SUPERCHLORINATION (SOO-per-KLOR-uh-NAY-shun) SUPERCHLORINATION

Chlorination with doses that are deliberately selected to produce free or combined residuals so large as to require dechlorination.

SURFACE LOADING SURFACE LOADING

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 OVERFLOW RATE.

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

or

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

TRIHALOMETHANES (THMs) (tri-HAL-o-METH-hanes) TRIHALOMETHANES (THMs)

Derivatives of methane, CH_4, in which three halogen atoms (chlorine or bromine) are substituted for three of the hydrogen atoms. Often formed during chlorination by reactions with natural organic materials in the water. The resulting compounds (THMs) are suspected of causing cancer.

TURBIDITY (ter-BID-it-tee) TURBIDITY

The cloudy appearance of water caused by the presence of suspended and colloidal matter. In the waterworks field, a turbidity measurement is used to indicate the clarity of water. Technically, turbidity is an optical property of the water based on the amount of light reflected by suspended particles. Turbidity cannot be directly equated to suspended solids because white particles reflect more light than dark-colored particles and many small particles will reflect more light than an equivalent large particle.

TURBIDITY (ter-BID-it-tee) UNITS (TU) TURBIDITY UNITS (TU)

Turbidity units are a measure of the cloudiness of water. If measured by a nephelometric (deflected light) instrumental procedure, turbidity units are expressed in nephelometric turbidity units (NTU) or simply TU. Those turbidity units obtained by visual methods are expressed in Jackson turbidity units (JTU), which are a measure of the cloudiness of water; they are used to indicate the clarity of water. There is no real connection between NTUs and JTUs. The Jackson turbidimeter is a visual method and the nephelometer is an instrumental method based on deflected light.

UNIFORMITY COEFFICIENT (UC) 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.

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

WYE STRAINER WYE STRAINER

A screen shaped like the letter Y. Water flows through the upper parts of the Y and the debris is trapped by the screen at the fork.

ZEOLITE 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.

CHAPTER 4. SMALL WATER TREATMENT PLANTS

(Lesson 1 of 2 Lessons)

4.0 IMPORTANCE OF SMALL WATER TREATMENT PLANTS

4.00 Need for Effective O & M

Small water treatment plants (Figure 4.1) are much more numerous than large plants. Most water treatment plants are small facilities that supply water to systems ranging in size from a few connections up to several hundred connections. For every large water plant serving a large population in a big service area, there are probably several hundred small plants that serve groups of people in small communities, subdivisions, commercial properties, resorts, and summer camps.

The volume of water produced by these small plants may vary from only fifteen gallons per minute (one liter per second) up to a few hundred gallons per minute. Regardless of the amount of water a plant produces, it must be properly operated to produce safe drinking water. Small plants face many of the same problems as larger ones but often the small plant does not perform as well because of poor design, poor operation, poor maintenance, inadequate budgets, and other causes. However, it is very important that these small plants be operated effectively because many people depend on them for their daily home water supply and many others drink the water on an occasional or intermittent basis.

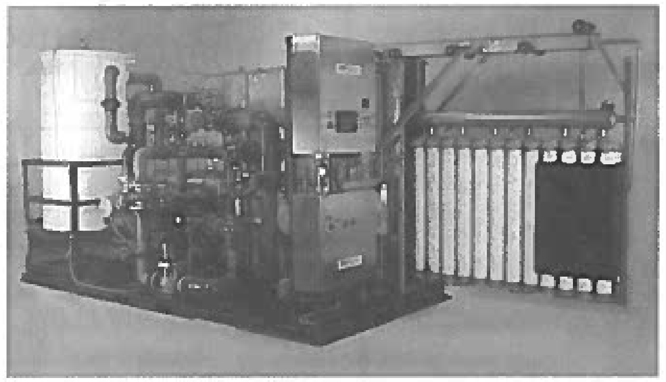
Small water treatment plants are common because the source of water for many small communities requires treatment. Surface water must be clarified and disinfected to ensure it is safe and to make it pleasing to the senses. Many groundwater sources require treatment for disinfection or for removal of undesirable minerals and gases in solution. Thus, almost any source of supply is likely to require treatment of some kind. The water supply that needs no treatment whatsoever is increasingly rare today as polluted waters are found everywhere and as standards for domestic water quality become more restrictive.

4.01 Surface Waters

A typical small water treatment system for treating surface waters may include any or all of the following components (see Figure 4.2).

1. Raw Water Storage

   Surface water sources are frequently developed from lakes, ponds, or reservoirs. These impoundments provide storage for the raw, untreated water and frequently are helpful to the treatment processes. One important effect of raw water storage is to slow the rate of change in water quality that occurs in surface water sources and to reduce the magnitude of the change. For instance, a rainstorm may cause a sudden, drastic change in the turbidity or the mineral composition of a stream source. If the stream flows into a large reservoir, however, the water quality changes much more slowly and less drastically than in the stream. The overall effect is to make available a raw water supply from the reservoir whose quality is more uniform and consistent. This uniform water quality will make any water treatment plant easier to operate and more effective.



