the flocculant particles within the container will cause a certain amount of carryover of solids to occur. Operators who are not familiar with solids-contact units tend to become upset and overreact because of the potential carryover problem. This phenomenon is not a matter of serious concern because, as the position of the sun changes, the convection currents change. The clouds of flocculant particles appear and disappear in response to the currents and there is no real need to control this phenomenon if the overall settled turbidity meets your objective. As long as the major portion of the sludge blanket lies in the settling zone, the few clouds of flocculant particles (which look like billowing clouds) really do not significantly harm the operation of the unit or the quality of the water produced.

Dramatic changes in temperatures and flow rates may sometimes make it impossible to control or prevent process upsets. If the slurry rises to the weirs and is carried over onto the filters, reduce the flow rate. If possible, use weighting agents before changing flow rates in cold water. The use of weighting agents may cause problems with the slurry requiring changes in recirculation rates. However, too high a recirculation rate may also cause the slurry to overflow onto the filters. During a change in temperature (cold water), be very careful in changing the flow rate.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 276.

4.7A List at least two advantages of solids-contact units.

4.7B How can the level of the slurry or sludge blanket be determined in solids-contact units?

4.7C What should be done when a rapid change in turbidity is expected?

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[25] *Overflow Rate.* One of the guidelines for the design of settling tanks and clarifiers in treatment plants. Used by operators to determine if tanks and clarifiers are hydraulically (flow) over- or underloaded. Also called SURFACE LOADING.

$$\text{Overflow Rate, GPD/sq ft} = \frac{\text{Flow, gallons/day}}{\text{Surface Area, sq ft}}$$

or

$$\text{Overflow Rate, } \frac{\text{cu m/day}}{\text{sq m}} = \frac{\text{Flow, cu m/day}}{\text{Surface Area, sq m}}$$

If we divide the overflow rate by 7.48 gallons per cubic foot and also divide by 1,440 minutes per day, we will have converted the overflow rate to a rise rate in feet per minute.

4.71 Fundamentals of Operation

The operator of a solids-contact unit controls the performance of the unit by adjusting three variables:

1. Chemical dosage
2. Recirculation rate
3. Sludge control

All three of these variables are interrelated, and you often may have trouble distinguishing which one is the root of a problem you are encountering. However, if you will use the following analytical techniques, you should be able to separate the three fundamentals into separate groups of symptoms and diagnose the cause of the upset. This is not to say that if you have one problem, it may not coexist with the other two.

First, let us consider chemical dosage. As in conventional treatment plants, proper consideration must be given to chemical dosage, otherwise the entire system of solids-contact clarification will collapse. There must always be sufficient alkalinity in the raw water to react with the coagulant. Assuming the coagulant used is aluminum sulfate, for every mg/*L* of alum added, 0.45 mg/*L* of bicarbonate alkalinity is required to complete the chemical reaction. To drive the chemical reaction sufficiently to the right (that is, for precipitation to occur), there should be an excess of 20 mg/*L* of alkalinity present. You may have to add sodium hydroxide (caustic soda), calcium hydroxide (lime), or sodium carbonate (soda ash) to cause sufficient alkalinity to be present. For example, if there was only 20 mg/*L* of natural alkalinity present, for every mg/*L* of alum added you should add 0.35 mg/*L* of lime if calcium hydroxide was being used.

All of this information can be verified by jar testing, which is fundamental in determining proper coagulation by chemical dosing. You should never attempt to make changes in solids-contact unit operation without first determining the proper chemical dosage through jar testing. For most solids-contact units, use the chemical dosages that produce floc that gives the lowest turbidity within a five-minute settling period after stopping the jar tester. Using the above criteria, the operator now can set the chemical feeders to dose the raw water entering the solids-contact unit.

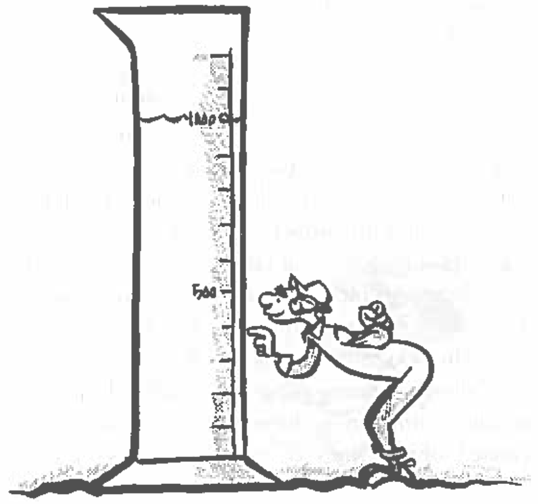
The next control mechanism is recirculation. Here, most often, the plant operator is misled by intuitive judgment. The recirculation rate is established by the speed of the impeller, turbine, pumping unit, or by air injection. Any of these devices causes the slurry to recirculate through the coagulation (reaction) zone. To help you visualize how the slurry should look in the reaction zone, take another look at the lower drawing in Figure 4.19 and note the cloud-like, billowy appearance of the flocculated slurry in this area. Under normal operating conditions, the entire mass of suspended floc clumps billows and flows within the chamber. Its motion is continually being influenced by the mixing of recirculated sludge and incoming raw water. In principle, you are attempting to chemically dose the raw water when it enters the reaction zone and is mixed with the recirculated sludge. Coagulation and flocculation occur in the reaction zone and then the water and sludge pass into the settling zone. Some sludge is recirculated and mixed with incoming raw water and the rest of the sludge settles and is removed from the bottom of the settling area. At the point where water and sludge pass from the reaction zone to the settling zone, approximately one liter of water should rise and one liter of slurry should be returned into the reaction zone.

In order to sort out the effects of chemical dosages, recirculation rate, and sludge control, you should keep a log of the speed (RPM) of the recirculation device. If air is used for mixing, then the cubic feet of air applied per minute should be recorded. There is a direct relationship between the percentage of slurry present and the speed at which the mixing device is traveling.

To control the process, the operator must maintain the correct slurry volume in the reaction zone by exercising control of the rate of recirculation. The percentage of slurry can be determined by performing a volume over volume (V/V) test. The test procedure is as follows: using a 100-m*L* graduated cylinder, collect a sample from the reaction zone. Let the sample sit for five minutes and then determine the volume of slurry accumulated (m*L*) using the formula:

$$\text{V/V, \%} = \frac{(\text{Settled Slurry, m}L)(100\%)}{\text{Total Sample Volume, m}L}$$

At the same time, observe the clarity of the supernatant (settled water) that remains in the graduated cylinder. The clarity of the water above the slurry (the supernatant) will indicate to you how well the chemical reaction is proceeding. The percentage of accumulated solids by volume will indicate whether a proper amount of slurry is in the reaction zone. Customarily, such reactors require 5 to 20 percent solids, or a higher percentage in the graduated cylinder at the end of a five- to ten-minute settling period.



Through recordkeeping and experience, you will find an optimum percentage of solids to maintain. You should perform the above analyses hourly and more frequently when the raw water quality is undergoing change. Accurate records must be kept.

The final step in control of the solids-contact unit is the removal of sludge that has accumulated on the bottom of the clarifier (settling zone). There are several means of sludge collection.

Some devices are located in areas of clarifiers that hold the sludge and are controlled by opening and closing recirculation gates. Others have scrapers that collect the sludge and move it to a discharge sump. In both cases, the sludge is removed by hydraulic means (water pressure) through a control valve. The sludge removal mechanisms are generally on a timer, which operates periodically for a time duration set by the operator. The means of making this judgment is quite simple. Once again, use a graduated cylinder to collect a sample from the sludge discharge line. The sludge being discharged should be 90 to 98 percent solids in a V/V test, as indicated above. A five- to ten-minute period should be sufficient to make this determination. When slurries or sludge weaker than 90 percent is pumped, the operator is discharging a considerable amount of water and not leaving enough sludge to be recirculated into the reaction zone. If the percentage is considerably greater than 90 percent, then too much sludge may be accumulating and the recirculation device could become overloaded with too much return slurry.

If you will visualize the above reactions, you can see that, with increased speed of the recirculation device, a larger amount of slurry can be retained in the unit. At the same time, if this amount becomes too great, it may cause the sludge to rise and ultimately spill over the effluent weirs with the treated water. If the recirculation rate is too low, the solids may settle too soon and, without sufficient recirculation, will not return to the reaction zone. The absence of solids in the reaction zone causes improper coagulation. The net result is a failure of the total solids-contact system.

Considering the above principles and provided with some experience, you should be able to determine an optimum amount of slurry to be present that will satisfy a given recirculation rate, coupled with proper chemical dosage, and a sufficient percentage of solids for recycling. You should always be aware of the amount of solids in the reaction zone and, based upon practical experience, know approximately the percentage required. Some of the obvious difficulties in this judgment will occur as the raw water turbidity changes. For instance, in muddy streams carrying silt, sedimentation may occur very rapidly, thus requiring increased circulation rates to maintain sufficient slurry in the reaction zone (even with proper chemical dosage), and also requiring greater sludge removal rates. As the raw water turbidity becomes lighter, the increased circulation rate may cause the slurry blanket to rise to an uncontrolled depth in the settling zone. Removing too much sludge will also produce this same effect. All of these problems are readily observed in the V/V test for solids determination in the reaction zone; also, this is cause for increased observations of the V/V during water quality changes.

Another problem may be caused by cold water when the recirculation rate may be too high for the densities of the particles present. A set of recirculation speeds for warm-weather operation may be entirely different from those used during cold weather. As a remedy, the operator may select a nonionic polymer as a weighting agent to increase the settling rate in cold waters. Other alternative chemicals are powdered calcium carbonate or the use of activated silica. A note of caution in chemical dosage determination: the reactions in the jar tester should be reasonably rapid to ensure comparable reactions within the solids-contact unit.

Another important point when determining chemical dosage for a solids-contact unit is that a specific set of jar test guidelines will be needed for each plant. For example, you should determine the volume of the reaction zone and the period of detention of the raw water in that reaction zone. This, along with knowledge of the speed of the recirculation device, should allow you to determine the detention time and flocculator speed in the jar tester.

In the real world, this means that if the flow rate of the solids-contact unit is 10 minutes in the reaction zone and the speed is two feet per second (0.6 m/sec), then the jar tester mixer should turn at a speed equal to two feet per second with a coagulation period of 10 minutes. You should duplicate in the jar tester, as nearly as possible, those conditions of chemical dosage, detention period, and mixing speeds that occur in the solids-contact unit. Using these guidelines, you should be able to approach approximate real-world conditions in the laboratory and better optimize chemical dosages.

4.72 Maintenance

Solids-contact units, like all waterworks equipment, require at least a minimum of maintenance. The primary consideration is the recirculating device, which needs lubrication and regular inspection of the belt drive and gear boxes. Also, if the unit has a sludge collector, then its drive and gear boxes require the same attention. The units should be inspected daily and lubricated in accordance with the manufacturer's recommendations. Also, the contact unit may need to be drained periodically and the sludge collectors inspected for wear and corrosion.

Sludge collector devices are usually constructed of steel within a concrete container. Thus, there is a need to inspect the *CATHODIC PROTECTION*[26] system if one is provided with the unit. Weekly readings should be kept concerning the amperes and voltage supply. Changes in these readings indicate that a problem may be developing. The cathodic protection devices should be inspected and, if any defects are detected, they should be corrected as soon as possible.

For additional information on solids-contact units, see *WATER TREATMENT PLANT OPERATION,* Volume I, Section 5.243, "Arithmetic for Solids-Contact Clarification," page 172, in this series of operator training manuals.

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[26] *Cathodic* (kath-ODD-ick) *Protection.* An electrical system for prevention of rust, corrosion, and pitting of metal surfaces that are in contact with water, wastewater, or soil. A low-voltage current is made to flow through a liquid (water) or a soil in contact with the metal in such a manner that the external electromotive force renders the metal structure cathodic. This concentrates corrosion on auxiliary anodic parts, which are deliberately allowed to corrode instead of letting the structure corrode.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 276.

4.7D How is the proper chemical dose selected when operating a solids-contact unit?

4.7E List the devices that may be used to provide recirculation in a solids-contact unit.

4.7F How is the percentage of slurry present in the reaction zone determined?

4.8 SLOW SAND FILTRATION

by Peg Hannah

4.80 Development of Process

The use of slow sand filtration to purify water dates back to 1829 when the process was first used in London. The method was later used widely throughout Europe, but it was not often practiced in the United States. The two most widely used filtration systems in the US today, high rate gravity filters and pressure filters (described in Section 4.4), are modifications of the slow sand filtration process and were designed to make the process better, faster, and cheaper.

A renewed interest in slow sand filtration developed during the late 1980s, and a growing number of pilot projects were undertaken to study the process. The driving force behind these efforts was the Safe Drinking Water Act of 1974 and its Amendments (1986), in particular the Surface Water Treatment Rule (SWTR), which the Environmental Protection Agency promulgated in 1989. The SWTR is especially significant for small water supply systems. The rule requires all water systems whose water supply is surface water or groundwater under the influence of surface water[27] to disinfect their water and, under most circumstances, to install filtration equipment. The rule further specifies which filtration methods are acceptable and the turbidity monitoring frequencies and limits. In 1990, it was estimated that about 2,900 water systems used surface water as a source of supply but did not practice filtration; approximately 90 percent of those systems served populations of fewer than 10,000. The practical result of the SWTR was that most of these small water systems had to begin filtering their source water using one of four modes (or methods) of water treatment by filtration: conventional, direct, diatomaceous earth, or slow sand. The best mode for a particular community will depend upon the characteristics of the supply water, the daily volume of filtered water required to serve the community, and the cost and availability of qualified operators.

Of the four methods of filtration, slow sand filtration is a simple, cost-effective option for small water systems. The purpose of this section is to describe the slow sand filtration equipment and process, identify the factors that should be considered before installing a slow sand filter, and provide general guidelines for the operation and maintenance of a slow sand filter. (The other three filtration methods (conventional, direct, and diatomaceous earth) were described earlier in Section 4.4, "Filtration," and are also described in *WATER TREATMENT PLANT OPERATION,* Volume I, in this series of operator training manuals.)

Even though the equipment is relatively simple, design guidelines and cost projections are greatly influenced by local conditions. A qualified engineer should assist in the design of a slow sand facility and it is strongly recommended that a pilot project be undertaken prior to construction of a full-scale plant in order to assess the effectiveness of a slow sand filter operating under actual local conditions. Other sources of information on slow sand filters are listed in Section 4.15, "Additional Reading."

4.81 Procedure for Treating Water

Typically, a filter removes suspended particles from water by means of several physical processes. The particles may be trapped in the filter if they are too large to pass through the openings in the filter media; this is the action of a simple strainer. To increase the effectiveness of the straining action, chemicals are usually added to cause the finer particles to clump together (coagulation/flocculation) into larger particles that can more easily be removed. As water moves through the sand (media) bed, suspended particles strike the media (sand grains), their movement is slowed, and they may settle (sedimentation) into the void spaces between sand grains. In addition to this straining and settling action, filters also remove particles that stick (adhere) to the media. The mechanisms that cause adhesion (adsorption) are not fully understood, but may include chemical bonding or electrical forces.

Slow sand filtration is a feasible alternative for small water systems even though the filtration rate is 50 to 100 times slower than rapid sand filtration. By combining a simple design, ease of operation requiring minimal staffing, and the ability to remove *Giardia lamblia* cysts as well as *Cryptosporidia,* coliforms, and other microorganisms, slow sand filters meet the needs of many small communities.

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[27] States must determine which community and noncommunity groundwater systems are under the direct influence of surface water. The SDWA defines "groundwater under the influence of surface water" as, "Any water beneath the surface of the ground with (i) significant occurrence of insects or other microorganisms, algae, or large diameter pathogens such as Giardia lamblia, or (ii) significant and relatively rapid shifts in water characteristics such as turbidity, conductivity, or pH which closely correlate to climatological or surface water conditions."

In slow sand filters, no filter-aid chemicals are used as they often are in other water filtering systems. However, an additional benefit of the slow sand process is that a biological process assists in the removal of suspended matter. As the layer of trapped matter at the surface of the filter builds up, a dense population of microorganisms develops. This mat is called the "schmutzdecke" (shmoots-DECK-ee), a German word meaning "dirty skin." The mat itself is only a few centimeters (about an inch) thick, but organisms within the film or mat feed on and break down incoming organic material trapped on the schmutzdecke. In doing so, they both remove organic matter and add mass to the layer, further developing the schmutzdecke and increasing the physical straining action of the layer.

At the same time, other varieties of organisms deeper within the sand media form a biofilm on the sand particles. Organic material passing through the media sticks to the biofilm where the organisms then use the material and thereby remove it or convert it to carbon dioxide and water. The schmutzdecke and biofilm develop or ripen over time and the filter is said to be mature when the population of organisms becomes well established and the filter produces acceptable filtered water. The filter will continue to operate in this condition until head loss indicates a clogged condition and adequate flow through the filter can no longer be maintained. Filter cycle times are widely variable but usually average at least 1½ to 2 months.

When performance indicators signal the need to clean the filter, the top layer of sand and accumulated material, usually less than one inch thick, is simply scraped off the surface and removed. With time, the cleaned sand bed ripens and will again produce design flows of acceptable quality. After several cleanings, new sand is added to bring the media back to its design depth.

The principal removal mechanism in a slow sand filter is physical straining or entrapment of particulates. Both the schmutzdecke and the biofilm contribute to overall particulate removal. There is some speculation that perhaps their relative removal rates vary from filter to filter, depending on factors such as the specific microorganisms that predominate, presence of algae, and maturity of the bed.

4.82 Components (Figure 4.21)

The structure of a slow sand filter is similar to a gravity sand filter. Components include a tank, underdrain piping, gravel media support, sand media bed, water intake and distribution piping, finished water (tailwater) weirs and holding tanks, flow control valves or weirs, and meters to measure head loss and flows. A cover is sometimes provided to prevent freezing of water in the tank, the growth of algae, and an accumulation of wind-blown debris.

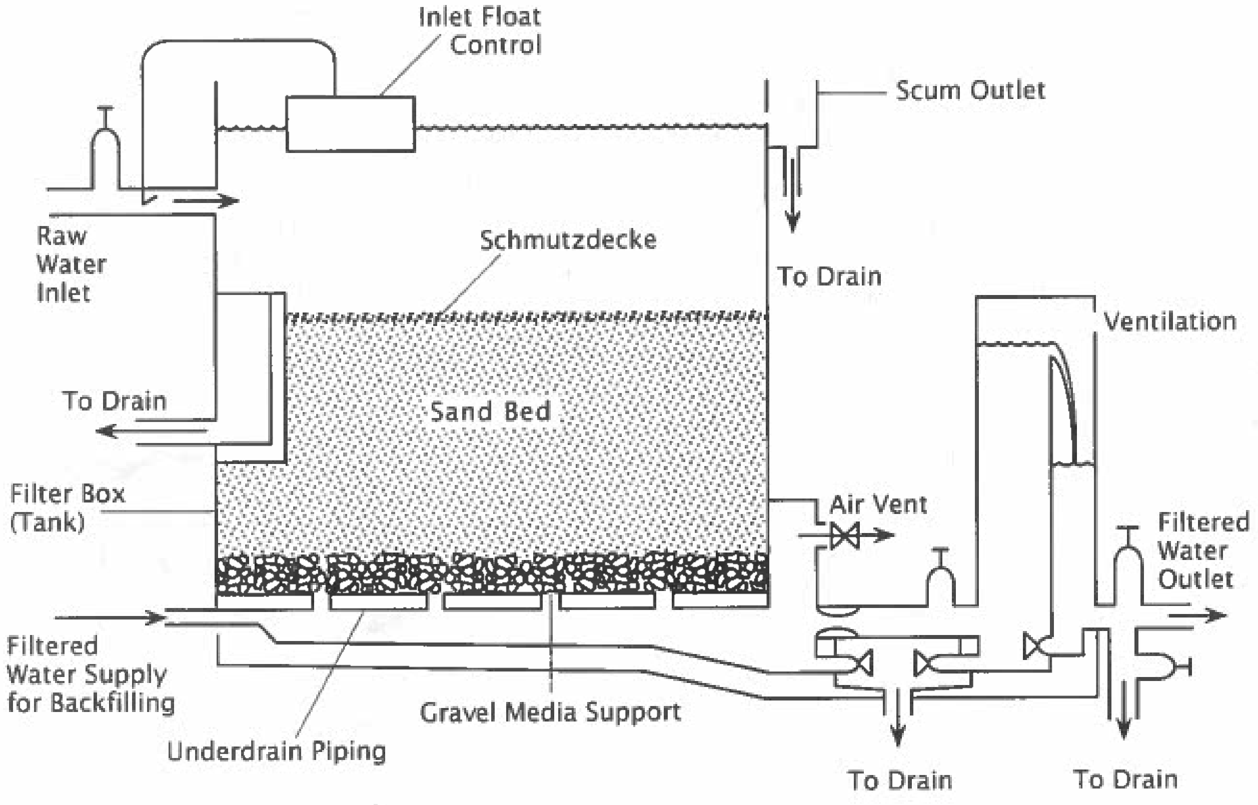


Fig. 4.21 Flow diagram of slow sand filtration system

(Adapted from "What Is Slow Sand Filtration?" *OPFLOW*, Vol. 18, No. 2 (Feb. 1992), by permission. Copyright © 1992, American Water Works Association)

4.820 Filter Tank

Slow sand filter tanks may be constructed at the site using steel-reinforced concrete, poured concrete, or earthen berms with a watertight liner. In small installations, prebuilt tanks made of fiberglass, galvanized steel, or reinforced concrete are sometimes an economical choice. The tanks may be circular, square, or rectangular. The filter tank should consist of two or more equal-sized chambers or cells, each of which can be operated independently of the others so that one can be shut down for cleaning while the others continue to operate. Design questions about the size, shape, and number of filters as well as methods of construction will be greatly influenced by the filter bed area needed to produce adequate treated water.