(Permission of Memcor/Siemens)

(Permission of Watermasters, Inc., Burlingame, CA)

Fig. 4.1 Small water treatment plants

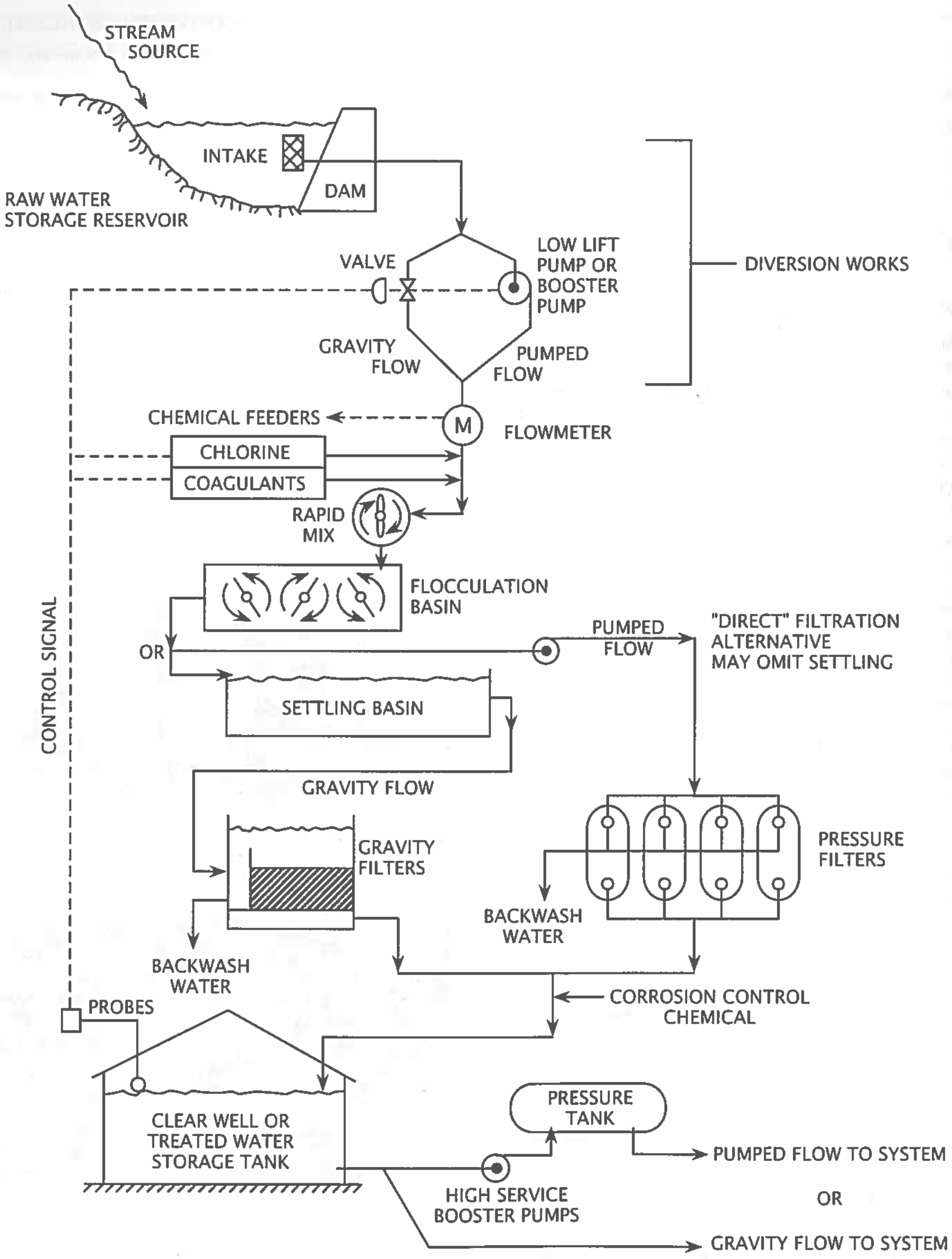


Fig. 4.2 Parts of a typical small water treatment system

If the water source is a canal or pipeline that is subject to shutdowns or outages, a raw water reservoir is necessary to keep the treatment plant in operation. Otherwise, the plant must stop operating whenever the water source is out of service.

2. Diversion Works

The diversion works consist of all the facilities used to divert water from the source into the treatment plant. These facilities may include a diversion dam, screens to exclude fish and trash, an intake pipe or structure, pumping equipment, piping or conduits to convey the water to the plant, and valves or gates to control the flow of water.

3. Flow Measurement

A flowmeter of some type is essential for proper operation of even the smallest water treatment plant. The meter should be the type that indicates both the instantaneous rate of flow as well as the total quantity of water that has flowed through it. The meter must be accurate enough to allow the operator to feed the proper chemical dosages. A fine screen or *WYE STRAINER*[1] should be installed upstream from the meter to keep it from being clogged or damaged by trash or rocks.

4. Disinfection

Chlorine is the chemical frequently applied to the water for disinfection. Prechlorination is often used because as the water flows through the treatment units, it receives the maximum contact time before reaching consumers. A chlorine residual in water flowing through the plant also discourages the growths of organisms and helps keep the filter media and other treatment equipment clean and free of organic growths. Prechlorination should not be used if natural organics are in the water and the formation of *TRIHALOMETHANES*[2] is a problem.

5. Coagulation

COAGULATION[3] facilities include the chemical feeding equipment for injecting coagulants and equipment for providing rapid mixing of the chemicals with the water.

6. Flocculation

Flocculation facilities include equipment for slowly mixing the water to promote growth of floc particles that will settle quickly or be removed by filtration.

7. Settling (sedimentation)

Settling allows suspended matter to be separated from the water by gravity. A very large portion of the suspended matter is usually removed in the settling tanks.

8. Filtration

Filters remove most of the suspended matter remaining in the water after settling.

9. Corrosion Control

Corrosion control treatment is used to stabilize the chemical nature of the water and make it less aggressive toward the materials used in pipelines, storage reservoirs, and customer appliances.

10. Treated Water Storage

Storage reservoirs for treated water may be installed either at the treatment plant (*CLEAR WELL*[4]) or out in the distribution system. Such reservoirs allow the treatment plant to be of smaller capacity than would otherwise be necessary because peak water demands can be supplied from storage. Storage also maintains the water supply during outages at the plant or at the source and it provides large amounts of water immediately for firefighting purposes.

11. High-Service Pumps

Unless the water system can be served entirely by gravity flow from a storage reservoir, high-service pumps are required. The pumps draw water from storage and supply it to the system under pressure. Often, one or more hydropneumatic pressure tanks are installed with the pumps.