FORMULA

The size of the tank filter surface area can be calculated by dividing the maximum expected flow by the maximum hydraulic loading rate when all but one cell is in service.

$$\text{Filter Surface Area, sq ft} = \frac{\text{Flow Rate, gal/day}}{\text{Hydraulic Loading Rate, GPM/sq ft}}$$

EXAMPLE 14

A slow sand filter has two cells; each is four feet wide and ten feet long. The desired flow is 7,000 gallons of filtered water per day at a hydraulic loading rate of 0.15 gallons per minute per square foot of filter surface area. Is the filter adequately sized to handle this demand?

Known		Unknown
Flow Rate, gal/day	= 7,000 gal/day	1. Surface Area, sq ft
Hydraulic Loading Rate, GPM/sq ft	= 0.15 GPM/sq ft	2. Is surface area adequate?
Length, ft	= 10 ft	
Width, ft	= 4 ft	

1. Calculate the filter surface area needed.

$$\begin{aligned}\text{Surface Area, sq ft} &= \frac{\text{Flow Rate, gal/day}}{\text{Hydraulic Loading Rate, GPM/sq ft}}\\ &= \frac{7{,}000\ \text{gal/day}}{(0.15\ \text{GPM/sq ft})(60\ \text{min/hr})(24\ \text{hr/day})}\\ &= \frac{7{,}000}{216\ \text{sq ft}}\\ &= 32.4\ \text{sq ft}\end{aligned}$$

2. Calculate the available surface area for each cell.

$$\begin{aligned}\text{Surface Area, sq ft} &= (\text{L, ft})(\text{W, ft})\\ &= (10\ \text{ft})(4\ \text{ft})\\ &= 40\ \text{sq ft}\end{aligned}$$

Since the surface area available from one cell is 40 square feet, which is greater than 32.4 square feet, sufficient surface area is available in one cell to meet the flow demand when the other cell is out of service.

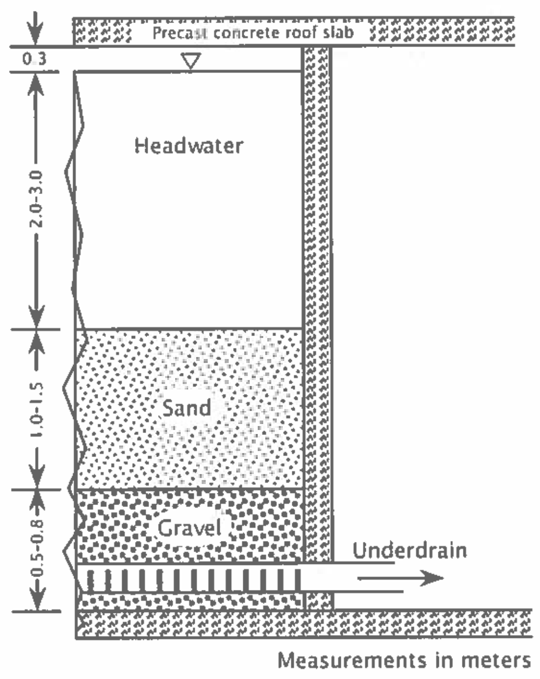
Because a slow sand filter must be shut down for cleaning and resanding, it will be necessary to build in enough extra capacity to provide 100 percent of expected flow during shutdowns. In a single tank with two independent chambers, each chamber must accommodate the entire amount. If four tanks or chambers are used, the total capacity of three must equal 100 percent of expected production; the fourth chamber thus represents excess capacity. In Example 14, on the left, each of the two cells must have at least 32.4 square feet of filter surface area; therefore, there is 32.4 square feet or more of excess capacity. As the number of chambers or tanks increases, the amount of excess capacity that must be built declines, thereby somewhat reducing initial construction costs. At some point, however, the savings realized by increasing the number of chambers will be offset by the cost of piping and valves to the additional chambers. The designer must balance these factors to achieve the most economical design.

Other factors to be considered in selecting an appropriate tank design include required land area, need for a cover or enclosure, and the filter cleaning method. For example, tank construction for a medium to large plant may be influenced by the need to construct access ramps for cleaning equipment. Access to round tanks for cleaning can be more difficult. Basins formed by earthen berms require more land area than comparable capacity concrete tanks so the type of construction may be limited by the available land area. If the local climate is such that freezing will be a problem, a roof may be needed and the designer must consider the added structural weight in the design of the basin. Small filters may need to be fitted with a removable cover that permits easy access for cleaning. Many such considerations influence tank design, but it is beyond the scope of this discussion to consider them here.

The surface area of the filter will vary from site to site since it is based on the required capacity, but the depth of the tank is somewhat less variable. This dimension is the sum of the depths of the gravel support layer/underdrain system, the sand bed, maximum water depth (headwater) above the filter, and the freeboard. If the filter is covered or enclosed, additional headspace must be provided to permit safe access for cleaning activities and equipment. Figure 4.22 illustrates a cross section of a slow sand filter box. The upper limits shown for filter bed depth and headwater depth in this illustration are slightly higher than typical.

4.821 Underdrain System

The structure and functions of a slow sand filter underdrain system are similar to the underdrain system of the rapid rate gravity filter described in Section 4.4, "Filtration." Perforated or slotted PVC pipe is frequently used for underdrain piping. In the most common configuration, a series of slotted pipes are laid parallel along the bottom of the tank and are connected to a larger manifold or header pipe. Filtered water collects in the perforated pipes, flows through the header, and flows by gravity out of the filter tank to a clear well or reservoir. (In other types of gravity filters, the underdrain distributes backwash water to clean the filter media.)



NOTE: To convert the above measurements in meters to feet, multiply the above values by 3.281 feet/meter.

Fig. 4.22 Cross section of slow sand filter showing filter box with underdrain, gravel support, sand, headwater, and freeboard

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A bed of gravel covers the perforated underdrain piping. As with rapid rate gravity filters, the gravel bed may consist of several layers of different gravel sizes arranged from largest on the bottom in contact with the underdrain piping to smallest on top in contact with the sand. The gravel support layer reduces the velocity of the water, supports the sand media, prevents the sand from being carried into the underdrain pipes, and helps to distribute water evenly when the tank is being filled. Before gravel is placed in the filter it should be carefully washed to remove any dirt, clay, or other loose debris. Unless these materials are washed out before the filter is placed into operation, they will wash out during operation and cause increased effluent turbidity.

An important factor that must be considered in the design of a slow sand filter underdrain system is the method that will be used to clean the filter. Allowance must be made for the additional weight of equipment and operators who will be working on the surface of the filter bed during cleaning operations. In a very small plant, this may only be one person with a wheelbarrow, but in larger installations heavier equipment such as tractors may be used.

4.822 Sand Media Bed

The material used as media in a slow sand filter is, as the name implies, sand (generally silica sand). Materials such as anthracite coal, garnet sand, and diatomaceous earth are frequently used in other types of filters (as described in Section 4.4), but long experience has proven silica sand to be an effective and inexpensive filter media for the slow filtration process.

In selecting sand for the media bed of a slow sand filter, the goal is to construct a bed that produces acceptable quality finished water while ensuring that the bulk of the filtered particulate matter accumulates in the upper sand layers without reducing filter cycle time to unreasonably short filter runs. Field studies indicate that this can be accomplished using sand with an *EFFECTIVE SIZE*[28] between 0.15 and 0.35 millimeters. Smaller sand tends to clog and cause short filter runs while larger sands may permit the buildup of filtered particulates deeper in the media. Acceptable rates of *PATHOGENIC ORGANISMS*[29] can be achieved with sand that is larger than the recommended effective size of 0.15 to 0.35 millimeters if the bed is biologically mature.

A second factor that must be considered when selecting sand is the consistency of grain size among sand grains, or *UNIFORMITY COEFFICIENT.*[30] The recommended uniformity coefficient is 1.5 to 3; however, uniformity coefficients up to 5 have been used successfully.

Sand meeting the specifications for effective size and uniformity coefficient can often be purchased locally from building supply companies and is generally classified as masonry or concrete sand. Sand specifically graded for filter use may be purchased from commercial filter media suppliers in 100-pound sacks of a specified size, hardness, and cleanliness.

Sand represents a major capital expense in construction of a slow sand filter. The use of local sand for filter media if it meets size, gradation, and cleanliness standards is preferred for cost considerations. Initially, a slow sand filter may require 30 to 100 times more sand than needed for a high rate filter producing the same amount of finished water. In addition, the dirty sand that is periodically removed during filter cleaning is sometimes discarded and replaced rather than washed and reused. When local sand can be used as filter media, costly shipping expense is avoided. Also, if low-cost, clean local sand is available, it may not be cost-effective to wash dirty sand and reuse it.

Whatever the source of the sand, it must be clean. Particles of dirt, clay, or organic matter present in the sand when placed in the filter will slowly wash out in the filtered water contributing to increased filtered water turbidity. Since slow sand filters are not backwashed, unacceptably high turbidity could continue for an extended period of time (sometimes as long as one to two years) if the sand is not clean when placed in the filter.

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[28] *Effective Size (ES).* The diameter of the particles in a granular sample (filter media) for which 10 percent of the total grains are smaller and 90 percent larger on a weight basis. Effective size is obtained by passing granular material through sieves with varying dimensions of mesh and weighing the material retained by each sieve. The effective size is also approximately the average size of the grains.

[29] *Pathogenic* (path-o-JEN-ick) *Organisms.* Organisms, including bacteria, viruses, or cysts, capable of causing diseases (giardiasis, cryptosporidiosis, typhoid, cholera, dysentery) in a host (such as a person). There are many types of organisms that do not cause disease. These organisms are called nonpathogenic.

[30] *Uniformity Coefficient (UC).* The ratio of (1) the diameter of a grain (particle) of a size that is barely too large to pass through a sieve that allows 60 percent of the material (by weight) to pass through, to (2) the diameter of a grain (particle) of a size that is barely too large to pass through a sieve that allows 10 percent of the material (by weight) to pass through. The resulting ratio is a measure of the degree of uniformity in a granular material, such as filter media.

$$\text{Uniformity Coefficient} = \frac{\text{Particle Diameter}_{60\%}}{\text{Particle Diameter}_{10\%}}$$

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 276.

4.8A How does the Surface Water Treatment Rule (SWTR) significantly impact the drinking water treatment processes used by small water supply systems?

4.8B Why is a tank cover sometimes provided on a slow sand filter?

4.8C What factors make up the depth of a slow sand filter tank?

4.8D What happens if the diameters of sand particles in a slow sand filter are too small or too large?

4.823 Flow Control Piping, Valves, and Gauges

Effective operation of a slow sand filter requires a constant flow of water through the filter. The flow rate through the filter depends on the head (height) of water maintained above the sand filter and the head (friction or energy) losses as the water flows through the sand filter. The head loss increases over time as the schmutzdecke develops and as material is retained in the top layer of the sand. As the head loss increases, a constant flow through the filter can be maintained in either of two ways: (1) by adjusting the raw water influent valve (B. Top of Figure 4.23), or (2) by adjusting the finished water effluent valve (I. Bottom of Figure 4.23) at the point where filtered water flows from the underdrain piping to the outlet chamber.

Influent Flow Control: Influent flow rate control (Top, Figure 4.23) permits the operator to adjust the filtration rate by controlling the amount of water that flows into the filter. This method is sometimes referred to as the rising water level method because when influent flows at a constant rate, the level of the headwater gradually rises due to increasing head loss through the filter as the run progresses. The filtration rate can be held constant by this method or adjusted as needed by opening or closing the influent valve. When the operator increases the flow into the filter, the headwater depth rises; this increases the head on the filter. Greater head (pressure) increases the filtration rate and thus produces more filtered water.

At the start of a filter run when filter head loss is low, the water surface of an influent-controlled filter is only a short distance above the media. To prevent disturbance and erosion of the sand bed, water entering the filter should first strike a splash plate above the sand surface to reduce the force of the water stream.

The headwater surface level rises as head loss through the filter increases. The rise is gradual at the start of the filter run when head loss increases are gradual. Near the end of the filter run, however, head loss develops more rapidly and the corresponding rise in headwater surface level is easily visible. By monitoring the rising headwater level (both visually and with gauges), the operator can anticipate when the filter will need to be shut down and cleaned and can make the necessary preparations.

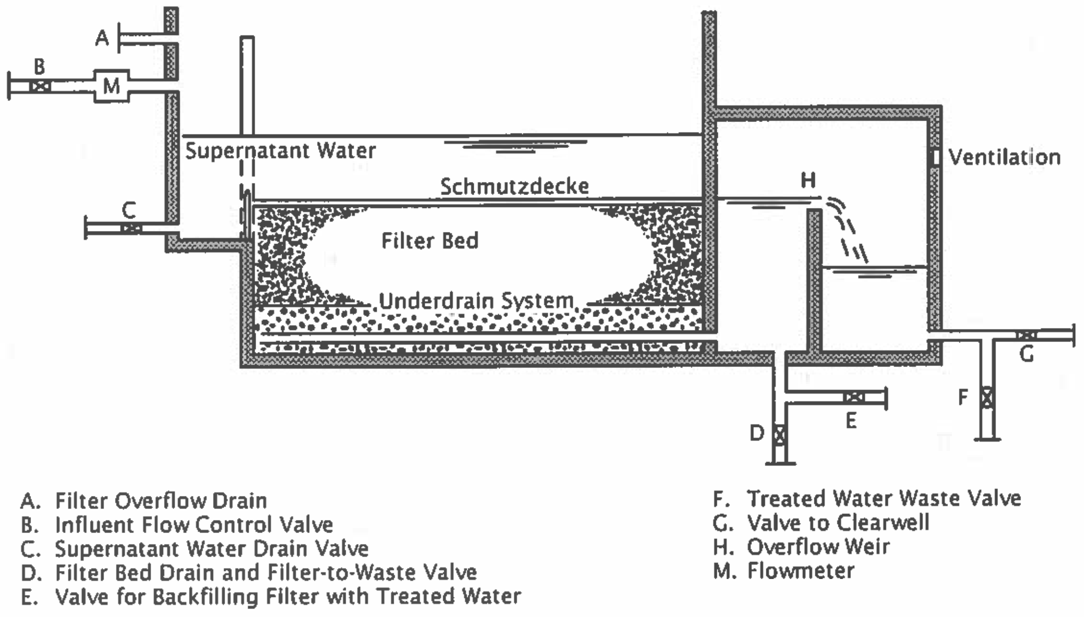
Filtered water leaves the influent-controlled system over a weir higher than the filter sand surface, but no effluent valve is needed to control the rate of flow.

Effluent Flow Control: Effluent flow control is another approach to controlling the filtration flow rate to meet flow demands. The effluent flow control valve (I. Bottom of Figure 4.23) can be used to maintain sufficient head to keep the unfiltered water at the desired level above the filter sand. As the head loss increases in the filter during the run, the valve is opened enough to lower the head loss through the valve and achieve the desired flow rate. When the effluent flow control valve is fully opened and the desired flow cannot be sustained or obtained, the filter must be removed from service and cleaned.

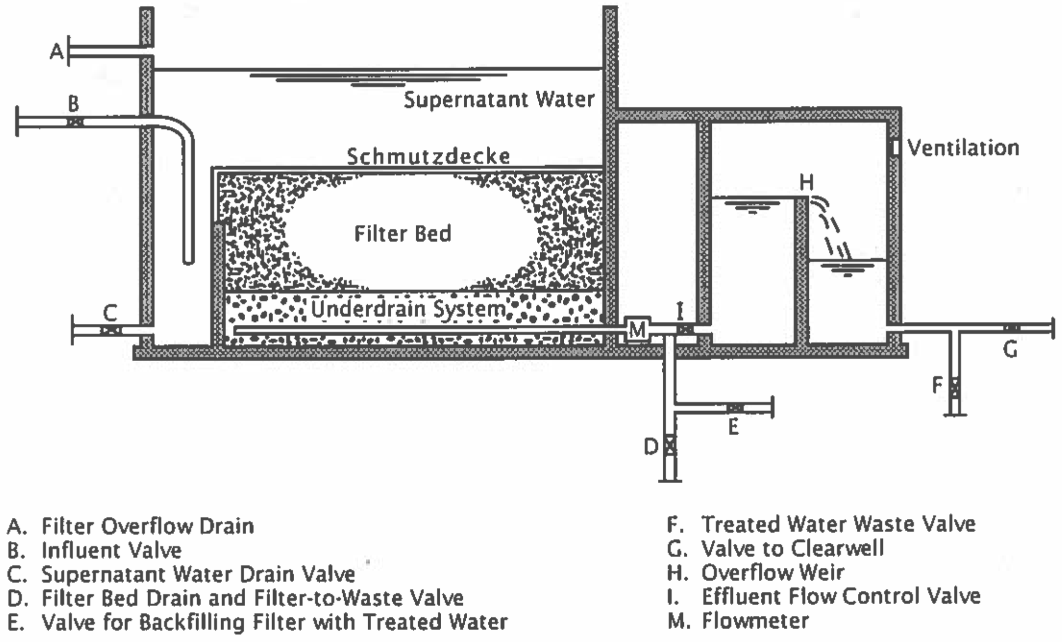
Effluent-controlled filters require a float valve or level sensor to regulate the rate of flow into the filter to maintain a constant flow through the filter. The float valve throttles the influent flow to precisely match the effluent flow. However, if the filter is supplied by gravity flow, a slight excess flow can be delivered to the filter (by adjusting an influent valve or weir) and wasted back to the source using the supernatant overflow or filter overflow drain. This condition represents the maximum head possible on the filter and operators should be careful not to exceed design flows or head conditions except during an emergency such as a fire.

4.824 Outlet Chamber

The function of the outlet chamber is to maintain at least three inches (8 cm) of water over the top of the sand bed during operation. This is necessary to prevent accidental dewatering



(a) Basic components of a slow sand filter with influent flow control and rising water level.



(b) Basic components of a slow sand filter with effluent flow control.

Fig. 4.23 Influent and effluent flow control

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and drying of the filter. It also prevents air from entering and becoming trapped in the media (air binding), a condition that will cause serious operational problems.

An adjustable weir (see Figure 4.23) on the outlet chamber can be raised at the start of the filter run so that the weir crest (tailwater elevation) is about one foot (0.3 m) higher than the surface of the media. As the filter run progresses and filtered material builds up on and in the media, head loss through the filter will gradually increase. As head loss increases, the weir can be lowered gradually until head loss across the sand bed is greater than one foot (0.3 m) and the weir crest is at or slightly above the level of the sand bed surface. Maintaining the tailwater elevation at this level will ensure the sand media is always covered with water, even if the influent flow is interrupted.

If flow measurement is desired, a hook gauge can be installed to measure the depth of water flowing over the weir crest. Tables and formulas are available to convert the flow depth to a flow rate in gallons per minute (GPM). The weir should be considered an auxiliary flowmeter and not a substitute for conventional flowmeters.