Many small water treatment facilities are package plants (Figure 4.3), which can be purchased as a complete pre-assembled unit from a single manufacturer. Such package plants are available from a number of manufacturers. These units are most commonly supplied for filtration of turbid waters and for removal of dissolved iron and manganese. Usually, the package plant includes all the treatment equipment, pumps, chemical feeders, and controls. As soon as the water pipes and the electric power have been connected, the plant is ready to operate. Thus the package plant is frequently a quick way to provide the needed treatment. Another advantage of the package plant is that the design and the equipment have been proven effective and reliable by experience. All the bugs have been eliminated and the purchaser can usually have a high degree of confidence in the performance of the plant.

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[1] *Wye Strainer.* A screen shaped like the letter Y. Water flows through the upper parts of the Y and the debris is trapped by the screen at the fork.

[2] *Trihalomethanes (THMs)* (tri-HAL-o-METH-hanes). Derivatives of methane, CH_4, in which three halogen atoms (chlorine or bromine) are substituted for three of the hydrogen atoms. Often formed during chlorination by reactions with natural organic materials in the water. The resulting compounds (THMs) are suspected of causing cancer.

[3] *Coagulation* (ko-agg-yoo-LAY-shun). The clumping together of very fine particles into larger particles (floc) caused by the use of chemicals (coagulants). The chemicals neutralize the electrical charges of the fine particles, allowing them to come closer and form larger clumps. This clumping together makes it easier to separate the solids from the water by settling, skimming, draining, or filtering.

[4] *Clear Well.* A reservoir for the storage of filtered water of sufficient capacity to prevent the need to vary the filtration rate with variations in demand. Also used to provide chlorine contact time for disinfection.

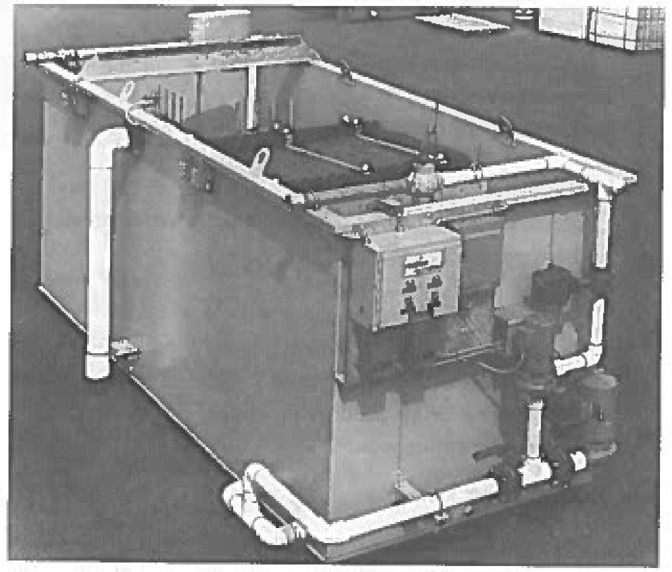

Fig. 4.3 Package water treatment plant
(Permission of Neptune Microfloc)(Now Microfloc Products)

When operating a package plant, beware of claims that the plant operates automatically. Even automatic systems require maintenance, repairs, and occasional process control changes. These plants may be easily upset by sudden changes in source water quality.

The alternative to a purchased package plant is a custom-designed plant that is assembled from equipment and materials supplied by several different manufacturers. This approach is sometimes less expensive than a package plant but the effectiveness of the resulting treatment plant is less predictable and may be unsatisfactory. The success of the plant depends on the ability of the person who designs the equipment and the skill and knowledge of the operator.

4.02 Groundwaters

Many small communities obtain their drinking water from wells. Sometimes the only additional treatment needed is the application of chlorine for disinfection. Other well waters may require treatment to remove iron and manganese or softening to remove excess hardness. In this chapter we will discuss the control of iron and manganese and also hardness at small water treatment plants. The application of chlorine for disinfection follows similar procedures when treating either surface or groundwaters.

1. Iron and Manganese Control

   Iron in drinking water can be controlled by converting iron from the liquid ferrous (Fe^{2+}) to the solid ferric (Fe^{3+}) form by the *OXIDATION*[5] process. First, an oxidizing agent such as chlorine or potassium permanganate is used. Next, oxygen is introduced to the water by the use of sprays, cascades, or trays. Finally, an hour or so (depending on the chemical makeup of the water) is allowed for the oxidation reaction to be completed and the insoluble *PRECIPITATES*[6] of iron and manganese to be formed. The precipitates are removed by sedimentation and filtration or by filtration alone. Sometimes, manganese is controlled by the addition of polyphosphates followed by chlorination.

2. Softening

   Hardness in water is caused mainly by the presence of calcium and magnesium. Excessive hardness is undesirable to domestic consumers due to difficulties in doing the laundry and washing dishes. Water is softened by either the ion exchange process or by chemical precipitation (lime–soda ash softening). Softened water delivered to consumers usually has a hardness level of around 80 to 90 mg/*L* expressed as *CALCIUM CARBONATE EQUIVALENT.*[7]

4.03 Operator Responsibility

Operators of small water treatment plants probably have the toughest job of anyone in the waterworks field. In many small plants, they have to do all of the work themselves. They have full responsibility to produce and deliver a pleasant and potable water. There is no one else to share the responsibility with them. Often, these operators receive fairly low pay, support from others is minimal, there never is enough of the right kinds of tools, money for maintenance and repairs is always of concern, and nobody appreciates how hard the operator works. If you are in this position, you can do a good job if you use a lot of imagination and initiative. We hope this manual will provide you with the information to convince your supervisors and consumers that you need more help to do your job.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 275.

4.0A Why is a water supply that needs no treatment very rare?

4.0B How does the storage of raw water in lakes, ponds, or reservoirs help the water treatment plant operator?