4.825 Finished Water Holding Facility

The size of the finished water storage facility is based on capacity needed to provide detention time for disinfection, meet peak daily demand and fire protection requirements, and provide emergency reserves expected to be needed in case of power outages or other disruptions in water production. The capability to store enough water to equalize flows over a period of time is very important to the operation of a filter. Slow sand filters operate most efficiently at a steady flow rate; frequent or abrupt changes in flow rate can disrupt the process and may cause a reduction in water quality. A storage capacity equal to 12 hours' production (or more) of finished water would be appropriate at a slow sand filter plant.

Selecting a point of application for disinfection requires consideration of a number of factors. If disinfectant (usually chlorine) is applied before the finished water enters the storage tank, any excess water wasted from the tank will contain chlorine. Chlorinated water can harm wildlife and vegetation and should not be returned to the source water stream or reservoir. Therefore, safe disposal of the chlorinated water may be a problem. At some plants a clear well has been installed between the filter and the storage facility. Water is chlorinated after it leaves the clear well. This permits excess water to be wasted from the clear well before it is chlorinated.

If installing an additional clear well is not feasible, another way to avoid wasting chlorinated water is to apply chlorine as water leaves the storage facility and enters the distribution system. With this arrangement, it is important to determine whether sufficient contact time can be provided as water flows through the distribution system. Also, flow past the disinfection equipment will vary with demand so the chlorine must be applied at a rate proportional to the flow.

When calculating CT (Concentration of disinfectant × Contact Time) values (see Section 4.5 for details) to determine the efficiency of disinfection for *Giardia lamblia* inactivation, the time the water is in the holding facility is part of the contact time, T, if the disinfectant is applied before the finished water holding facility. If chlorine is applied as water enters the distribution system, contact time is measured from the point of application of the disinfectant to the point of use by the consumer.

4.826 Hydraulic Controls and Monitoring Devices

In addition to the flow control valves and weirs previously described, several other simple valves, meters, and devices are usually provided to control and monitor the filter operation. As illustrated in Figure 4.23, these devices include:

- Influent valve—used to isolate the filter for maintenance.
- Supernatant drain valve—permits the operator to adjust the level of water in the tank, if necessary, and to dewater the filter rapidly prior to cleaning.
- Filter overflow drain—prevents flooding of the facility if the filter suddenly clogs and the tank fills before the water is shut off.
- Filter bed drain—used to lower the water level below the sand surface prior to cleaning.
- Filter-to-waste valve—permits inadequately treated water to be returned to the influent line or otherwise disposed of during the ripening period after cleaning or resanding.
- Backfilling valve—used to fill a new or newly cleaned filter through the underdrain system.
- Treated water waste valve—permits disposal of excess finished water when stored supply exceeds demand.
- Valve to clear well—used to isolate filter during maintenance.
- Clear well overflow—(not shown in Figure 4.23) permits excess water (from continuous operation) to be sent back through the filter. Placement of the overflow line must not permit a cross connection through which unfiltered water could flow into the clear well and contaminate the finished water.
- Flowmeters—(1) may be installed in raw water intake lines to measure total plant inflow; (2) may be installed to measure flow into each filter tank or chamber to ensure uniform flow distribution and to measure the volumes of water filtered between cleanings; (3) are often installed between the underdrain manifold outlet and the finished water storage facility to measure total production; and (4) are sometimes installed at the clear well outlet to record the total volume of water delivered to the community. In some small plants, residential service meters are used to measure and record flows.

- Head loss gauges or piezometers—(not shown in Figure 4.23) installed on each filter unit of effluent-controlled filters to monitor the degree of clogging, which will indicate when the filter needs to be cleaned.
- Rate of flow indicators—(not shown in Figure 4.23) installed on each filter or chamber to indicate actual rate of filtration.
- Staff gauges—(not shown in Figure 4.23) may be permanently installed inside each filter cell to permit the operator to monitor the level of sand or water in the filters.
- Sight tubes—(not shown in Figure 4.23) sometimes installed in the filter tank or clear well to enable the operator to see the level of the supernatant in the filter or water in the clear well without removing the filter cover or opening the clear well.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 276.

4.8E The flow rate of water through a slow sand filter depends on what factors?

4.8F List the two methods of controlling flow through a slow sand filter.

4.8G What factors are considered to determine the size of the finished water storage facility?

4.8H What is the purpose of head loss gauges or piezometers on slow sand filters?

4.83 Typical Filter Operating Cycle

4.830 Start-Up

When placing a new filter in service or restarting a filter after cleaning, close all outlet valves and fill the tank from the bottom through the underdrain system. Use filtered water and fill slowly to permit air bubbles trapped in the sand to escape to the atmosphere. Continue filling the tank from the bottom until there is enough water (4 to 6 inches) over the sand surface to protect it from disturbance by the force of influent flow from the intake structure (a splash plate below the intake port will help prevent sand erosion by falling water). Once this shallow level of water covers the sand, slowly open the influent flow control valve and continue filling the tank with raw water until the desired supernatant operating level is reached (3 to 5 feet of water above the sand in an effluent-controlled filter).

A new filter, or one that has just been resanded, usually will not produce filtered water of acceptable quality immediately upon start-up. In most cases, the filter must be run continuously for a period of weeks or months before it becomes mature and achieves its full potential to remove turbidity, *Giardia*, and other microorganisms. New or resanded filters may produce acceptable turbidity levels (less than 0.1 NTU) during the ripening period shortly after start-up but usually are not capable of removing high levels of *Giardia* until the filter matures. Source water quality and temperature greatly influence the time required for a filter to mature. Operators should, therefore, rely on the results of turbidity and bacteriological tests to determine when filtered water meets the required standards.

A filter that is being started after scraping will ripen and produce acceptable water much more quickly than a new or resanded filter, often within a few hours or days. This is because only the schmutzdecke and a small amount of sand is removed. The media still contains a mature population of organisms that will quickly recover from the cleaning operation.

During the ripening period, the filtered water that is produced is drained to waste by means of a filter-to-waste valve located between the underdrain manifold and the finished water storage facility. When turbidity and bacteriological tests indicate that the water quality meets desired standards, the ripening period is over. A good target turbidity value is 0.1 NTU. The turbidity level of a filter that has just been cleaned or resanded should at least return to what it was before cleaning. The recommended bacteriological target level is less than 1 coliform per 100 *mL*. When the filter produces acceptable quality water, slowly close the drain-to-waste valve and then slowly open the effluent valve and permit the treated water to flow to storage.

4.831 Daily Operation

The actual day-to-day operation of a properly designed slow sand filter requires very little operator involvement. If the effluent-control design is used, the operator may need to adjust the effluent flow control valve or effluent weir every day or two to offset the slowly increasing resistance (head loss) of the developing filter skin (schmutzdecke). This procedure continues until the valve is fully open or the weir cannot be lowered any more and the desired filtration rate can no longer be maintained, or there is a decline in water quality.

If the filter flow rate is controlled at the influent, the operator must set the rate at start-up and no further adjustments are needed until it is time to shut down the filter for cleaning. For surface waters, a filter rate between 0.04 and 0.08 GPM/sq ft (2.5 and 5.0 MGD/acre) is usually satisfactory. This rate can be increased to a rate as high as 0.16 GPM/sq ft (10 MGD/acre) if necessary for brief periods but steady flow operation is a much safer operating strategy. The operator should occasionally check the flow rate to make sure the flow has not been restricted or increased due to an undetected malfunction of a valve or pump or a plugged water inlet.

An advantage of influent flow control is that the operator can see the effects of increasing head loss. As the schmutzdecke develops and trapped debris begins to accumulate at the filter skin, it offers greater resistance to the flow of water. Since raw water is flowing in at a fixed rate, the increasing resistance of the surface causes a visible increase in water level above the media. Under this situation, the water surface would have to be manually skimmed to remove scum and floatables when necessary because the supernatant overflow outlet could not be used. Also, there would be no excess flow to waste, as is sometimes necessary with effluent flow control of a filter.

Other routine daily operator duties include monitoring and recording influent flow, individual filter and total plant production, head loss as measured by headwater and tailwater elevations, and headwater temperature. The operator will also be responsible for collecting daily turbidity samples, inspecting the facility regularly, checking the operation of pumps or any other mechanical equipment and lubricating as necessary, checking the disinfection system, and measuring the disinfectant residual. The finished water storage facility will need to be inspected regularly and cleaned every year or two.

4.832 Cleaning the Filter Media

When head loss reaches the level at which the filter is no longer able to maintain the desired filtration rate, the filter must be shut down and cleaned. Two processes are commonly used to clean slow sand filters: scraping or raking. The goal is to remove the thin schmutzdecke and a small amount of sand just below it, usually totaling about 1 inch (2.5 cm) of material, so that water can once again penetrate the sand media.

The length of time a filter will operate between cleanings is highly variable from plant to plant, ranging from several weeks to several months. Cycle length depends on such factors as filtration rate, available head, media grain size distribution (uniformity coefficient), influent water turbidity, and water temperature. Head loss at the beginning of the filter run is usually about 4 inches (10 cm), but it slowly increases to whatever depth is permitted by the height of the filter box, usually no more than 6 feet (2 m). If the raw water is of exceptionally good quality, the filter could run for a year or more between cleanings. Filter operating cycles of less than six to eight weeks become uneconomical because of the high labor costs associated with frequent cleaning operations. Scraping a filter is a labor-intensive operation that accounts for a large portion of the operating costs of a filter. On the average, it takes about 4.2 person-hours to scrape 1,000 square feet (100 sq m) of surface area to remove a depth of 1 inch (2.5 cm) of sand.

Prior to cleaning the filter, some operators raise the supernatant level high enough to wash loose material such as leaves and other floating debris out of the filter through the overflow weir or valve. Next, the influent valve is closed and the tank water level is lowered 1 to 2 inches (2 to 5 cm) below the sand surface. Some operators favor rapid dewatering using both the supernatant drain and the waste valve on the underdrain. Others simply close the inlet valve and permit the level in the tank to drop of its own accord to the desired level. Using the slower draining method, it may take several hours for the water surface to drop below the schmutzdecke, but then the water drains rapidly due to lack of resistance from the schmutzdecke.

The filter surface can be scraped and the material removed manually using asphalt rakes, shovels, buckets, and wheelbarrows in small plants. Manual cleaning operations are usually manageable for filters up to about 2,000 square feet (200 sq m) surface area. The sand is scraped into low, parallel windrows (see Figure 4.24) and then shoveled into buckets or wheelbarrows and removed from the filter. The scraping operation should be carried out in a short time period to prevent drying of the media to minimize the impact of cleaning on the microorganisms in the remaining sand media. If it is necessary to return the filter to service quickly, the windrows may be left in place and removed during the next scraping.

Motorized equipment can also be used in the scraping operation. Garden tractors with dump-type carts, all-terrain vehicles, and lawn tractors with flotation tires have been used to remove and haul sand from the filter in small installations. Mechanized scrapers and dump trucks (Figure 4.25) are sometimes used in very large filter installations. The cleaning method to be used must be taken into account during the design of the filter to provide needed access ramps, drains, and adequate structural support.

After scraping has been completed, smooth the surface of the bed by raking or dragging a piece of metal mesh (cyclone fence) across the surface (Figure 4.26). To avoid the possibility of water short-circuiting through the filter at the walls, some operators gently tamp a six-inch strip around the edges of the tank.

Fill the filter through the underdrain system with water from an adjacent filter or from filtered water storage. Use the same procedures that were used for initial start-up, that is, fill slowly (less than 0.6 ft/hr) from the bottom until the sand is covered by several inches of water or water reaches the level of the influent distribution line. Complete the operation by filling to the desired supernatant level with raw influent water. Monitor the water produced by the newly cleaned filter and drain to waste until bacteriological or turbidity tests indicate the ripening period has ended and the filter is producing water of acceptable quality. As previously indicated, a typical turbidity target value

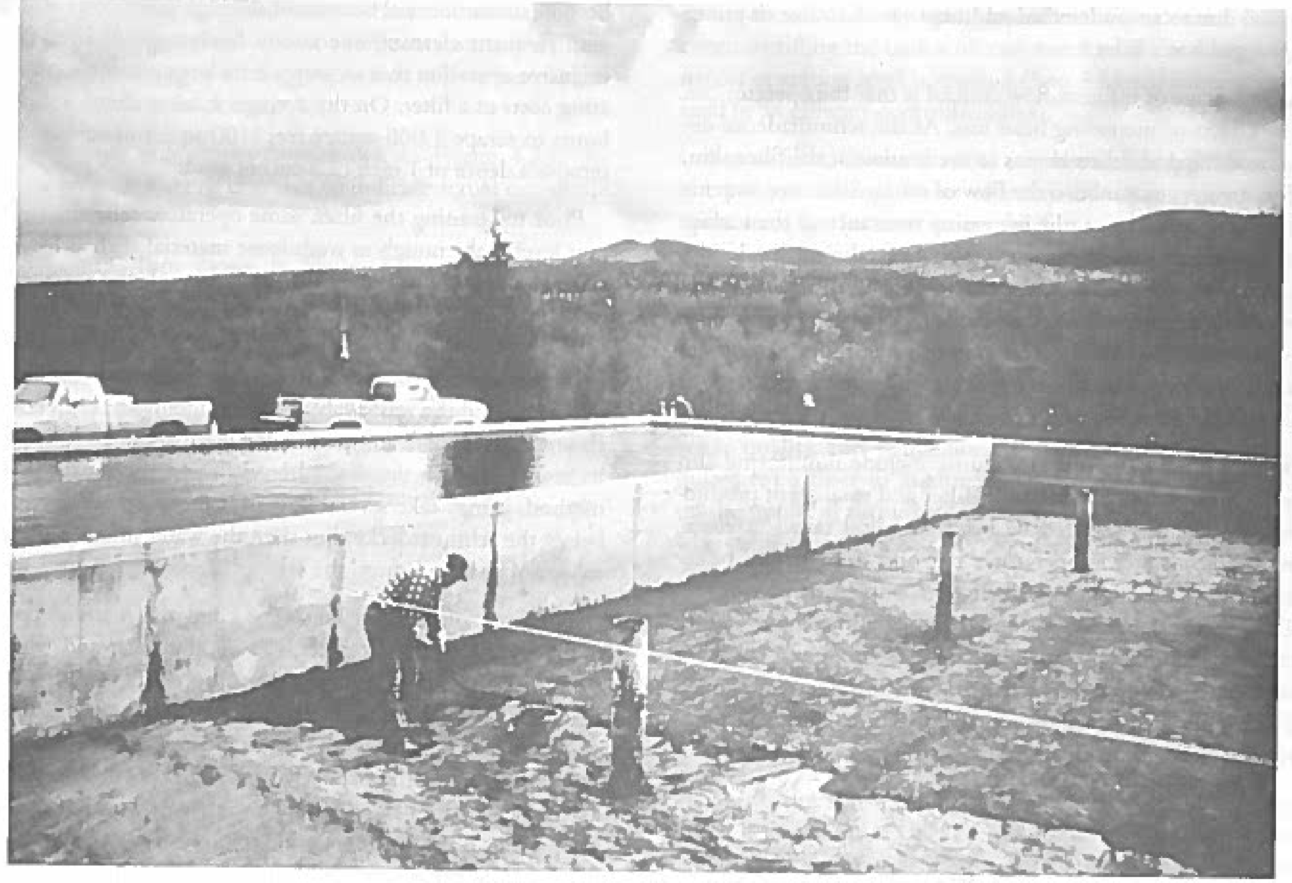


Fig. 4.24 Operator manually cleans filter by scraping schmutzdecke into parallel windrows for later removal and disposal

(Source: Wickiup Water District, Wickiup, OR)

is 0.1 NTU or the level at which the filter was operating prior to cleaning.

The period during which water is drained to waste is highly variable from plant to plant, but in all cases should be based on the quality of the finished water. Ripening periods of a few days to several weeks are very common. A typical target value for coliforms is less than 1 per 100 *mL*. Some operators simply establish a fixed period of time, usually 24 to 48 hours, during which water from the filter is drained to waste before the filter is placed in service. Use of a fixed period of time is advisable only after experience with a particular filter indicates consistently that water quality standards can be met within that time period.

A controversial process called "raking" is sometimes used to extend the filter run time between scrapings. In this process, an ordinary garden rake is used to disturb the surface of the filter and loosen the schmutzdecke so that water will again pass into the sand layer and be filtered. Some operators lower the water level below the sand surface before raking; others rake the surface while it is still covered with several inches of water. There are reports of a plant that used one to five rakings before the filter had to be shut down for scraping; each successive raking was less effective than the previous one in extending the filter cycle. Raking requires less labor than scraping so it can reduce costs, but there is some evidence that this procedure reduces finished water quality and drives waste material deeper into the media. The short-term savings on labor may thus be offset by the eventual need to remove a deeper layer of sand during scraping.

A less widely practiced cleaning method, wet-harrow cleaning, is used in a few locations as a substitute for scraping. Horizontal and sometimes vertical water streams are used to flush the raked deposits to a surface drain or overflow weir. Resanding is infrequent, but necessary when the depth of sand gets too low and filtered water quality starts to drop.

The process of scraping removes about an inch (2.5 cm) of filter media each time. Eventually, the sand must be replaced to restore the original media depth. The process of replacing filter media is called "resanding." In some installations, operators replace scraped sand with clean sand each time the filter is scraped. There is some evidence, however, that this practice causes a buildup of waste material at deeper layers of the media bed, which may cause repeated clogging and short filter runs. More typically, a filter is scraped until overall media depth has dropped 12 inches (30 cm), although for deeper beds, the drop may reach 24 inches (60 cm). Filter performance (particle removal efficiency) is affected by filter bed depth so the bed should never be scraped to less than 1.6 to 2 feet (0.5 to 0.6 m).

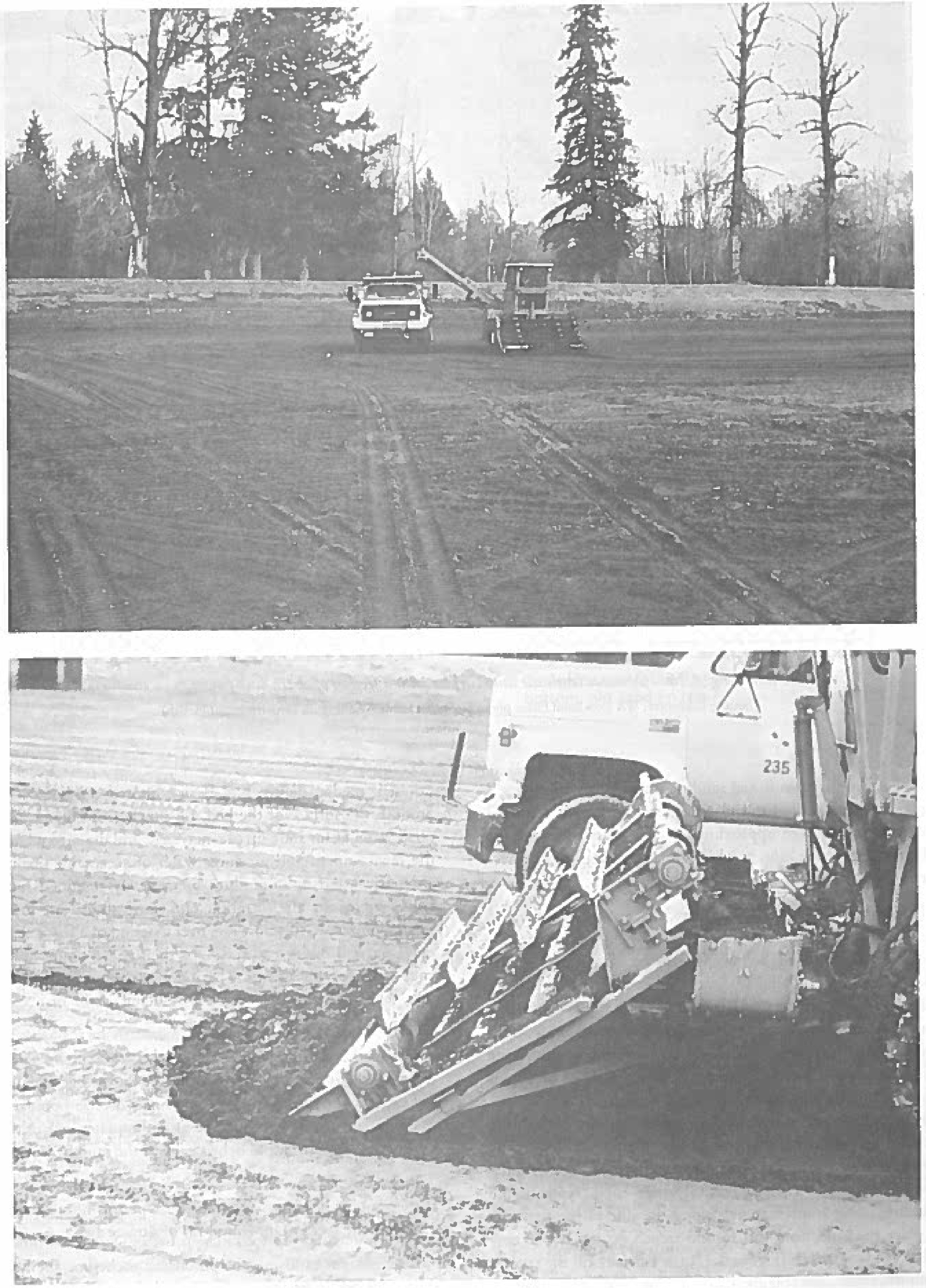


Fig. 4.25 Mechanical equipment used for cleaning a large slow sand filter

(Source: Salem, OR Water/Wastewater District)

Fig. 4.26 Operator levels the sand surface with a section of chain-link fencing
(Source: Cashmere, WA Slow Sand Filter, photo by Steve Deems, Washington Department of Health)

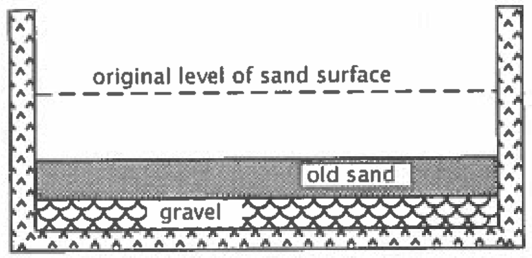
Thus, if a filter with an initial sand depth of 30 to 36 inches is scraped every two months and one inch (2.5 cm) is removed each time, it will take approximately two years to lower the media surface by one foot, at which time resanding will be necessary.