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[5] *Oxidation.* Oxidation is the addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound; in the environment and in wastewater treatment processes, organic matter is oxidized to more stable substances. The opposite of REDUCTION.

[6] *Precipitate* (pre-SIP-uh-TATE). (1) An insoluble, finely divided substance that is a product of a chemical reaction within a liquid. (2) The separation from solution of an insoluble substance.

[7] *Calcium Carbonate ($CaCO_3$) Equivalent.* An expression of the concentration of specified constituents in water in terms of their equivalent value to calcium carbonate. For example, the hardness in water that is caused by calcium, magnesium, and other ions is usually described as calcium carbonate equivalent. Alkalinity test results are usually reported as mg/*L* $CaCO_3$ equivalents. To convert chloride to $CaCO_3$ equivalents, multiply the concentration of chloride ions in mg/*L* by 1.41, and for sulfate, multiply by 1.04.

4.0C What information does an operator obtain from a flowmeter?

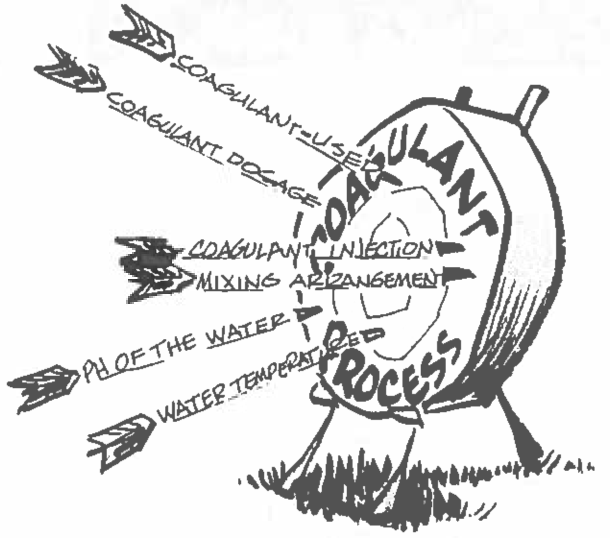
4.0D How can a flowmeter be protected?

4.0E Groundwaters may require what types of treatment?

4.1 COAGULATION

Coagulation is the chemical reaction that occurs when a coagulating chemical is added to water. The most common coagulating chemical used is aluminum sulfate (alum) but other chemicals are sometimes used. When one of these coagulants is added to water, it reacts directly with the water and with certain minerals dissolved in the water to form floc particles. These are small, jelly-like, filmy particles that look like snowflakes.

The coagulant also reacts physically with the fine particles of suspended matter in the water. These particles, which cause the water to appear turbid or cloudy, normally have a negative electrical charge on their surface. This charge causes the particles to repel one another and remain suspended in the water rather than clumping together and settling to the bottom. The effect of the coagulant is to neutralize the negative charge on the suspended particles (destabilize the particles) so they can be brought together into larger clumps that are heavy enough to settle.



Many factors affect the coagulation process. Among the most important are the coagulant used, the coagulant dosage, the pH of the water, the mineral content of the water, the water temperature, and the coagulant injection-mixing arrangement. Under any given set of conditions, a particular water requires a certain optimum dosage of coagulant for coagulation to be successful. If the coagulant dosage is either too high or too low, coagulation will be incomplete and the results of treatment will be unsatisfactory. The pH of the water must be controlled within a narrow range during coagulation to achieve optimum results. The water must have an adequate *ALKALINITY*[8] content to achieve good coagulation with alum. The treatment is even more effective if the water contains abundant amounts of certain minerals, such as calcium and magnesium. Other chemicals (phosphate compounds for example) inhibit coagulation and require larger dosages of coagulant. Any chemical reaction proceeds faster when the water is warm than when it is cold and the method of injecting the coagulant and mixing it with the water has a very significant effect on the results of coagulation treatment. For effective treatment, the chemical must be completely mixed throughout the water being treated.

All these variables make it impossible to calculate what dosage of coagulant will produce the best results under a given set of conditions. Thus, in even the largest water treatment plant, the coagulant dosage must be estimated by performing a *JAR TEST.*[9] A jar test is a laboratory procedure in which varying dosages of coagulant are tested in a series of glass or plastic jars under identical conditions. A jar test apparatus like the one shown in Figure 4.4 is required for the test. The machine consists of a set of six paddle mixers (gang stirrer) all driven by a variable-speed motor. A jar containing the water to be treated is placed under each paddle mixer and varying dosages of coagulant are added to the jars. If the optimum dosage is suspected to be about 20 milligrams per liter of alum, that dosage plus both higher and lower dosages would be tested for comparison. For instance, the following dosages might be tested in one jar test series.

Jar Number	Alum Dosage, mg/*L*
1	14
2	16
3	18
4	20
5	22
6	24

After the proper coagulant dosage is added to each jar, the paddles are run at high speed for a short time to simulate rapid mixing. Then, the paddles are adjusted to a very low speed for a longer period of time to simulate conditions in the flocculation basin of the plant. After a period of time, the paddles are stopped and all jars are observed to evaluate the settling results. The evaluation can be made by simple visual observations or by performing further laboratory tests. Ordinarily, the operator will visually observe which coagulant dosage produces the first visible floc, which dosage produces the largest, strongest floc, or which dosage produces the floc that settles the fastest. On this