The most common technique used to resand a slow sand filter is called "throwing over," a process by which clean (new or recycled) sand is added below the existing sand to bring the media bed back to its original depth. This method is illustrated in Figure 4.27. To resand a filter, first clean (scrape) the media. Then, drain the filter until the water just covers the underdrain gravel support layer (Figure 4.27(a)). Dig a trench along one wall of the tank removing the old sand and placing it on top of the sand along the opposite wall (Figure 4.27(b)). Take care not to disturb or damage the gravel bed and underdrain piping. Fill a portion of the trench with new sand (Figure 4.27(c)). (The depth of the new sand layer can be calculated by the formula: Depth of New Sand = Original Bed Depth – Bed Depth Before Resanding.) Dig another trench along the side of the first one and place the sand from this second trench on top of the new sand in the first trench (Figure 4.27(d)). Partially fill the second trench with new sand (Figure 4.27(e)). Continue in this manner until all of the old sand has been moved to the surface and the original media depth has been restored (Figure 4.27(f)). Smooth the surface of the bed, fill slowly from below with filtered water as for start-up of a new bed, and drain to waste until the media ripens and produces water of acceptable quality. An alternative start-up procedure for a newly resanded filter involves increasing the filtration rate slowly from one-fourth of the design rate to full-flow rate over a period of a few weeks. Filtered water is drained to waste for the first 48 hours (if experience indicates that this time period is adequate) or until laboratory tests indicate the filter is producing water of acceptable quality.

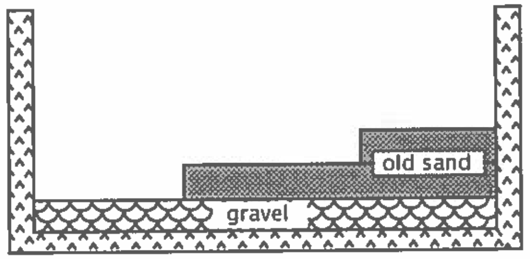
Use of the throwing-over technique is thought to minimize the time required for ripening of the resanded bed because the old sand in the top of the bed contains a diverse population of microorganisms. This procedure also eliminates any unwanted buildup of organisms and debris deep in the sand bed.

Resanding is approximately 10 times more labor-intensive than scraping. Typically, it takes 53 person-hours to resand 1,000 square feet (50 hr/100 sq m) of surface area.

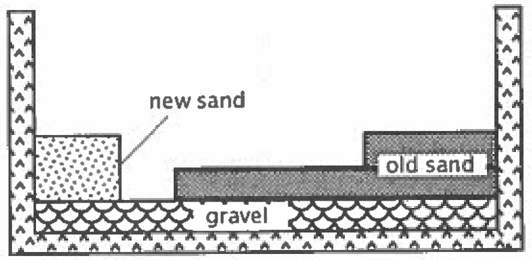
Replacement sand may be purchased each time the filter requires resanding or the sand removed during scraping and resanding operations can be washed and reused. The decision about which option to use depends mainly on economic considerations. Costs of purchasing new sand include the cost of the sand and transportation, and the cost of disposing of dirty sand when it is removed from the filters. (In one location, discarded sand is reportedly used for road sanding in the winter.) Purchasing new sand is an attractive option when clean sand of the correct grain size and uniformity is available locally.



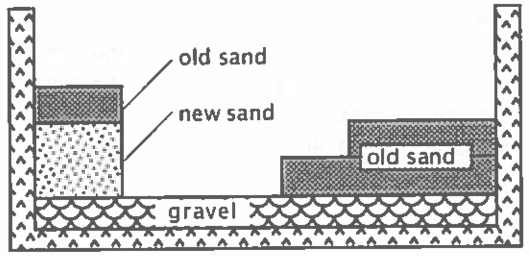
(a) Sand bed level before resanding



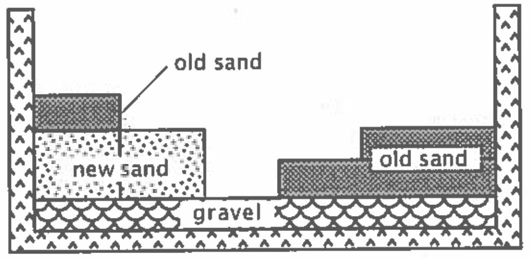
(b) Placement of old sand on old sand



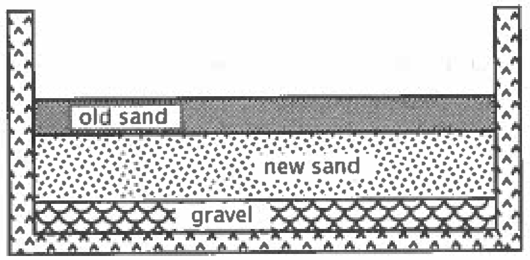
(c) Placement of new sand



(d) Placement of old sand on new sand



(e) Placement of additional new sand



(f) Completion of resanding with new sand on bottom, old sand on top

Fig. 4.27 Steps in resanding filter bed
(Adapted from *MANUAL OF DESIGN FOR SLOW SAND FILTRATION*, by permission. Copyright © 1991, American Water Works Association)

On the other hand, washing and reusing sand may be a less expensive option if new sand must be hauled a considerable distance, if the filter site can accommodate a sand-washing operation, and if there is adequate space to store the washed sand. The cost of labor to wash the sand must also be considered.

Purchased sand should be checked carefully to verify that it is clean and meets the desired specifications for size and uniformity. This precaution is particularly important when buying sand from a new source or resanding a filter with new sand that is different from the sand originally used for the filter.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 277.

4.8I How often will a finished water storage facility need to be cleaned?

4.8J When should a slow sand filter be taken out of service and the surface scraped or raked?

4.8K The time between slow sand filter cleanings depends on what factors?

4.8L What is an advantage of using the throwing-over process to resand a slow sand filter?

4.84 Preventive Maintenance

All mechanical equipment requires periodic inspection, lubrication, and adjustment to keep it functioning as intended. Even though slow sand filters are designed to minimize operator involvement, an established program of preventive maintenance is essential. Reprinted below (with permission) is the suggested general maintenance schedule for the water treatment facility operated by the City of Dover, Idaho.

1. *DAILY*
   a. Check all controls and panels for proper operation.
   b. Visually check all pumps, motors, and valves.
   c. Check turbidimeter and recorder.
   d. Check chlorinator and chlorine residual.
2. *WEEKLY*
   a. Wipe down all exposed machinery.
   b. Check operating supplies and order, if necessary.
   c. Lubricate equipment as necessary, per schedule.
   d. Operate all valves and gates; lubricate as necessary.
   e. Change turbidimeter charts.
   f. Mix and refill chlorine solution.
3. *MONTHLY*
   a. Inspect each pump and service as required.
   b. Inspect all safety equipment.
   c. Lubricate rotating equipment per manufacturer's schedule.
   d. Perform general cleanup.
4. *BIANNUALLY*
   a. Inspect intake pipeline.
   b. Calibrate turbidimeter.
5. *ANNUALLY*
   a. Paint equipment and building interiors and exteriors as required.
   b. Dismantle pumps, check impellers, shaft sleeves, shafts, and pump bowls, replace all worn equipment or parts.
   c. Have diver inspect intake structure.

HOUSEKEEPING

The appearance of a treatment facility is generally a good indication of the efficiency of the operator. An operator who takes pride in the appearance of the facility usually is also concerned with the efficient operation of the facility.

4.85 Troubleshooting

A properly designed and constructed slow sand filter should operate reliably with very little operator intervention. Alarm systems are usually installed to alert the operator to existing or developing problems. The following troubleshooting guide was adapted from a guide prepared by Ruen-Yeager & Associates, Inc., for the City of Dover Water Treatment Facility, Coeur D'Alene, Idaho, and is included here with permission of the City of Dover.

Indicator	Corrective Action
Slow Sand Filter Controls	
High water alarm	This alarm will not indicate unless overflow and drain are blocked. Clear the blockage.
Low water alarm	Filtration rate is greater than inflow rate. Decrease filtration rate and allow to restore.
Reservoir Controls	
High water alarm	Reservoir overflowing. Too much water being pumped to reservoir. Allow use to lower level.
Low water alarm	Use greater than supply. Increase filtration rate to pump more water. May indicate if fighting fire, which is OK.
Clear Well	
Low water alarm	Pumps are pumping level of clear well down too much. Pump control valve may be malfunctioning.
Intake Pumps	
No flow past flow switch	Check valve could be blocked, intake screen clogged. Clear blockage.
Booster Pumps	
Pump control valve not operating correctly	Valve at reservoir intake is closed; pump has a vapor lock.
Turbidimeter	
High turbidity alarm	Indicates an alarm if turbidity is greater than 1.0 NTU. Decrease filtration rate.

Air binding is a problem that sometimes occurs when slow sand filters are filled too quickly during start-up or after cleaning or resanding. If air binding is suspected to be the cause of a sudden drop in water production, try backing filtered water through the underdrain piping and up through the media. If the surface of the water in the filter looks bubbly like a soda bottle that has just been opened, air binding is probably the cause of the problem. To correct the problem, shut down and drain the filter. Then, using the underdrain system, fill the filter slowly enough to allow the trapped air bubbles to rise to the surface of the water and escape to the atmosphere.

4.86 Finished Water Standards

Most of the drinking water standards in the US establish contamination limits in terms of maximum contaminant levels (MCLs) for specific substances; they leave the choice of methods to achieve compliance to the discretion of the water supply or treatment agency. Departing from this regulatory approach, the Surface Water Treatment Rule (SWTR), promulgated in 1989, specifies the treatment techniques that are to be used as well as turbidity and microorganism removal rates. Compliance with the SWTR is measured in terms of how well the treatment plant is operated (removal efficiencies) as determined by laboratory testing of the source water and of the finished water.

The goal of the SWTR is to reduce the contamination of water supplies by disease-causing organisms, which are also called "pathogens." The protozoan *Giardia lamblia* is presently the organism most implicated in waterborne disease outbreaks in the United States. These microscopic creatures are found mainly in mountain streams, and have been found to be widespread in small community water systems. Once inside the body, they cause a painful and disabling illness called giardiasis. The symptoms of giardiasis are usually severe diarrhea, gas, cramps, nausea, vomiting, and fatigue. Another pathogen found in water supplies, the *legionella* bacterium, causes severe upper respiratory disease.

Viruses, *legionella* bacteria, *Giardia lamblia* cysts, and *Cryptosporidia* are all highly resistant organisms and are difficult and costly to detect. No single method presently available is effective in removing or inactivating all of the various types of pathogens that threaten public health. For this reason, the EPA requires most water suppliers to use a combination of treatment techniques (disinfection and filtration) to ensure the safety of drinking water delivered to the public. Disinfection is known to be effective in killing or inactivating bacteria and viruses, which are small enough to pass through most filters. Filtration is known to be effective in removing or inactivating cysts, which are extremely resistant to chemical disinfection methods. The combination of treatment techniques thus ensures removal of both the very smallest and the most resistant types of pathogens.

All public water systems (which may include some privately owned systems serving the public) using surface water or groundwater under the influence of surface water are required by the SWTR to disinfect the water they distribute to the public; no exceptions to this requirement are permitted. Compliance with this rule is confirmed by the presence of at least 0.2 mg/*L* disinfectant (chlorine) residual in the finished water and a detectable residual throughout the distribution system.

In addition to the disinfection requirements, water suppliers may be required to install filtration equipment unless the system can meet stringent guidelines concerning source water quality (turbidity and microbial population), watershed control, and backup disinfection capability. Slow sand filtration is one of the treatment techniques acceptable to the US Environmental Protection Agency for meeting the SWTR requirements. (Conventional filtration, diatomaceous earth filtration, and direct filtration are also acceptable treatment techniques and are described in Section 4.4, "Filtration.")

The SWTR's microbiological standards require that the combination of filtration and disinfection must achieve a 99.9 percent[31] reduction (by removal or inactivation) of *Giardia lamblia* cysts and a 99.99 percent reduction (by removal or inactivation) of viruses. Slow sand filters are particularly notable for their ability to remove *Giardia* cysts and have been shown to achieve the greater than 3-log removal level when the filter bed is mature. Even with new sand, *Giardia* removals remain high.

Since turbidity can interfere with the disinfection process, the SWTR also sets maximum allowable levels for turbidity. The filtration requirement for turbidity of finished water from a slow sand filter is less than one NTU in 95 percent of the samples taken and no sample may exceed 5 NTU, with monitoring to occur at least once per day. Higher effluent turbidity levels (up to 5 NTU) may be allowed by the EPA or state if it can be shown that the higher levels do not interfere with disinfection.

For a complete description of the Safe Drinking Water Act and Surface Water Treatment Rule provisions, see *WATER TREATMENT PLANT OPERATION,* Volume II, Chapter 22, "Drinking Water Regulations," in this series of operator training manuals and consult the poster provided with this manual.

4.87 Factors Affecting Filter Performance

The particle removal efficiency of a slow sand filter depends on many variables such as the hydraulic loading rate, temperature, sand bed depth, sand size, and filter bed maturity, and on interactions between and among these and other variables. Despite having been used since the early 1800s and despite many research efforts to pinpoint the relative importance of various factors, slow sand filtration is still not fully understood. Nonetheless, slow sand filtration has been shown to be an extremely effective, low-cost, low-tech way to remove bacteria, viruses, cysts, spores, silt, and most other suspended organic and inorganic particles from drinking water. However, it is less effective in removing dissolved organic materials and fine clay particles.

Many of the variables that affect filter performance have been described in earlier portions of this section. The following paragraphs describe the effects of raw water quality, cyclic influences, mode of operation, and hydraulic loading rates on slow sand filter performance.

4.870 Source Water Quality

In the most general terms, supported by surveys of operating plants, water with turbidity levels below 10 NTU may be suitable for slow sand filtration. However, it is impossible to predict

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[31] Percentages are often referred to using logarithm (log) numbers. Throughout the SWTR, reduction goals are expressed this way. It is easy to translate percentages into log numbers. Start with 90, and just add nines: 90 is one-log; 99 is two-log; 99.9 is three-log; 99.99 is four-log, and so forth. In this way, log numbers are a form of shorthand. It is much easier to say "three-log" than "99.9 percent." (Footnote from "Surface Water Treatment: The New Rules," by Harry Von Huben, *OPFLOW,* Volume 16, No. 11, November 1990, by permission of the American Water Works Association. Copyright © 1990 by American Water Works Association.)

how well this process will work based solely on turbidity measurements. Finely divided clay particles may not be removed effectively by slow sand filters. Pilot studies should be conducted to assess how well a slow sand filter removes microorganisms and particulate matter from a particular source of water, determine the length of filter runs, and determine the washout time of the new sand.

Ideally, a slow sand filter will produce acceptable quality water for at least a month between cleanings with little operator involvement except for daily monitoring, adjustment, and sampling. Cycle length is, of course, directly related to the buildup of filtered material on the schmutzdecke. The mix of filterable mineral sediments, organic detritus, bacteria, cysts, spores, and a variety of other microorganisms varies widely from source to source. Raw water turbidity measurements do not reliably predict either the rate of filtered particle buildup and resulting head loss that will occur or the microorganism removal rates that can be expected. However, raw water turbidity can serve as a very general starting point for those considering the use of a slow sand filtration system.

4.871 Cyclic Influences

Most slow sand filters are used to purify surface waters, which, by their nature, are subject to the seasonal effects of climate changes. For example, during periods of rainfall, the flow of runoff into rivers and streams may temporarily raise turbidity levels as high as 30 to 50 NTU, occasionally peaking at 1,000 NTU. Such an excessive solids load will quickly clog (blind) the filter media and the filter will have to be cleaned. If high turbidity conditions occur infrequently, the cost and inconvenience of extra scrapings may not be excessive. If high turbidity is more than an occasional problem, installing a settling basin or a sedimentation basin in advance of the filter may reduce turbidity levels enough to permit normal operation of the slow sand filter. If the turbidity is mainly clay, a gravel roughing filter (Figure 4.28) would be more effective than a sedimentation basin. However, installation of additional equipment such as sedimentation basins runs counter to one of the basic aims of slow sand filtration, which is keeping the process simple and inexpensive, with low labor requirements.

Seasonal changes in water temperature and the amount of solar radiation also affect filter performance. Temperature controls the physical viscosity of water and the rate of biological activity. Several studies of particle removal efficiencies in cold water compared to warm water have shown consistently better removal rates in warmer water. The temperature of the filter influent is largely beyond the control of the operator once a plant is built. If low water temperature is anticipated during the design phase, especially if nutrient levels are also low, consideration might be given to alternatives such as below-ground construction or installation of a cover or other enclosure.

Seasonal changes in the amount of solar radiation affect algal growth in the headwater (supernatant) as well as within and immediately below the schmutzdecke in uncovered filters. Under favorable conditions (temperature, nutrients, solar radiation), algae multiply rapidly and algal blooms can occur, causing serious operating problems. Apart from consuming some nutrients, algae do not contribute to the treatment that occurs in a mature sand filter. The decay of algae in the filter skin can impart unpleasant tastes and odors in the filtered water. Also, as algae build up at the surface of the media, head loss will increase rapidly. A roof over the filter or some other form of shading such as shade cloth has been shown to improve filter run lengths in filters experiencing only occasional algal blooms. When algal populations are more consistent, however, shading the filter has produced mixed results and no clear recommendation on the use of shading has emerged from field studies.

Another cyclic factor, diurnal (day/night) fluctuations in solar radiation, also affects the organisms in a slow sand filter, especially if the filter is shut down at night. During daylight hours, algae in the headwater and sand media produce oxygen; at night they consume oxygen. All other organisms in the filter consume oxygen at all times, day and night. Therefore, during daylight hours, the dissolved oxygen level in the water rises slightly and then drops off at night. If the filter is shut down overnight or operated at very low filtration rates, dissolved oxygen levels drop and there is a possibility of totally depleting the dissolved oxygen. The somewhat longer contact time that accompanies low filtration rates can lead to *ANAEROBIC*[32] conditions and the resulting severe water quality problems. If anaerobic conditions develop, water turns black, gives off foul odors, and has a greatly increased chlorine demand.

Resanding a filter can be considered a cyclic influence on filter performance because it disrupts the balance of microorganisms in a mature filter bed and disturbs the established biofilm. Dewatering the filter for more than a few hours, which might be necessary when resanding medium to large filters, destabilizes the microbial population, which will then require time to become reestablished. Additionally, if the new sand added to the bed has not been properly washed to remove organic material, clay, and dirt, turbidity increases in the finished water can be expected to occur while this material washes out of the filter.

One might think that periodic scraping of the filter media would also cause a temporary decrease in filter performance, but removal rates usually are not significantly affected if the sand bed is mature. Field studies in this area suggest that disturbance of the lower layers of the media bed and dewatering of the filter during scraping are more significant factors in reduced removal rates than the removal of the schmutzdecke.

4.872 Mode of Operation

Slow sand filters operate most reliably under continuous steady-flow conditions. If the raw water supply is intermittent or uneven, a flow equalization tank can be installed ahead of the filter to dampen fluctuations in the supply to the filter. Intermittent filter operation should be avoided because it has been shown to reduce the bacteriological quality of the finished water within 4 to 5 hours after the filter is restarted.

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[32] *Anaerobic* (AN-air-O-bick). A condition in which atmospheric or dissolved oxygen (DO) is *NOT* present in the aquatic (water) environment.

Fig. 4.28 Gravel roughing filters

As previously described, shutting a filter down overnight poses the risk of developing anaerobic conditions; this is a practice that should be avoided. To reduce production without dropping the filtration rate so low as to cause oxygen depletion, some operators of effluent-controlled filters close off the influent water supply at night (or at other times during the day) and let the filter continue to operate under a declining head of water. Declining rate filtration reportedly produces almost the same quality of finished water as full rate filtration but there is less risk of creating anaerobic conditions in the filter. The dissolved oxygen level that usually signals declining *AEROBIC*[33] bacterial activity due to oxygen starvation is approximately 0.5 mg/*L*.

To ensure that a filter operating in a declining flow rate mode does not run dry (dewater) while operating unattended, the effluent from the filter should be adjusted to empty into the outlet chamber at a level slightly higher than the top of the sand bed.

4.873 Hydraulic Loading Rate

Slow sand filters are operated at hydraulic loading rates from 0.016 GPM/sq ft up to a maximum of 0.16 GPM/sq ft (1 to 10 MGD/acre or 0.04 to 0.4 m/hr). Rates from 0.04 to 0.08 GPM/sq ft (2.5 to 5.0 MGD/acre or 0.1 to 0.2 m/hr) are typical. The rate may vary slightly from season to season, but the daily rate should be steady. Occasional increases in hydraulic loading rates can be tolerated for short periods (for example, to compensate when another filter is shut down for cleaning), but abrupt changes should be avoided.

Field studies have demonstrated that increasing the hydraulic loading rate of a slow sand filter reduces the percent removals of *Giardia* cysts, total coliform bacteria, fecal coliform bacteria, and standard plate count bacteria. However, removals were still high with a hydraulic loading rate of 0.16 GPM/ sq ft (10 MGD/acre or 0.40 m/hr).

4.874 Calculation of Hydraulic Loading Rate

Hydraulic loading rates (filtration rates) on slow sand filters may be reported in terms of:

1. Gallons per minute per square foot (GPM/sq ft)
2. Million gallons per day per acre (MGD/ac)
3. Feet of water fall or drop per hour (ft/hr) or cubic feet of water per hour per square foot of filter surface area (cu ft/hr/sq ft)

EXAMPLE 15

A flow of 20 GPM is applied to a slow sand filter 20 feet long and 20 feet wide. Calculate the hydraulic loading in (1) GPM/sq ft, (2) MGD/ac, and (3) ft/hr.

Known	Unknown
Length, ft = 20 ft	Hydraulic Loading Rate, 1. GPM/sq ft 2. MGD/ac 3. ft/hr
Width, ft = 20 ft	
Flow, GPM = 20 GPM	

1. Calculate the filter surface area in square feet.

$$\begin{aligned}\text{Surface Area, sq ft} &= (\text{Length, ft})(\text{Width, ft})\\ &= (20\text{ ft})(20\text{ ft})\\ &= 400\text{ sq ft}\end{aligned}$$

2. Convert the flow from GPM to MGD.

$$\begin{aligned}\text{Flow, MGD} &= \frac{\text{Flow, GPM}}{694\text{ GPM/MGD}}\\ &= \frac{20\text{ GPM}}{694\text{ GPM/MGD}}\\ &= 0.0288\text{ MGD}\end{aligned}$$

3. Calculate the hydraulic loading rate in gallons per minute per square foot of surface area.

$$\begin{aligned}\begin{array}{c}\text{Hydraulic Loading}\\ \text{Rate, GPM/sq ft}\end{array} &= \frac{\text{Flow, GPM}}{\text{Surface Area, sq ft}}\\ &= \frac{20\text{ GPM}}{400\text{ sq ft}}\\ &= 0.05\text{ GPM/sq ft}\end{aligned}$$

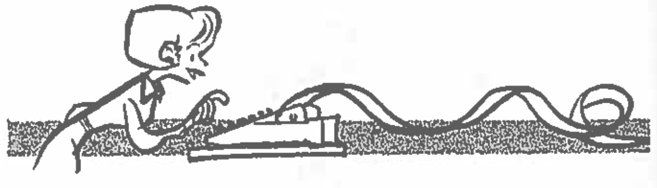
4. Calculate the hydraulic loading rate in million gallons per day per acre of surface area.

$$\begin{aligned}\begin{array}{c}\text{Hydraulic Loading}\\ \text{Rate, MGD/ac}\end{array} &= \frac{(\text{Flow, MGD})(43{,}560\text{ sq ft/acre})}{\text{Surface Area, sq ft}}\\ &= \frac{(0.0288\text{ MGD})(43{,}560\text{ sq ft/acre})}{400\text{ sq ft}}\\ &= 3.14\text{ MGD/ac}\end{aligned}$$

5. Calculate the hydraulic loading rate in feet per hour.

$$\begin{aligned}\begin{array}{c}\text{Hydraulic Loading}\\ \text{Rate, ft/hr}\end{array} &= \frac{(\text{Flow, GPM})(60\text{ min/hr})}{(\text{Surface Area, sq ft})(7.48\text{ gal/cu ft})}\\ &= \frac{(20\text{ GPM})(60\text{ min/hr})}{(400\text{ sq ft})(7.48\text{ gal/cu ft})}\\ &= 0.4\text{ ft/hr}\end{aligned}$$

In this formula, Flow, GPM, is divided by 7.48 gal/cu ft to convert flow to cubic feet per minute. Dividing flow in cubic feet per minute by Surface Area, sq ft, gives feet per minute, and multiplying by 60 min/hr gives feet per hour.



4.88 Recordkeeping

Accurate, up-to-date records that are easily accessible are very important to the proper operation of a water filtration facility.

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[33] *Aerobic* (air-O-bick). A condition in which atmospheric or dissolved oxygen is present in the aquatic (water) environment.

Good records provide a history of past operation and are legal proof of the performance of the facility. Equipment maintenance records that document the performance and repair history of each component are valuable resources for locating and solving operational problems. Accurate water production and cost records enable the plant administrator to prepare realistic budgets and make informed decisions about expenditures.

Recordkeeping does not need to be a complicated, time-consuming activity for the operator of a slow sand filtration system. Only three basic types of records are necessary: the operator's daily diary, maintenance records, and sampling and monitoring records (Figure 4.29). Information that should be recorded in the operator's daily diary includes equipment repairs, preventive maintenance performed, unusual operating conditions, and all sampling or tests performed. Each entry should indicate the name of the operator as well as the date and time the activity was performed.

The length of time records must be kept depends on the type of record. Maintenance records should be kept at least as long as the equipment is in use and longer if there is a specific reason for keeping them. Federal and state laws govern how long sampling records and laboratory analyses must be retained. Requirements for storage of records vary from state to state and operators are advised to check with their regulatory agencies for exact requirements.

4.89 Process Modifications

The simplicity, effectiveness, and low cost of slow sand filtration is well documented. A variety of modifications have been tried in an effort to adapt the process to less than ideal operating conditions and to extend the range of source waters that can be treated by this process. For example, certain types of roughing filters installed ahead of the filters have reduced raw water suspended solids enough to permit successful treatment by slow sand filtration. Nutrients (primarily nitrate and phosphate) were added to the raw water at one plant to shorten the ripening period of a filter treating low-temperature, nutrient-poor, mountain stream water. Sources of additional information about these and other process modifications are listed in Section 4.15, "Additional Reading," at the end of this chapter.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 277.

4.8M How is compliance with the Surface Water Treatment Rule (SWTR) confirmed with regard to disinfection?

4.8N What information can be obtained from pilot studies regarding the performance of slow sand filters?

4.8O What can happen to water quality if anaerobic conditions develop?

4.8P What types of records should be kept at a slow sand filtration plant?

4.8Q Why were nutrients added to the raw water at one slow sand filter plant?

4.810 Summit Lake Slow Sand Filter

This section is presented to illustrate some of the operating considerations at an existing slow sand filter plant. Figure 4.30 shows the layout of the small filter unit installed in 1981 at Summit Lake, Lassen National Park, California.

CONSTRUCTION FEATURES

The filter structure was built with steel-reinforced concrete and the control house at the effluent end of the structure was built of concrete blocks. Some excavation was needed to situate the tanks below the ground surface yet provide easy access to the effluent end of the filter (see Figure 4.31(a)). Wood framing supports the easily removable roof panels. The stilling well at the influent end of each filter measures 3.5 feet by 4 feet, each filter cell measures 8.5 feet by 4 feet, and sidewall depth is 5.5 feet.

The filter media is Monterey sand, which is purchased in 100-pound sacks from a vendor in nearby Redding, California. The depth of the sand media is 3 feet 4 inches, effective size is 0.20 to 0.40 millimeters, and uniformity coefficient is 2.0 to 3.0.

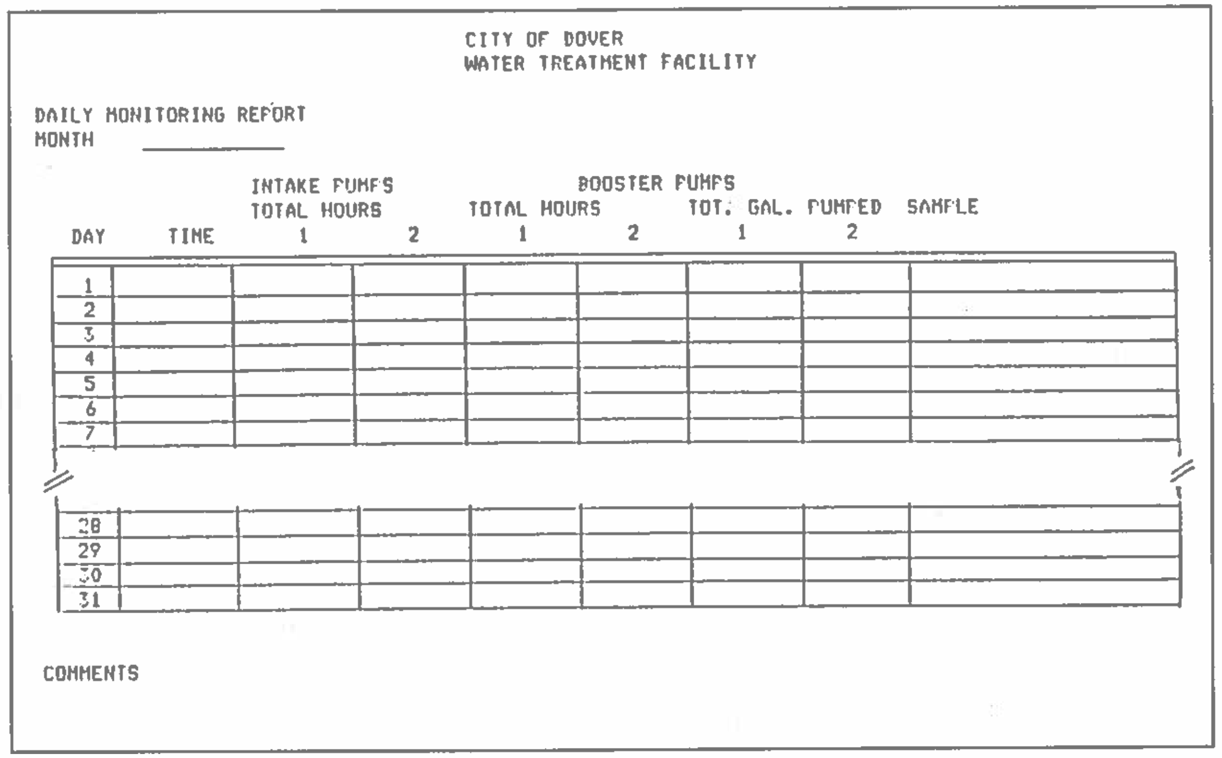
Beneath the sand media, a 10-inch deep bed of gravel surrounds and covers the 1½-inch perforated PVC underdrain piping. However, the gravel support layer does not entirely cover the bottom of the tank. When the filter was constructed, a one-foot wide band of media sand was placed along the walls and then four layers of gravel graded by size were used to cover the underdrain piping in the center of the tank floor. The purpose of this arrangement was to prevent water from short-circuiting along the walls of the filter. Gravel sizes range from ⅛- to ¼-inch at the top to ¾- to 1½-inch at the bottom.

PVC piping, brass gate valves, and standard residential water meters are used to channel, control, and record flow into and out of the filters. The inlet control valves are located in underground vaults (Figure 4.31(b)) constructed several feet from the main structure.

START-UP

In early May, operators prepare to start the filtration plant by cleaning the finished water storage tank, checking all valves for proper operation, checking the disinfection equipment and supplies, and performing any necessary maintenance. When all equipment has been checked and made ready, the operator begins filling the filter.

The usual procedure for filling filter cells is to fill slowly through the underdrain with finished water until the surface of the media is covered by a few inches of water and then open the inlet valve to finish filling with supply water. In most slow sand filter installations, an adjustable weir in the outlet structure can be used to control tailwater elevation (and thus maintain headwater elevation) until water covers the surface of the media. Because both source water and finished water flow by gravity at the Summit Lake plant, operators there encountered problems filling the filters with finished water by means of the underdrain piping. The finished water storage tank is located about one-quarter of a

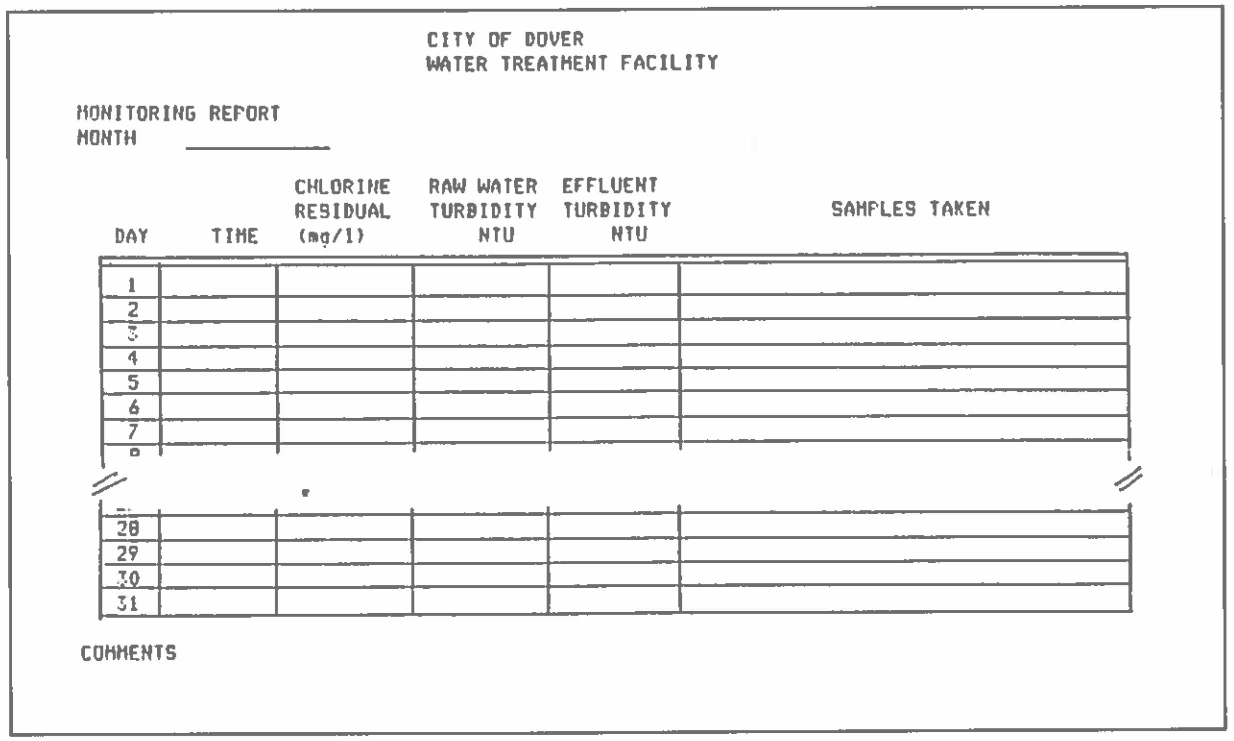


CITY OF DOVER
WATER TREATMENT FACILITY

DAILY MONITORING REPORT
MONTH ________

DAY	TIME	INTAKE PUMPS TOTAL HOURS		BOOSTER PUMPS TOTAL HOURS		BOOSTER PUMPS TOT. GAL. PUMPED		SAMPLE
		1	2	1	2	1	2	
1								
2								
3								
4								
5								
6								
7								
28								
29								
30								
31								

COMMENTS



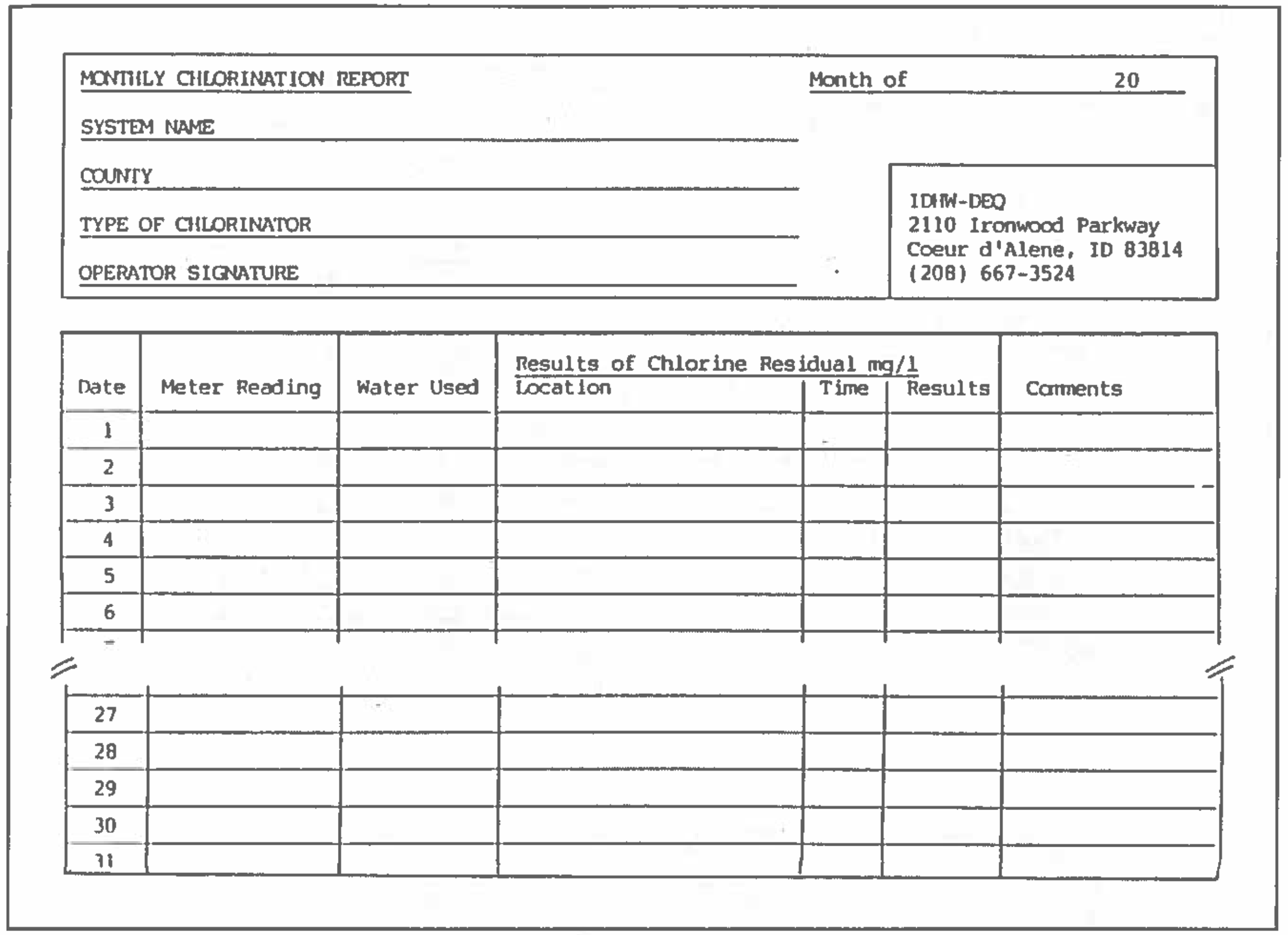
CITY OF DOVER
WATER TREATMENT FACILITY

MONITORING REPORT
MONTH ________

DAY	TIME	CHLORINE RESIDUAL (mg/l)	RAW WATER TURBIDITY NTU	EFFLUENT TURBIDITY NTU	SAMPLES TAKEN
1					
2					
3					
4					
5					
6					
7					
28					
29					
30					
31					

COMMENTS

Fig. 4.29 Daily and monthly monitoring report forms for a slow sand filtration plant
(Source: *OPERATION AND MAINTENANCE MANUAL FOR THE CITY OF DOVER WATER TREATMENT FACILITIES*, reprinted with permission of the City of Dover, ID)



MONTHLY CHLORINATION REPORT — Month of ______________ 20 ____
SYSTEM NAME ______________
COUNTY ______________
TYPE OF CHLORINATOR ______________
OPERATOR SIGNATURE ______________

IDHW-DEQ
2110 Ironwood Parkway
Coeur d'Alene, ID 83814
(208) 667-3524

Date	Meter Reading	Water Used	Results of Chlorine Residual mg/l Location	Time	Results	Comments
1						
2						
3						
4						
5						
6						
27						
28						
29						
30						
31						

Fig. 4.29 Daily and monthly monitoring report forms for a slow sand filtration plant (continued)
(Source: *OPERATION AND MAINTENANCE MANUAL FOR THE CITY OF DOVER WATER TREATMENT FACILITIES*, reprinted with permission of the City of Dover, ID)

mile below the slow sand filter so the operators had no way to fill the filter cell using the underdrain except by filling from the other cell next to it. When they tried to do this, however, air entered the underdrain piping and then became trapped in the finished water line to the storage tank when the cell was put back in service after filling the other cell. The operators found that the problems caused by air trapped in the gravity line to the storage tank were more difficult to correct than the relatively minor problems caused by filling the cells with supply water without disturbing the sand surface. The plant has not experienced any adverse effects in either turbidity or coliform levels using this method, but the process of filling the filter cells would be much easier if an outlet chamber with adjustable weir to control tailwater elevation had been installed when the plant was built.