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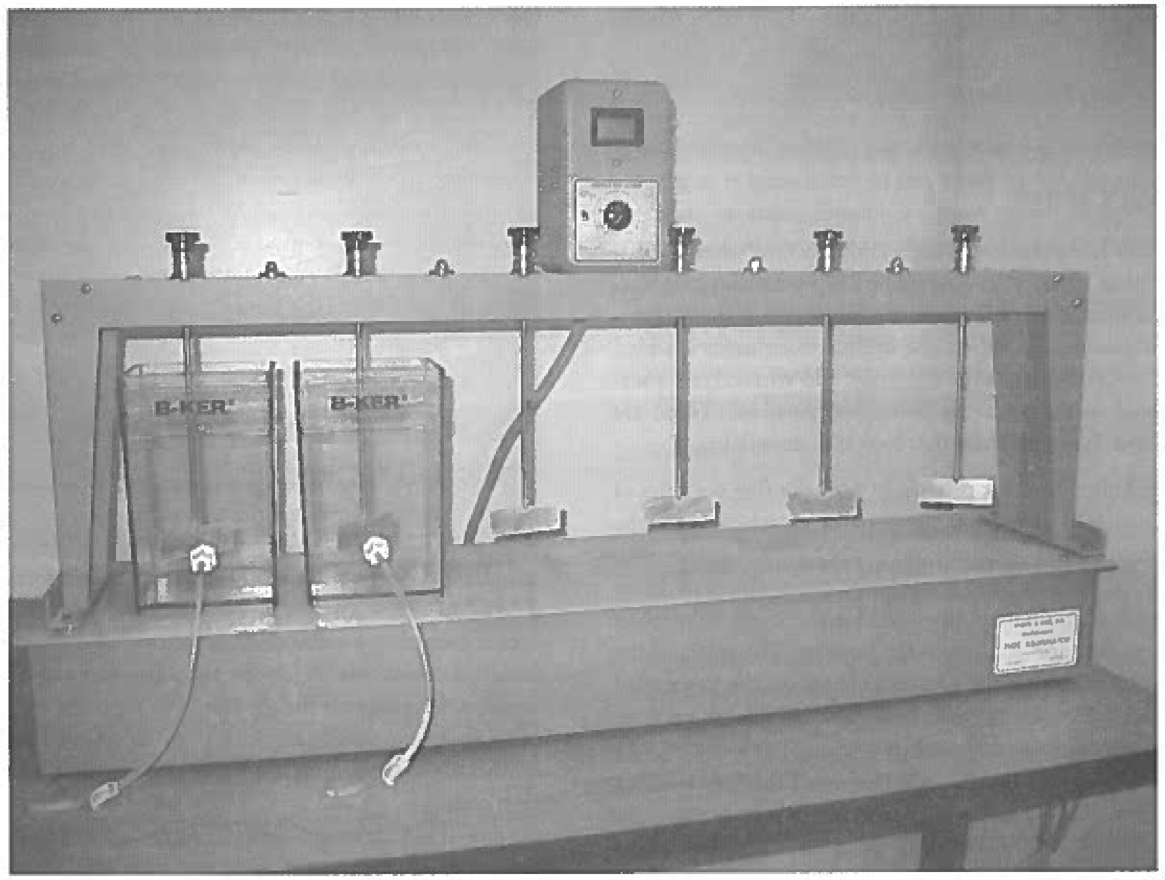
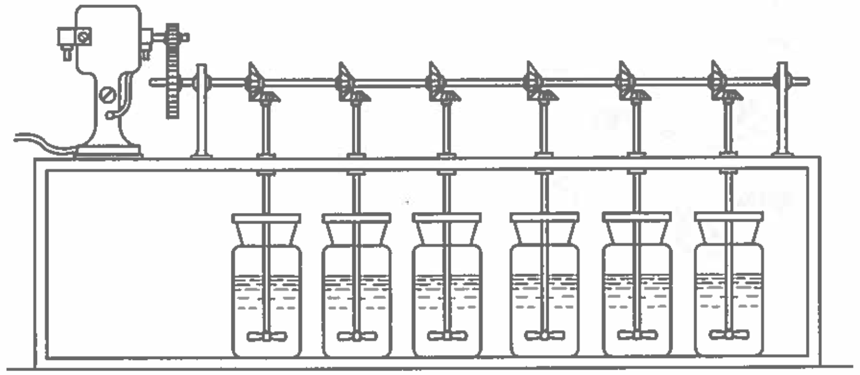
[8] *Alkalinity* (AL-kuh-LIN-it-tee). The capacity of water or wastewater to neutralize acids. This capacity is caused by the water's content of carbonate, bicarbonate, hydroxide, and occasionally borate, silicate, and phosphate. Alkalinity is expressed in milligrams per liter of equivalent calcium carbonate. Alkalinity is not the same as pH because water does not have to be strongly basic (high pH) to have a high alkalinity. Alkalinity is a measure of how much acid must be added to a liquid to lower the pH to 4.5.

[9] *Jar Test.* See Chapter 11, "Laboratory Procedures," in *WATER TREATMENT PLANT OPERATION,* Volume I, for additional details on how to perform the Jar Test.





Laboratory stirring device

(Reprinted from *HANDBOOK OF APPLIED HYDRAULICS*, by permission. Copyright 1952, McGraw-Hill Book Company)

Fig. 4.4 Jar test apparatus

basis the operator can often select the optimum dosage to use in the plant. Other laboratory tests that are sometimes used to evaluate a jar test are: (1) the pH of the water, (2) the turbidity of the settled water, and (3) the filterability of the water as determined by filtration through some type of small laboratory filter.

If the characteristics of the source water change rapidly because of storm conditions or other causes, jar tests may have to be conducted very frequently. At other times, when the raw water quality is nearly the same from day to day, a jar test may be necessary only on occasion to verify the dosage. Some operators measure the turbidity of the source water and perform the jar test to determine the optimum coagulant dosage. By keeping accurate records, they can develop a plot of turbidity as it relates to dosage. Whenever the turbidity changes, they have a good idea of the optimum dosage.

If you do not have a jar test apparatus, collect a water sample in a glass jar directly from the outlet of the rapid mix chamber in the plant. By gently hand stirring the water sample for a few minutes, you can sometimes get an idea of how well the water is coagulating. This method is crude but it is better than doing nothing to monitor coagulation.