When the headwater level reaches approximately 16 inches, flow through the filter is established by opening the filter-to-waste drain. Filtered water is wasted back to the creek for 24 hours and is then routed to the finished water storage tank. During this relatively short wasting period, some ripening of the media takes place, but the filter does not fully mature until late in the summer due largely to the very cold source water. Nonetheless, the plant is able to produce water that meets turbidity and bacteriological standards because of the high quality of the raw water.

OPERATION

The Summit Lake water treatment plant supplies water to Lassen Park visitors at the Summit Lake Campground during the summer season, usually from mid-May through October. At the end of the season, the filter is cleaned and shut down for the winter.

Source water of relatively high quality (0.10 to 0.15 NTUs, low in organic matter) flows to the filter by gravity from above

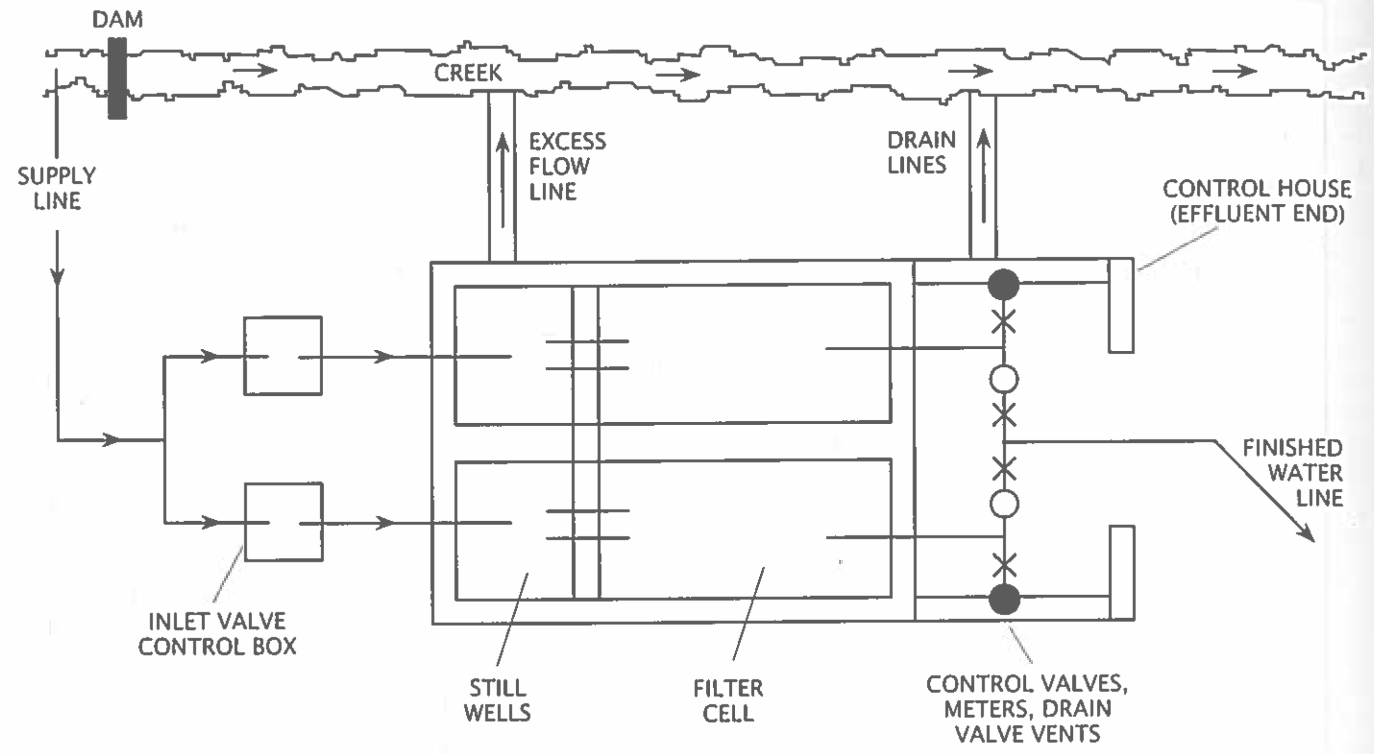


Fig. 4.30 Layout of the slow sand filter at Summit Lake, Lassen National Park, California

the dam on a creek approximately 100 feet above the filter (Figure 4.30). Water is fed continuously at a rate of 7.0 GPM. The supernatant level is maintained at about 16 inches above the sand surface and any excess influent is wasted from the surface of the supernatant in each cell back to the creek.

Filtered water flow is controlled by ¾-inch (gate) valves (Figures 4.32 and 4.33) on the filter effluent lines. When cells are placed in service, the operator opens the gate valves enough to establish the correct flow rate and head loss across the filters. Each day, the operator checks the flowmeters. If the readings indicate that less than the desired amount of water was produced the previous day, the operator opens the effluent valve another half turn. Filtered water flow can be controlled in this manner for approximately two months until head loss readings signal the need to clean the filter.

Finished water flows by gravity from the filter to a storage facility located approximately one-quarter of a mile away. The storage tank is a 10,000-gallon steel tank with a girdered ceiling. As filtered water flows to the tank, sodium hypochlorite is applied for disinfection at a point 30 feet upstream of the storage tank.

Operation of the Summit Lake filter requires very little operator time. An operator visits the facility daily to check and adjust the effluent control valves and chlorination equipment, if necessary. The operator also checks turbidity levels and disinfectant residuals daily and, as necessary, collects samples for coliform analysis by a laboratory in a nearby city.

FILTER CLEANING

The Summit Lake filter operates for about eight weeks between cleanings. When cleaning is necessary, both cells are scraped at the same time since the total surface area is small enough to complete the task in a short time. At this facility, the filters are always cleaned by scraping rather than by raking (which is used at some other plants) in order to avoid the possibility of driving particulate material deeper into the sand bed.

The operator first removes the roof panels and then shuts off the supply water. The filter is allowed to drain until the water level drops to about one foot below the sand surface, just far enough that the sand will support the weight of an operator. When water reaches the correct level, the operator closes the effluent or outlet valves.

Standing in the center of the filter, an operator uses a flat-edged shovel to remove approximately one inch of material from the surface of the media bed. The operators at Summit Lake

(a) Effluent end of filter outside the valve meter area.

(b) Inlet valve boxes (lower right) and cover over filter with two panels opened.

Fig. 4.31 Exterior views of the slow sand filter at Summit Lake, Lassen National Park, California

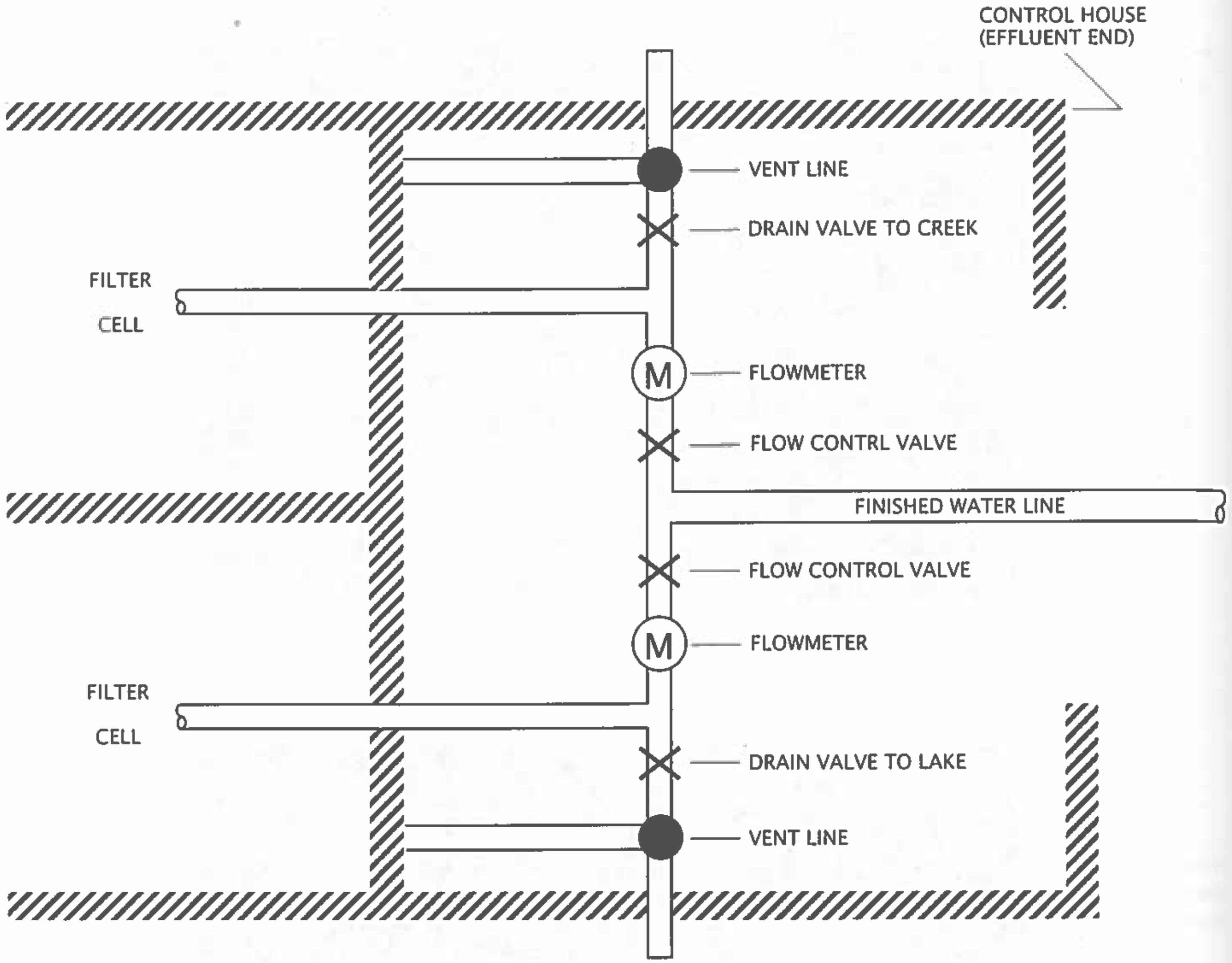


Fig. 4.32 Layout of meters, valves, and vents at effluent end of the Summit Lake filter

report that as the mat begins to dry, it starts to curl away from the sand surface, making it easier to remove. The sand and waste material scraped from the filter is shoveled onto the ground outside the filter. It is later bagged up and hauled to a nearby wastewater treatment plant where it is added to the mounds used for treated wastewater disposal. After scraping the surfaces of both cells, the operator uses a rake to level the surface of the sand. The total cleaning time for one operator is about 30 minutes.

After scraping has been completed, the cells are slowly filled with supply water until the surface of the bed is covered. The inlet valve is then opened to flood the cell to operating depth. When the water reaches a level about one foot above the media surface, the outlet valve is slowly opened to reestablish flow across the filter. Filtered water flows to waste for one hour and then is routed to the finished water storage facility. Samples are collected and tested for coliform and turbidity levels. Experience at this plant has demonstrated that the unusually short (one-hour) filter-to-waste period is a sufficient amount of time for the filtered water quality to return to the levels achieved before cleaning.

SHUTDOWN

At the end of the summer season, the Summit Lake slow sand filter is shut down and scraped in the usual manner. A permanent metal staff gauge mounted on an inside wall of each filter permits the operator to easily monitor the depth of the sand bed. In 12 years of operation, new sand was added once to restore the filter media to design depth.

The filtered water storage tank is drained and cleaned at the end of each operating season to prevent freezing.

4.811 Acknowledgment

We wish to thank John Brady, Steve Tanner, Sig Hansen, Graham Dobson, and Mike Lafkas for their review of this material and helpful suggestions.

1. Finished water line in center.
2. Flow control valves for each cell.
3. Flowmeters for each cell.
4. Drain valves and vent lines for each cell.

Fig. 4.33 Effluent meters and valves

4.9 IRON AND MANGANESE CONTROL

Excessive iron and manganese in drinking waters are objectionable because they stain clothes and encourage the growth of iron bacteria. These bacteria form thick slimes on the walls of pipes. When these slimes break away from the pipes, the iron causes a rust-colored water and the manganese produces black particles. These slimes also impart foul tastes and odors to the water. For these reasons, iron should not exceed 0.3 mg/*L* and manganese 0.05 mg/*L* in drinking waters.

If a new well is drilled and excessive amounts of iron or manganese are discovered, the best solution may be to drill a new well. Consult with well drillers in the area and also collect and analyze samples from nearby wells. Discuss your situation with the state agency responsible for the regulation of well drilling. Sometimes, a new well is cheaper and a lot less trouble than trying to control or remove iron and manganese. In many areas, a new well will produce water with just as much iron and manganese. Surface waters also may contain excessive amounts of iron and manganese, especially when you have small, shallow reservoirs. Usually, manganese is more of a problem than iron.

If the water contains less than 1.0 mg/*L* iron and less than 0.3 mg/*L* manganese, the use of polyphosphates followed by chlorination can be effective and inexpensive. Any of the three polyphosphates (pyrophosphate, tripolyphosphate, or metaphosphate) can be used, but sodium metaphosphate usually requires a lower dosage than the others.

To determine the best polyphosphate, prepare a series of samples with varying concentrations of polyphosphate. Stir to ensure that the polyphosphate is well mixed. Add enough chlorine to produce a chlorine residual of 0.25 mg/*L* after a five-minute contact time period. Be sure the samples are well mixed. Observe the samples daily against a white background, recording the amount of discoloration. The proper polyphosphate dose is the lowest dose that delays noticeable discoloration for a period of four days.

The addition of either chlorine or potassium permanganate will oxidize iron and manganese to insoluble precipitates that can be removed by filtration. Chlorine will oxidize manganese to insoluble manganese dioxide and iron to insoluble ferric hydroxide. The higher the chlorine residual, the faster the reaction goes.

Some plants add chlorine to produce a residual of from 5 to 10 mg chlorine per liter (*SUPERCHLORINATION*[34]). The insoluble precipitates are removed by filtration. The water is dechlorinated by the use of reducing agents such as sulfur dioxide (SO_2), sodium bisulfite ($NaHSO_3$), and sodium sulfite (Na_2SO_3). Bisulfite is commonly used because it is cheaper and more stable than sulfite. A chlorine residual must be maintained in the treated water throughout the distribution system.

Potassium permanganate can be used to accomplish the same result as chlorine. The dose must be exact. Too little permanganate will not oxidize all of the manganese for removal and too much will allow permanganate to enter the distribution system and cause a pink color.

Filtration is used to remove the insoluble precipitates. Sometimes a *GREENSAND*[35] is used, which oxidizes iron and manganese to their insoluble oxides. The greensand is capable of both oxidation and filtration. The greensand may be regenerated by the use of potassium permanganate.

Iron can be oxidized by *AERATING*[36] water to form insoluble ferric hydroxide. The higher the pH, the faster the reaction. The oxidation of manganese by aeration is so slow that this process is not used on waters with high manganese concentrations. Aeration is achieved by spraying water into the air, allowing the water to flow over steps, or passing the water over coke trays. After aeration, adequate holding time in a retention basin is required for the oxidation reactions to take place. After the ferric hydroxide is formed, the insoluble precipitate is removed by sedimentation and filtration, or by filtration alone. The main advantage of this method is that no chemicals are required. For information on the operation of pressure filters, see Section 4.4, "Filtration."

Ion exchange can be used to remove both iron and manganese if the water to be treated contains no dissolved oxygen. Usually, groundwaters do not contain dissolved oxygen. If dissolved oxygen is present, the exchange resin becomes fouled with iron rust or manganese dioxide. Cleaning the resin is expensive. The procedures for operating and maintaining ion exchange units are outlined in the next section on softening.

For additional information and details on the control of iron and manganese, see *WATER TREATMENT PLANT OPERATION,* Volume II, Chapter 12, "Iron and Manganese Control," in this series of operator training manuals.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 277.

4.9A Why are excessive amounts of iron and manganese in drinking waters objectionable?

4.9B Why is greensand sometimes used to treat iron and manganese?

4.9C What is the main advantage of treating iron by aerating water?

4.9D Why must there be no dissolved oxygen present when using ion exchange units to remove iron and manganese?

4.10 SOFTENING

4.100 Lime–Soda Ash Softening

The exact procedures used to soften water by chemical precipitation using the lime–soda ash process will depend on the hardness and other chemical characteristics of the water being treated (pH, alkalinity, temperature). A series of jar tests is commonly used to determine optimum dosages. In many cases, the feed rates determined by jar tests do not produce the exact same results in an actual plant. This is because of differences in water temperature, size and shape of the jar as compared with plant basins, mixing equipment, and influence of the coagulant (a heavy alum feed will neutralize more of the lime). You must remember that jar test results are a starting point. You may have to make additional adjustments to the chemical feeders in your plant based on actual analyses of the treated water.

Let us set up some jar tests to determine the optimum dosages for lime or lime–soda treatment to remove hardness from well water. To get started, add 10.0 grams of lime to a one-liter container and fill to the one-liter mark with distilled water. Thoroughly mix this stock solution in order to dissolve all of the lime. One m*L* of this solution in a liter of water is the same as a lime dosage of 10 mg/*L* (0.5 m*L* in 500 m*L* is still the same as a 10-mg/*L* lime dose).

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[34] *Superchlorination* (SOO-per-KLOR-uh-NAY-shun). Chlorination with doses that are deliberately selected to produce free or combined residuals so large as to require dechlorination.