Some operators will collect samples from the outlet of the rapid mix chamber and use this water for a jar test. They will add additional doses of coagulant to two jars and dilute a couple of the jars with raw water. Observing the results can indicate whether the dosage should be increased or decreased.

Streaming current meters are devices used by operators to optimize coagulant doses. The streaming current meter is a continuous on-line measuring instrument. Properly used, the streaming current meter can function as an on-line jar test.

Most particles in water are anions (negative charge) and most coagulants are cationic (positive charge). The streaming current meter presumes that by bringing the total charge of the water being treated to neutral (zero, 0), the coagulation process has been optimized. Most operators run the charge of their water slightly negative by adjusting the coagulant dose.

The manner in which the coagulant is injected into the water is very important for proper coagulation. The coagulant should be brought into contact with every portion of water and completely mixed with it as soon as possible. Therefore, the injection facilities and mixing equipment must be designed to produce good mixing. Mixing must be very rapid and turbulent because the coagulation reactions occur quickly, probably in the first few seconds and certainly within one minute. Experience has shown repeatedly that the optimum injection/rapid mix arrangement can greatly improve the results of coagulation and, at the same time, significantly decrease the amount of coagulant chemical that is used.

The best type of injector is usually one with multiple-feed orifices that will uniformly distribute the chemical solution throughout the flow of water. Thus, a perforated pipe that extends completely across the width of the channel or the diameter of the pipeline is a better injector than one that injects at a single point. Also, locating the injector at a point of turbulent flow, such as a *PARSHALL FLUME*,[10] provides better mixing than locating the injector in an area of smooth, quiet flow. Thorough distribution of the chemical in combination with violent mixing is the most desirable arrangement.

If coagulation is not properly done, the treatment processes that follow (*FLOCCULATION*,[11] settling, and filtration) will be much less effective in purifying the water. Suspended matter will pass through the filters because of poor coagulation and the treated water will be cloudy and turbid. Dissolved alum may also pass through the filters and coagulate later in the clear well reservoir or in distribution system pipelines, causing customer complaints about particles in the water and a dirty-tasting water. Therefore, if alum floc appears in the treated water or if alum is present in the treated water in concentrations greater than 0.1 mg/*L*, review the coagulation treatment for proper operation.

If you suspect that the coagulation treatment is substandard or if excessive dosages of coagulant are required, check the items listed below.

1. Perform a series of jar test experiments to simulate conditions in the treatment plant and determine the optimum coagulant dosage needed for the prevailing water quality conditions. Remember, the jar test is an indication of what is happening in your plant. You must observe the actual coagulation, flocculation, and settling in your plant to determine the optimum chemical dosage.
2. Measure the pH of the water after the coagulant is added. Is the pH the same that normally prevails when good coagulation occurs? A record of daily pH readings is very helpful in determining the optimum pH for coagulation under different conditions. Sometimes, jar tests are run at different pH levels to find the optimum pH. Coagulation may not occur unless the pH is very close to optimum.
3. Measure the alkalinity. Is adequate alkalinity present for the coagulation reaction to occur? If not, consider increasing the alkalinity to have at least 30 mg/*L* remaining when the chemical reactions are complete by adding sufficient lime or soda ash prior to coagulation.
4. Is the chemical feeder supplying the correct dosage of coagulant? The feeder may be broken or plugged up. Also, the feeder may be incorrectly adjusted. Measure the amount of chemical actually being fed and calculate the dosage. See Examples 1 and 2 on page 201. If the coagulant chemical is

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[10] *Parshall Flume* (PAR-shul FLOOM). A device used to measure the flow in an open channel. The flume narrows to a throat of fixed dimensions and then expands again. The rate of flow can be calculated by measuring the difference in head (pressure) before and at the throat of the flume.

[11] *Flocculation* (flock-yoo-LAY-shun). The gathering together of fine particles after coagulation to form larger particles by a process of gentle mixing. This clumping together makes it easier to separate the solids from the water by settling, skimming, draining, or filtering.

fed in the dry form, the operator can simply weigh the amount of coagulant that the feeder supplies in a certain period of time, say three minutes. A sensitive laboratory scale is needed to weigh the chemical accurately. If the coagulant chemical is fed in a water solution, the simple measuring device illustrated in Figure 4.5 can be used to measure the volume of solution supplied by the feeder pump in a given time. See Examples 3 and 4.

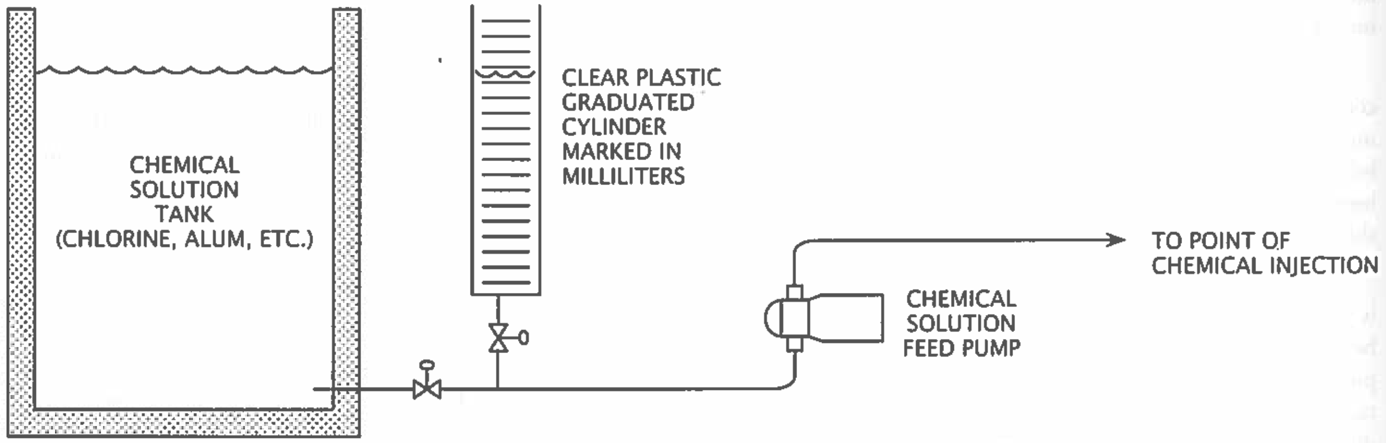
5. Does the chemical feeder inject a steady feed of chemical into the water? If the feeder injects in pulses or slugs, are the pulses as frequent as possible? If the feeder injects a slug only at rather long intervals, the chemical is not being uniformly distributed throughout the water. This can be corrected by diluting the chemical solution and readjusting the feeder pump to pulse more frequently.
6. Is the chemical injector distributing the coagulant completely throughout the flow of water? Injectors with multiple-feed orifices are better than those with a single-feed orifice.
7. Is violent, rapid mixing provided just after the chemical is injected into the water? If not, the operator can install a mechanical mixer or relocate the point of injection to a zone of turbulent flow such as a Parshall flume, a pump intake, or an in-line static mixer.
8. Consider use of a coagulant aid such as an organic *POLYMER.*[12]
9. Examine the source water for a change in quality due to pollution, stormwater runoff, use of a different water source, or other causes.
10. Modify conditions at the intake or diversion to provide a water of more uniform quality to the plant. If large temporary changes occur frequently in the source water (during a storm), if possible, turn off the plant and wait until water quality conditions are more stable and uniform.
11. Investigate the suitability of other coagulants. Pure aluminum sulfate is a cheaper and more effective coagulant than potassium alum or ammonium alum. These chemicals can be easily confused by suppliers and operators who are not aware of their differences.

For additional information on coagulation, see *WATER TREATMENT PLANT OPERATION,* Volume I, Chapter 4, "Coagulation and Flocculation," in this series of operator training manuals.

FORMULAS

In order to determine the actual feed rate of a dry chemical feeder:

1. Weigh a pan.
2. Place the pan under the feeder and then weigh the pan and chemicals.



The feed rate of a chemical solution feed pump can be determined by measuring the amount of solution withdrawn from a graduated cylinder in a given time period. Allow the cylinder to fill with solution. Then, close the valve on the line from the tank so the feed pump takes suction from the cylinder only. Observe the milliliters of solution used in one minute. Compare this result with the desired feed rate and adjust the feed pump accordingly.

Fig. 4.5 Calibration of a chemical feed pump

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[12] *Polymer* (POLY-mer). A long-chain molecule formed by the union of many monomers (molecules of lower molecular weight). Polymers are used with other chemical coagulants to aid in binding small suspended particles to larger chemical flocs for their removal from water. Also see POLYELECTROLYTE.

3. Record the time the pan collected the chemical.
4. Calculate the actual chemical feed or dose in pounds per day.

$$\text{Actual Chem Feed, lbs/day} = \frac{(\text{Weight of Chem, lbs})(60\ \text{min/hr})(24\ \text{hr/day})}{(\text{Time Chemical Collected, min})}$$

$$\text{Weight of Chem, lbs} = \frac{(\text{Weight, grams})}{454\ \text{grams/lb}} \qquad \text{(Use this formula only if scale weighs in grams.)}$$

In order to determine the desired feed rate from a dry chemical feeder:

1. Measure and record the flow of water being treated. If the flow is in gallons per minute (GPM), convert the flow to million gallons per day (MGD).
2. Determine the desired dose in mg/*L* using the jar test.
3. Calculate the desired feed rate in pounds per day.

$$\text{Desired Chem Feed, lbs/day} = (\text{Flow, MGD})(\text{Dose, mg}/L)(8.34\ \text{lbs/gal})$$

Dose, mg/*L*, is the same as Dose, lbs/Million lbs, therefore, multiplying Flow, MGD, times Dose, lbs/Million lbs, times 8.34 lbs/gal will give an answer in lbs/day.

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

In Figure 4.5, the chemical solution tank contains a hypochlorite solution containing 0.1 pound of chlorine per gallon of solution or the solution may be given as a percent. The clear plastic graduated cylinder is filled with the hypochlorite solution. In order to determine the actual feed rate of the chemical solution feed pump in pounds per day:

1. Pump a portion of the chemical solution from the graduated cylinder and record the volume pumped in milliliters.
2. Determine the time required to pump the volume in milliliters.
3. Calculate the concentration of the chemical solution in either milligrams per liter or milligrams per milliliter.

$$\text{Chem Conc, mg}/L = \frac{(\text{Chem Conc, lbs/gal})(1{,}000{,}000/\text{Million})}{8.34\ \text{lbs/gal}}$$

Where this formula converts lbs/gal to lbs/Million lbs, which is the same as mg/*L*.

or

$$\text{Chem Conc, mg}/L = (\text{Chem Conc, \%})(10{,}000\ \text{mg}/L/\%)$$

Where this formula uses the conversion factor that 10,000 mg/*L* is the same as a one-percent concentration, so 10,000 mg/*L*/% converts % to mg/*L*.

$$\text{Chem Feed, lbs/day} = \frac{(\text{Chem Conc, mg}/L)(\text{Vol Pumped, m}L)(60\ \text{min/hr})(24\ \text{hr/day})}{(\text{Time Pumped, min})(1{,}000\ \text{m}L/L)(1{,}000\ \text{mg/gm})(454\ \text{gm/lb})}$$

In this formula, Chemical Concentration, mg/*L*, is multiplied by Volume Pumped, m*L*, and divided by Time Pumped, min, and the conversion factors convert this result to Chemical Feed, lbs/day.

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

In this formula, we divide Chemical Feed, lbs/day, by Flow, MGD, and 8.34 lbs/gal. The result gives an actual dose of pounds of chemical per million pounds of water or milligrams of chemical per liter of water.