[35] *Greensand.* A mineral (glauconite) material that looks like ordinary filter sand except that it is green in color. Greensand is a natural ion exchange material that is capable of softening water. Greensand that has been treated with potassium permanganate ($KMnO_4$) is called manganese greensand; this product is used to remove iron, manganese, and hydrogen sulfide from groundwaters.

[36] *Aeration* (air-A-shun). The process of adding air to water. Air can be added to water by either passing air through water or passing water through air.

Set up a series of hardness tests by adding 5.0 m*L*, 10.0 m*L*, 15.0 m*L*, 20.0 m*L*, 25.0 m*L*, 30.0 m*L*, 35.0 m*L*, and 40.0 m*L* to one-liter (1,000-m*L*) containers or jars. Fill the containers to the 1,000-m*L* mark with the water being tested. Mix thoroughly, allow the precipitate to settle, and measure the hardness remaining in the water above the precipitate. A plot of the hardness remaining against the lime dosage will often reveal the optimum dosage. See Figures 4.34, 4.35, and 4.36.[37]

Examination of Figures 4.34, 4.35, and 4.36 reveals that the water of all three cities responded differently to the increasing lime dosage. City 1 (Figure 4.34) should be providing a lime dosage of 100 mg/*L*. The cost of increasing the dosage to 150 mg/*L* is not worth the slight reduction in hardness from 110 to 100 mg/*L* as $CaCO_3$. Note that an overfeed of lime will actually increase the hardness.

City 2 (Figure 4.35) should be providing a lime dose of 200 mg/*L*. A dose of 300 mg/*L* will reduce hardness, but the increase in lime costs are too great. City 3 (Figure 4.36) should be dosing lime between 200 and 250 mg/*L*. Note that the greater the lime dose, the less the hardness, but the greater the quantities of sludge that must be handled and disposed of.

If lime added to the water does not remove sufficient hardness, select the optimum lime dose and then add varying amounts of soda ash. From Figure 4.36, we found that the optimum lime dose was 200 mg/*L* (300 mg/*L* would have reduced the hardness only slightly more). Let us take six one-liter containers and add 20 m*L* of our lime stock solution (a dosage of 200 mg/*L*). Prepare a stock solution of soda ash similar to our lime solution. Add 10 grams of soda ash to a one-liter container, fill with distilled water, and mix thoroughly. Add zero, 2.5 m*L* (2.5 mg/*L* dose), 5 m*L*, 7.5 m*L*, 10 m*L*, 12.5 m*L*, and 15 m*L*. Mix thoroughly, allow the precipitate to settle, and measure the hardness remaining in the water above the precipitate. A plot of hardness remaining against the soda ash dosage will reveal the desired dosage. We would like the final hardness to be in the 80- to 90-mg/*L* as $CaCO_3$ range.

To select the optimum doses of lime and soda ash, consider the items discussed below.

1. Optimum dosage of lime was based on increments of 50 mg/*L*. You should refine this test by trying at least two 10 mg/*L* increments above and below the optimum dose. From Figure 4.34, we found that 100 mg/*L* was the optimum dose. Try lime doses of 80, 90, 100, 110, and 120 mg/*L*.
2. Optimum dosage of soda ash can be refined by trying similar increments also.
3. Try slightly increasing the actual lime dose in your plant to see if there is any decrease in the remaining hardness. Is the decrease in hardness worth the increase in lime costs?
4. Try slightly increasing and decreasing both lime and soda ash dosages at your plant one at a time, and evaluate the results.
5. If you are treating well water or a water of constant quality, all you have to do to maintain proper treatment is to make minor adjustments to keep the system fine-tuned.
6. If you are treating water from a lake or a river and the water quality (including temperature) changes, you will have to run jar tests and closely monitor plant performance whenever the source water quality changes. Water quality changes of concern include raw water hardness, alkalinity, turbidity, and temperature.
7. Remember, you do not want to produce water of zero hardness. If you can get the hardness down to around 80 to 90 mg/*L*, that usually will be low enough for most domestic consumers.

After the chemicals have been mixed, the precipitates are allowed to settle out in some type of settling or sedimentation basin. Sludges from the lime or lime–soda softening processes are usually disposed of in sanitary landfills.

The next process is recarbonation. This process introduces carbon dioxide into the treated water to lower the pH and stabilize the water to prevent the precipitation of carbonate compounds on the filter media, in the clear well, and in the pipes in the distribution system. The pH to which the water should be lowered is determined by the Marble test. See *WATER TREATMENT PLANT OPERATION,* Volume II, Chapter 21, "Advanced Laboratory Procedures," in this series of operator training manuals for details on how to perform the Marble test. For information on how to operate gravity filters, see Section 4.4, "Filtration," and Section 4.8, "Slow Sand Filtration."

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 277.

4.10A The procedures for softening water by chemical precipitation using the lime–soda ash process depend on what factors?

4.10B If lime added to water does not reduce the hardness of a water sufficiently, what would you do?

4.10C Why should softened waters from the lime–soda ash process pass through a recarbonation process before filtration?

---

[37] These figures were adapted from an article titled, "Use of Softening Curve for Lime Dosage Control," by Michael D. Curry, P.E., which appeared in *THE DIGESTER/OVER THE SPILLWAY,* published by the Illinois Environmental Protection Agency.

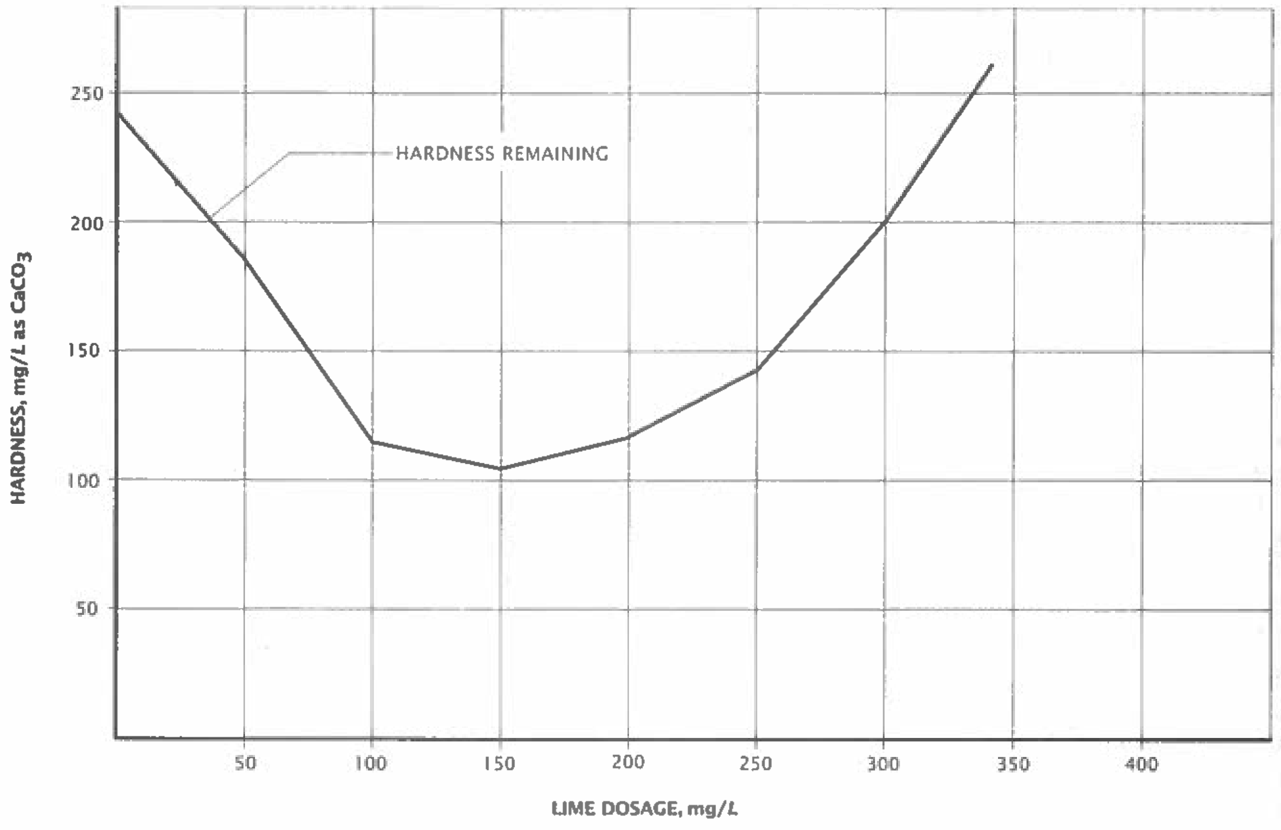

Fig. 4.34 Softening curve for City 1

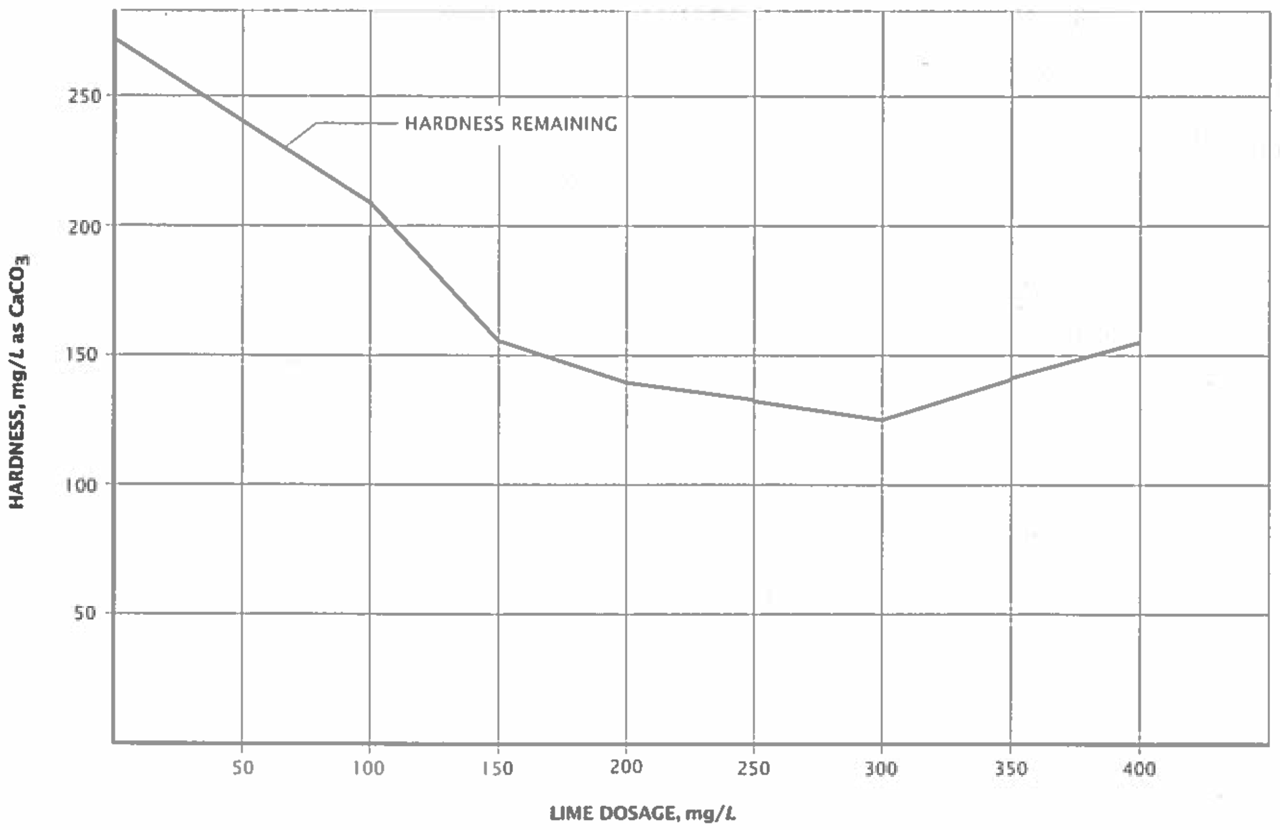

Fig. 4.35 Softening curve for City 2

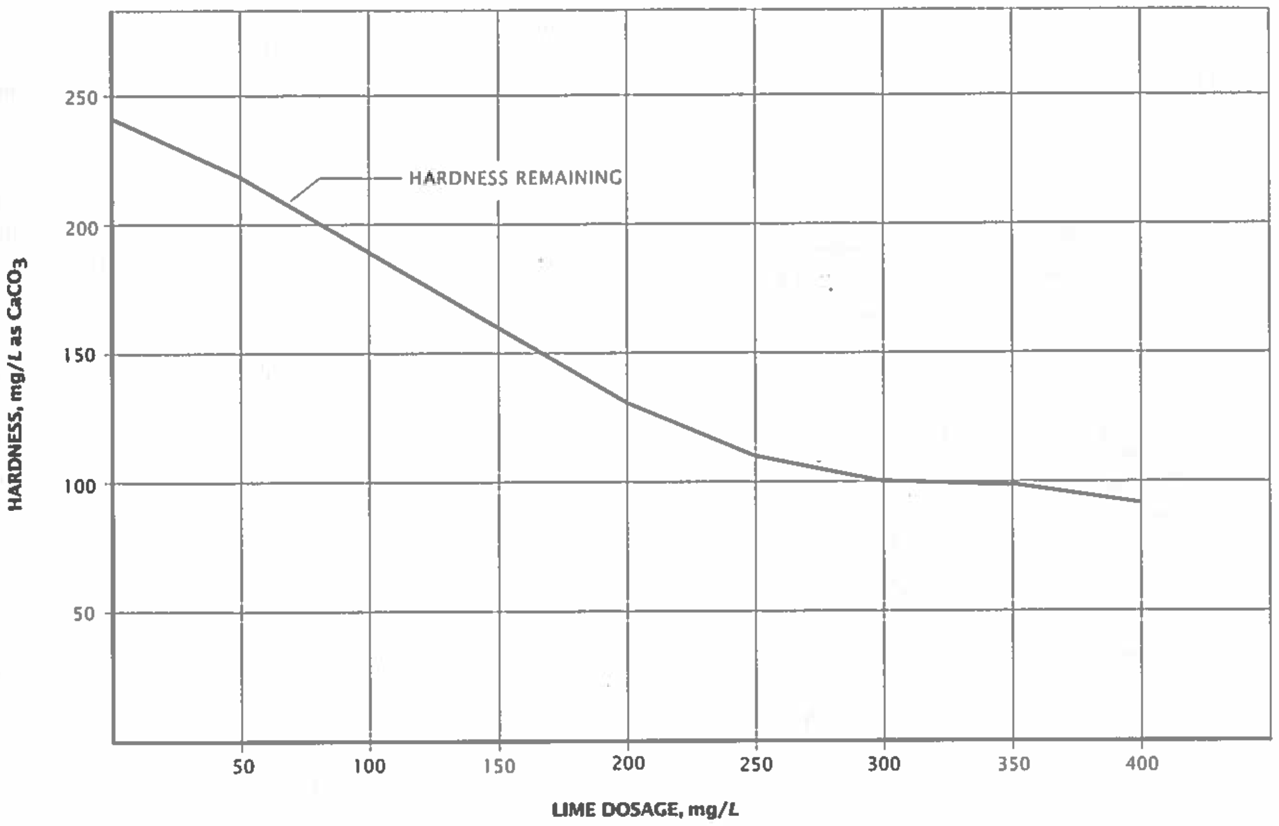

Fig. 4.36 Softening curve for City 3

4.101 Ion Exchange Softening

Ion exchange water softening is a process in which the hardness-causing ions (mainly calcium and magnesium) are exchanged (or traded) for sodium ions by passing the water through an ion exchange media. *ZEOLITE*[38] softening refers to sodium ion exchangers and will mean the same as ion exchange in this manual.

There are three basic types of ion exchangers in use today. One type is an upflow unit in which the water enters from the bottom and flows up through the resin exchange bed and out the top. Another type operates like a gravity sand filter. The water enters at the top, flows down through the softening media and out the bottom. The most common type is the pressure down-flow ion exchange softener.

Try to operate your ion exchange unit at design flows or less. Measure the hardness of the water entering the unit and the hardness of the water leaving (there should be zero hardness leaving). Monitoring influent hardness is very important, especially for surface waters. Zeolite softeners are designed to remove a specified amount of hardness before they require regeneration. See Example 16.

If design flows through a zeolite softener cannot be achieved or if the head loss through the softener becomes greater than normal, the resin may need backwashing. To backwash an ion exchange softener, take the unit out of service and reverse the flow pattern through the unit. The purpose of backwashing is to expand and clean the media particles, thus freeing any material such as iron and manganese that might have been removed during the softening stage.

Slowly allow the backwash water to enter the softener and gradually increase the backwash rate to the design flow. Periodically during the backwash process, catch a sample of effluent with a glass beaker. A trace amount of media should cause no alarm, but a steady loss of media could indicate a problem in the unit. Try to find the source of the problem as soon as possible and correct the problem. The backwash duration and flow rate will vary depending on the manufacturer and the type of media used.

When the effluent from the zeolite softener no longer has zero hardness or your calculations (Example 16) indicate that the softener is reaching its exchange capacity, the softener must be regenerated. This process is called regeneration or the brine stage. In this stage, the sodium ions present in the brine solution

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[38] *Zeolite.* A type of ion exchange material used to soften water. Natural zeolites are siliceous compounds (made of silica) that remove calcium and magnesium from hard water and replace them with sodium. Synthetic or organic zeolites are ion exchange materials that remove calcium or magnesium and replace them with either sodium or hydrogen. Manganese zeolites are used to remove iron and manganese from water.

are exchanged with the calcium and magnesium ions on the resin that have been removed during the service or softening stage. If the regeneration process is performed correctly, the result is a bed that is completely recharged with sodium ions and will again soften water when the unit is returned to service.

After the regeneration process is completed, the softener should be rinsed. The flow pattern is very similar to the service or softening stage, with the exception that the softener effluent is going to waste instead of storage. Most rinse stages will last from 20 to 40 minutes depending on the size of the unit and the manufacturer. The rinse must be long enough to remove all traces of the brine from the softener. Near the end of the rinse cycle, taste the effluent to be sure that no salty taste remains. If the effluent tastes OK, the unit is now ready to be returned to service. The effluent from the filter should have zero hardness if the regeneration process was successful.

Zeolite softeners will remove iron and manganese in the soluble or precipitated form. If water high in iron and manganese is applied to the ion exchange media for very long, iron fouling or the loss of exchange capacity could result. If the media becomes coated with iron, the media will develop a rusty or orange appearance and the efficiency of the softener will be greatly reduced. High iron loadings (in the ferric or solid form) can plug the upper layer of the media and force water to channel or short-circuit through the bed. This will result in incomplete or insufficient contact between the water and the media, thus creating hardness leakage and a loss in softening efficiency.

Disposal of spent brine can be a serious problem. The brine is corrosive to material it comes in contact with and is toxic to many living plants and animals in the environment. Each ion exchange treatment plant probably has only one approved method of spent brine disposal, which must be carefully followed at all times.

The brine is corrosive to the brine carrying system; therefore, frequent inspection and routine maintenance are important. Immediately repair all leaks in the brine pumping and piping system and also in the brine storage area.

If the bed turns an orange or rusty color, iron fouling is becoming a problem. Try increasing the length of the backwash stage. A chemical cleaner (sodium bisulfite) can be used to remove heavy iron coatings from the media. The sodium bisulfite can be added to the brine during the regeneration stage or it may be mixed in solution form and poured into the softener when the softener is out of service. The softener should be rinsed before being returned to service.

The water produced by a zeolite softener has near zero hardness and is very corrosive. For these reasons, this water is mixed or blended with other water (untreated or unsoftened water) to produce water of acceptable hardness (80 to 90 mg/*L*) for the consumers. The amount of blend water depends on the desired level of hardness in the finished water.

In most cases, ion exchange softening is used by smaller water softening plants instead of the lime–soda softening process due to economics. For additional information on water softening, see *WATER TREATMENT PLANT OPERATION,* Volume II, Chapter 14, "Softening," in this series of operator training manuals.

FORMULAS

The exchange capacity of ion exchange units is expressed in kilograins. Therefore, if an ion exchange unit has a capacity of 20 kilograins, the unit can remove 20 kilograins of hardness before requiring regeneration.

$$\text{1 grain per gallon or gpg} = 17.1\ \text{mg}/L$$

$$\text{Hardness, grains/gallon} = \frac{\text{Hardness, mg}/L}{17.1\ \text{mg}/L/\text{gpg}}$$

$$\begin{array}{l}\text{Exchange}\\ \quad\text{Capacity,}\\ \quad\text{grains}\end{array} = (\text{Media Vol, cu ft})(\text{Removal Capacity, grains/cu ft})$$

$$\text{Water Treated, gal} = \frac{\text{Exchange Capacity, grains}}{\text{Hardness, grains/gallon}}$$

$$\begin{array}{l}\text{Operating Time, hr}\\ \quad\text{(Before Regeneration)}\end{array} = \frac{(\text{Water Treated, gal})(24\ \text{hr/day})}{\text{Avg Daily Flow, gal/day}}$$

EXAMPLE 16

A zeolite softener contains 200 cubic feet of media with a hardness removal capacity of 20 kilograins per cubic foot of media. The water being treated has a hardness of 250 mg/*L* as $CaCO_3$. How much water can be treated before the softener will require regeneration?

Known		Unknown
Media Volume, cu ft	= 200 cu ft	Water Treated, gal
Removal Capacity, gr/cu ft	= 20,000 grains/cu ft	
Hardness, mg/*L*	= 250 mg/*L*	

1. Convert the hardness from mg/*L* to grains per gallon.

$$\begin{aligned}\text{Hardness, grains/gal} &= \frac{\text{Hardness, mg}/L}{17.1\ \text{mg}/L/\text{gpg}}\\ &= \frac{250\ \text{mg}/L}{17.1\ \text{mg}/L/\text{gpg}}\\ &= 14.6\ \text{grains per gallon}\end{aligned}$$

2. Calculate the exchange capacity of the softener in grains.

$$\begin{aligned}\begin{array}{l}\text{Exchange}\\ \quad\text{Capacity,}\\ \quad\text{grains}\end{array} &= (\text{Media Vol, cu ft})(\text{Removal Capacity, grains/cu ft})\\ &= (200\ \text{cu ft})(20{,}000\ \text{grains/cu ft})\\ &= 4{,}000{,}000\ \text{grains}\end{aligned}$$

3. Calculate the volume of water in gallons that may be treated before regeneration.

$$\begin{aligned}\text{Water Treated, gal} &= \frac{\text{Exchange Capacity, grains}}{\text{Hardness, grains/gallon}}\\ &= \frac{4{,}000{,}000\ \text{grains}}{14.6\ \text{grains/gallon}}\\ &= 274{,}000\ \text{gallons}\end{aligned}$$

EXAMPLE 17

The zeolite softener described in Example 16 treats an average daily flow of 200,000 gallons of water per day. How often (hours) should the softener be regenerated? From Example 16, the softener can treat 274,000 gallons of water before requiring regeneration.

Known		Unknown
Water Treated, gal	= 274,000 gal	Operating Time, hr
Avg Flow, gal/day	= 200,000 gal/day	

Calculate the number of hours the softener can operate before requiring regeneration.

$$\begin{aligned}\text{Operating Time, hr} &= \frac{(\text{Water Treated, gal})(24\ \text{hr/day})}{\text{Avg Daily Flow, gal/day}}\\ &= \frac{(274{,}000\ \text{gal})(24\ \text{hr/day})}{200{,}000\ \text{gal/day}}\\ &= 32.9\ \text{hours}\end{aligned}$$

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 277.

4.10D How does an ion exchange water softening process work?

4.10E When should a zeolite softener be backwashed?

4.10F How can you tell when the rinse cycle of a zeolite softener is adequate?

4.10G What problems does excessive iron cause in a zeolite softener?

4.11 OPERATION

The operators of water treatment plants must be responsible, knowledgeable, and conscientious. A poor operator may not do a good job with even the best equipment, whereas a competent operator who is conscientious and responsible can often achieve good results with only ordinary or even inadequate equipment. Over and over again, experience has shown that it is the abilities of the operator that determine whether a water treatment plant produces acceptable quality water. Frequently, large sums are spent on the design and construction of a water treatment plant but all too often selection and training of the operator is hardly given a second thought. The need for a capable operator must not be ignored if the goal is to produce good water.

First of all, the operator must be interested in doing a good job. An operator must have the desire to produce the best quality water possible. Next, the operator should receive the necessary training. Prior experience in water treatment is very helpful but additional training is necessary. Many aspects of water treatment and water plant operation involve very technical or specialized subjects. These subjects include mathematics, hydraulics, water chemistry, water quality standards, electricity, plumbing, pumps, motors, bacteriology, recordkeeping, and public relations. Classroom instruction is sometimes available but frequently the operator's only choice is individual study at home. However, when seminars, classes, and meetings are offered, the operator should certainly attend.

The operators of small systems can often receive very helpful training and assistance from the operators of large water treatment plants in the area. Try to visit other plants and become acquainted with the operators. They are usually glad to help another operator.

Operator certification programs are available now in every state. Certification may be granted under a program conducted by the local water works association or by the state government. In either case, the operator should enroll in the program for the training and educational benefits and try to become certified. Operator certification is important because it is evidence of the operator's level of knowledge and proficiency on the job. As a result, operator job descriptions for many water utilities now require certification before hiring. Water treatment plant operators are finding it harder than ever to find work as an operator without being certified.

Following is a list of typical procedures the operator should follow in operating the small treatment plant.

DAILY

1. Inspect the plant daily including weekends and holidays. A trained substitute operator must be available when the regular operator is sick or on vacation.
2. Determine that all the plant equipment is operational.
3. Perform water quality and operational tests such as chlorine residual, turbidity, pH, and jar tests.
4. Actually smell and taste the treated water produced to detect any aesthetic problems.
5. Record readings from flowmeters, pressure gauges, filter head loss gauges, and reservoir level gauges.

PERIODICALLY

1. Dismantle, clean, and overhaul chemical feeders like chlorinators and coagulant chemical feed pumps.
2. Test start standby pumps, motors, and generators.
3. Perform preventive maintenance to inspect, lubricate, clean, and repair equipment.
4. Replenish chemical stocks.
5. Clean settling basins and dispose of sludge.
6. Overhaul major equipment such as filters, clarifiers, and pumps.
7. Calibrate flowmeters and chemical feeders.
8. Repaint piping, equipment, and buildings.
9. Perform electrical efficiency tests on all pumps.
10. Test emergency alarms and control systems.
11. Maintain stock of repair parts and spare equipment.
12. Collect routine bacteriological samples and occasional chemical samples for laboratory analysis.

The operator needs to become acquainted with local contractors, regulatory agencies, and suppliers of chemicals, equipment, and materials. Contractors must be hired occasionally to repair the water system, construct improvements, and perform other services. The operator should be familiar with the capabilities of each contractor and the cost of necessary services. Regulatory agencies, such as the health department, can assist the operator in solving problems that arise. Likewise, suppliers of equipment and materials are often experts in their field and frequently give generously of their time to assist an operator in using their products successfully. These resources should not be overlooked. A lot of good advice is available without charge and the operator should not hesitate to ask for assistance from any of these sources when the need arises.

Records of water system operation are vital and must be kept up to date by the operator. The essential records include the following items.

1. *PLANT OPERATING DATA*

   These data include the date and time that the plant was inspected, the operating flow rate, the amount of water treated, the dosage of chemicals being applied, the amount of chemicals fed, filter head loss, filter backwash time, reservoir levels, and weather conditions.

2. *DAILY LOG OR DIARY*

   Many operators keep a daily diary to supplement and explain information recorded in the log of operating data. The operator's diary usually consists of informal notes and the operator is free to record any important comments, observations, reminders, or explanations. The types of information recorded may include notes about equipment breakdowns, changes in treatment, severe weather, changes in water quality conditions, or visits by repair technicians, health inspectors, customers, or officials. This information is very helpful to the relief operator who must take over operation of the plant suddenly or on occasion.

3. *LABORATORY TEST RESULTS*

   Test results include those for tests performed by the operator as well as by private laboratories. The operator performs jar tests; measures turbidity, pH, and chlorine residual; and performs other simple chemical tests such as alkalinity tests. Complete chemical analyses and routine bacteriological sample testing is usually done by a private analytical laboratory. These test results must usually be reported to the health department and preserved for reference.

4. *SYSTEM RECORDS*

   System records include all available maps and drawings of the distribution system layout. These records are invaluable for locating pipelines, valves, and service connections. The location, size, age, and material of all pipelines should be shown on the plans.

   The operator should carefully preserve the plans and specifications for all structures including the treatment equipment and the storage reservoirs. These documents show the construction details on each piece of equipment or structure and they describe the materials that were used. The operator's files should also contain the technical manual and the maintenance records for each piece of equipment in the system. With this information available for reference, the operator should be able to understand how the system was built and how to keep it operating efficiently.

The backflow of polluted waters or liquids into the domestic water system must be prevented by a program of backflow prevention. Backflow, which is a reversal in the normal direction of flow, can occur in two ways. One way is backflow due to siphonage caused by vacuum conditions in the system. This backsiphonage is caused by a sudden major water demand such as a fire or a major system break. The second way is backflow due to pressure conditions created by a pump or other source of higher pressure.

Backflow from wastewater (sewage) facilities and from industrial or commercial operations is the most hazardous. Many hazardous chemicals and liquids are used in industry and these must be excluded from the water supply to prevent poisoning of consumers. Wastewater contains a variety of germs, often in great numbers, that can cause illness or death.

To limit backflow, the distribution system must be properly constructed and operated. Pipelines must be large enough to handle peak flows without creating vacuum conditions. Also, adequate pressures must be maintained in the system at all times. Pipeline outages and shutdowns should be limited and pipes thoroughly flushed before they are returned to service.

Water service connections to premises where backflow hazards exist should be protected with an appropriate backflow preventer. Typical types of backflow preventers include air gap separations, reduced pressure principle devices, double check valve assemblies, and vacuum breakers. See *WATER DISTRIBUTION SYSTEM OPERATION AND MAINTENANCE,* Chapters 3 and 5, for details on backflow preventers.

For additional information on taste and odor control and plant operation, see *WATER TREATMENT PLANT OPERATION,* Volume I, Chapter 9, "Taste and Odor Control," and Chapter 10, "Plant Operation"; and for information on fluoridation, see *WATER TREATMENT PLANT OPERATION,* Volume II, Chapter 13, "Fluoridation," in this series of operator training manuals.

4.12 MAINTENANCE

4.120 Program

The water plant operator cannot afford to ignore the need for equipment maintenance. The water treatment plant must normally operate every day and equipment outages cannot be tolerated if the treatment is to be effective. Therefore, the operator should strive to eliminate equipment breakdowns or at least minimize the time they cause the plant to be out of operation. Frequently, maintenance problems can be avoided by proper design or selection of the right piece of equipment.

Most other problems can be avoided if the operator will regularly inspect, clean, and lubricate the equipment. Maintenance inspections should be performed according to a regular schedule, which should be written down so inspections are not overlooked. Unusual noises, vibrations, leaks, and malfunctions should receive prompt attention. Regular cleaning of chemical feeders for chlorine, alum, and lime will prevent many breakdowns in this equipment. Spare parts should be kept on hand so breakdowns can be repaired quickly and so worn parts can be replaced when the feeder is disassembled for cleaning. Preventive maintenance for equipment should be based on manufacturers' recommendations. Other chapters in this manual should be consulted for more specific details on equipment maintenance.

The operator is also responsible for maintaining clean and tidy conditions in the plant grounds. Plant piping, buildings, and tanks should be painted regularly to prevent deterioration and to present a good public appearance. Pipes, plumbing fittings, chemicals, tools, and other materials must be stored in a safe and orderly manner. Junk and clutter should be eliminated.

For additional information on maintenance, see *WATER TREATMENT PLANT OPERATION,* Volume II, Chapter 18, "Maintenance," and Chapter 19, "Instrumentation and Control Systems," in this series of operator training manuals.

4.121 Tools

Nothing makes a maintenance or repair job tougher than to have the wrong tools or no tools at all. The following list of tools is provided as a guide to help you determine the tools you will need to do your job. This list is not complete. You may need additional tools to do your job and some of the tools you will not need.

Proper care of tools is essential. You must maintain your tools and hand equipment as necessary and keep everything in proper working order. After a job is completed, clean your tools and store them properly so they can be found and used when needed again.

LIST OF OPERATOR'S TOOLS

1. *WRENCHES*
   a. Deep-well socket set, ⅜" to 1¼" with ½" drive ratchet and breaker bar
   b. Pipe wrenches, assorted sizes 6" to 36"
   c. Crescent wrenches, assorted sizes 6" to 18"
   d. Combination open and box end wrench set ¼" to ¾"
   e. Allen wrench set
   f. Fire hydrant spanner wrench
   g. Gate valve wrench, 2" nut and 4" nut
   h. Corporation stop wrench
2. *SCREWDRIVERS*—Set, assorted sizes
3. *HAMMERS*
   a. Claw—16 oz
   b. Ball peen—16 oz and 8 oz
   c. Brass, rawhide, or soft plastic head
4. *SLEDGEHAMMERS*
   a. 2 pound
   b. 8 pound

5. *PLIERS*
   a. Slip joint common pliers
   b. Groove joint channel lock pliers
   c. Electric lineman's pliers
   d. Diagonal cutter pliers
   e. Needle nose pliers
   f. Vise grip pliers
   g. Electric terminal end pliers with wire stripper
   h. Fuse puller pliers
   i. Internal snap-ring pliers
   j. External snap-ring pliers
6. *HACKSAW*
7. *METAL FILES*—set of round and flat
8. *LIGHTS*
   a. 2-cell flashlight
   b. 6-volt battery lantern
9. *MEASURING TAPE*
   a. 10' retractable steel
   b. 100' cloth
10. *SHOVEL*
    a. Round point, heavy duty
    b. Square end
11. *PICK*
12. *PIPE VISE*—Truck mounted
13. *FLARING TOOLS AND CUTTER*—For copper and plastic pipe
14. *TUBING BENDER*
15. *CRIMPING TOOL*—For emergency shutoff of service pipes
16. *POCKET KNIFE*—Folding with blade lock feature
17. *GASKET SCRAPER TOOL*
18. *COLD CHISELS AND PUNCHES*—Set, assorted sizes
19. *PUTTY KNIFE*
20. *MANHOLE COVER PULLER HOOK*
21. *ELECTRIC DRILL*—½" reversible
22. *DRILL BITS*—Set, assorted sizes
23. *TAP AND DIE SET*
24. *EASY OUTS*—Set
25. *STUD BOLT PULLER*
26. *PACKING REMOVAL HOOKS*—Flexible, set of sizes
27. *LANTERN RING REMOVAL TOOLS*—Set
28. *PIPE CUTTING TOOLS*—Manual or electric power
29. *WIRE BRUSHES*
30. *STEEL PRY BARS*—8' long
31. *EXTENSION LADDER*—Aluminum
32. *COME-A-LONG*—2-ton capacity
33. *CHAIN HOIST*—2-ton capacity
34. *NYLON ROPE*—½" diameter
35. *WATER PRESSURE GAUGE*—With connection to hose faucet
36. *FIRE HOSE*—50'
37. *MUD PUMP*—3" positive displacement, gasoline powered
38. *CLOTHING*
    a. Rain suit—pants and jacket with hood or hat
    b. Rubber boots—calf length, hip length
    c. Rubber gloves
    d. Hard hat
    e. Face mask, clear plastic
    f. Eye goggles
    g. Leather gloves

39. *ELECTRIC VOLTAGE TESTER*—110 to 600 volts
40. *VOLTMETER/AMMETER TESTER*—Amprobe
41. *WATER TEST KITS*
    a. Chlorine residual
    b. pH
    c. Turbidimeter
42. *AMMONIA SOLUTION*—Industrial strength
43. *CHLORINE BLEACH*—Sodium hypochlorite
44. *CHLORINE TABLETS*—Calcium hypochlorite
45. *BREATHING MASK*—Self-contained, MSA
46. *RESPIRATOR MASK*—With replaceable filters

47. *GREASE GUN*—With graphite cartridges
48. *ELECTRONIC CALCULATOR*
49. *OPERATION MANUALS*—For plant equipment
50. *TOOL BOXES*—Lockable steel
51. *WIPING RAGS*
52. *PLASTIC ELECTRICAL TAPE*
53. *FIRST-AID KIT*
54. *PUSH BROOM*—Heavy duty
55. *PERMATEX NO. 1*—Gasket adhesive

4.13 SAFETY

When operating any type of water treatment facility,

Safety must always come first!

If you are the only operator at a small water treatment plant, you must take care of yourself. There frequently is no one else present to make sure that you follow safe procedures and that there are no safety hazards that can injure you. There may be no one else available to help you or to rescue you if you become injured.

Safety hazards of concern around any water treatment plant include chlorine, electric shock, and drowning. Studies have shown that the greatest causes of injuries to operators result from muscle and back strains caused by lifting and injuries resulting from slips and falls. These types of injuries can easily be prevented by alert and safety-conscious operators.

Be extremely careful whenever working with chlorine. If you are wearing a self-contained (or air line) breathing apparatus and the respirator fails, you could be overcome by a toxic gas or a lack of oxygen. Under these circumstances, two people should always be standing by for rescue purposes. The following rules are recommended:

1. Two (2) people should be present whenever entrance to a gas chlorine feed station or gas chlorine storage area (building or yard) is attempted.
2. Two (2) people shall be present when any type of maintenance, repair work, or work that might create a chlorine leak is attempted.
3. Two (2) approved, self-contained (or air line) supplied-air masks shall be available prior to entering a gas chlorine feed station and/or gas chlorine storage area.

NOTE: The word "should" indicates that a safety regulation will normally be followed as closely as possible, consistent with good judgment. "Shall" indicates that compliance with a safety regulation is mandatory at all times.

For additional information on safety, see Chapter 6, "Safety," in this manual and also *WATER TREATMENT PLANT OPERATION*, Volume II, Chapter 20, "Safety," in this series of operator training manuals.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 277.

4.11A Why should operators become certified?

4.11B List the essential records that must be kept up to date by the operator.

4.11C Which laboratory tests are commonly performed by operators?

4.12A How can the operator avoid maintenance problems?

4.13A What are the greatest causes of injuries to operators?

4.14 ARITHMETIC ASSIGNMENT

Turn to the Appendix, "How to Solve Small Water System Arithmetic Problems," at the back of this manual and read all of Section A.4, "Metric System."

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

1. A.130, "Flows"
2. A.131, "Chemical Doses"
3. A.132, "Wells"
4. A.133, "Small Water Treatment Plants"

4.15 ADDITIONAL READING

1. *NEW YORK MANUAL*, Chapter 1,* "Purpose of Water Treatment," and Chapter 19,* "Treatment Plant Maintenance and Accident Prevention."
2. *SLOW SAND FILTRATION*, edited by Gary S. Logsdon. Published by the American Society of Civil Engineers (ASCE). ISBN 0-87262-847-7. Out of print.
3. *TEXAS MANUAL*, Chapter 25,* "Water Treatment Plant Waste Disposal."

* Depends on edition.

End of Lesson 2 of 2 Lessons on SMALL WATER TREATMENT PLANTS

Please answer the discussion and review questions next.

DISCUSSION AND REVIEW QUESTIONS

Chapter 4. SMALL WATER TREATMENT PLANTS

(Lesson 2 of 2 Lessons)

Write the answers to these questions in your notebook. The question numbering continues from Lesson 1.

14. How can corrosion be controlled?
15. Why should corrosion control chemicals be applied to water after all other treatment has been accomplished?
16. The most serious limitation of solids-contact units is their instability during rapid changes in which three factors?
17. What problems can develop in a solids-contact unit if the recirculation rate is too high or too low?
18. Why are slow sand filters seen as a feasible alternative for small water systems?
19. How do microorganisms treat drinking water in the slow sand filtration process?
20. Why will a new filter or one that has just been cleaned or resanded not produce filtered water of acceptable quality immediately upon start-up?
21. How long should a newly cleaned filter operate (filter water) before it is placed back on line?
22. What cyclic factors can influence the performance of slow sand filters?
23. Why must the dose of potassium permanganate for the control of iron and manganese be exact?
24. Why do the results of jar tests often not produce the same results in a water treatment plant using the lime–soda ash softening process?
25. Depending on the quality of the water you are treating, how often should the chemical dosages be checked in a lime–soda ash water softening plant?
26. What is the optimum flow rate through an ion exchange softener?
27. Plant operating data includes what types of information?
28. How can the backflow of polluted waters or liquids into the domestic water system occur?
29. Why is safety especially important for the operator of a small water treatment plant?