EXAMPLE 1

A pan is placed under a dry alum feeder for exactly three minutes. The pan and alum are weighed. The alum weighed 45.4 grams. What is the actual alum feed in pounds per day?

Known		Unknown
Time, min	= 3 min	Actual Alum Feed, lbs/day
Alum Weight, gm	= 45.4 gm	

1. Convert alum weight from grams to pounds.

$$\begin{aligned}\text{Alum Weight, lbs} &= \frac{\text{Weight, gm}}{454\ \text{gm/lb}}\\ &= \frac{45.4\ \text{gm}}{454\ \text{gm/lb}}\\ &= 0.1\ \text{lb}\end{aligned}$$

2. Calculate the actual alum feed rate in pounds per day.

$$\begin{aligned}\text{Actual Alum Feed, lbs/day} &= \frac{(\text{Alum Weight, lbs})(60\ \text{min/hr})(24\ \text{hr/day})}{\text{Time Alum Collected, min}}\\ &= \frac{(0.1\ \text{lb})(60\ \text{min/hr})(24\ \text{hr/day})}{3\ \text{min}}\\ &= 48\ \text{lbs/day}\end{aligned}$$

EXAMPLE 2

Jar tests indicate that a water should be dosed with alum at 20 mg/*L*. The flow being treated is 200 GPM. What is the desired alum feed in pounds per day?

Known		Unknown
Alum Dose, mg/*L*	= 20 mg/*L*	Desired Alum Feed, lbs/day
Flow, GPM	= 200 GPM	

1. Convert the flow from gallons per minute (GPM) to million gallons per day (MGD).

$$\begin{aligned}\text{Flow, MGD} &= \frac{(\text{Flow, gal/min})(60\ \text{min/hr})(24\ \text{hr/day})}{1{,}000{,}000/\text{Million}}\\ &= \frac{(200\ \text{gal/min})(60\ \text{min/hr})(24\ \text{hr/day})}{1{,}000{,}000/\text{Million}}\\ &= 0.288\ \text{MGD}\end{aligned}$$

2. Calculate the desired alum feed rate in pounds per day.

$$\begin{aligned}\text{Desired Alum Feed, lbs/day} &= (\text{Flow, MGD})(\text{Dose, mg}/L)(8.34\ \text{lbs/gal})\\ &= (0.288\ \text{MGD})(20\ \text{mg}/L)(8.34\ \text{lbs/gal})\\ &= 48\ \text{lbs/day}\end{aligned}$$

NOTES

1. The actual alum feed in Example 1 of 48 lbs alum per day agrees with the desired alum feed in Example 2 of 48 lbs alum per day. If the actual feed does not agree with the desired feed, then the actual feed rate should be adjusted.
2. Remember that actual performance is what counts. Jar tests are used to help you get close to the desired dose. Fine adjustments must be made on the basis of actual field tests and observations.

EXAMPLE 3

The chemical solution feed pump in Figure 4.5 removes 500 m*L* from the graduated cylinder in 4 minutes. The concentration of the hypochlorite solution is 0.1 pound chlorine per gallon. Determine the chemical feed rate in pounds per day delivered by the pump.

Known	Unknown
Volume Pumped, m*L* = 500 m*L*	Chemical Feed, lbs/day
Time Pumped, min = 4 min	
Chem Conc, lbs/gal = 0.1 lb/gal	

1. Calculate the chemical concentration in the graduated cylinder in milligrams per liter.

$$\text{Chem Conc, mg}/L = \frac{(\text{Chem Conc, lbs/gal})(1{,}000{,}000/\text{Million})}{8.34\ \text{lbs/gal}}$$

$$= \frac{(0.1\ \text{lb/gal})(1{,}000{,}000/\text{Million})}{8.34\ \text{lbs/gal}}$$

$$= \frac{12{,}000\ \text{lbs Chlorine}}{1\ \text{Million lbs Water}}$$

$$= 12{,}000\ \text{mg}/L$$

2. Determine the chemical feed rate of the pump in pounds of chlorine per day.

$$\text{Chem Feed, lbs/day} = \frac{(\text{Chem Conc, mg}/L)(\text{Vol Pumped, m}L)(60\ \text{min/hr})(24\ \text{hr/day})}{(\text{Time Pumped, min})(1{,}000\ \text{m}L/L)(1{,}000\ \text{mg/gm})(454\ \text{gm/lb})}$$

$$= \frac{(12{,}000\ \text{mg}/L)(500\ \text{m}L)(60\ \text{min/hr})(24\ \text{hr/day})}{(4\ \text{min})(1{,}000\ \text{m}L/L)(1{,}000\ \text{mg/gm})(454\ \text{gm/lb})}$$

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

NOTE: If the concentration of the hypochlorite solution in Example 3 was given as a 1.2-percent solution, then:

$$\text{Chem Conc, mg}/L = (\text{Chem Conc, \%})(10{,}000\ \text{mg}/L/\%)$$

$$= (1.2\%)(10{,}000\ \text{mg}/L/\%)$$

$$= 12{,}000\ \text{mg}/L$$

EXAMPLE 4

Calculate the actual chlorine dose in milligrams per liter in the water being treated in Example 3. The hypochlorinator (chemical feed pump) delivers 4.8 pounds of chlorine per day and the flow rate of the water being treated is 250,000 gallons per day (0.25 MGD).

Known	Unknown
Chemical Feed, lbs/day = 4.8 lbs/day	Actual Dose, mg/*L*
Flow, MGD = 0.25 MGD	

Calculate the actual chlorine dose in milligrams per liter.

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

$$= \frac{4.8\ \text{lbs/day}}{(0.25\ \text{MGD})(8.34\ \text{lbs/gal})}$$

$$= 2.3\ \text{mg}/L$$

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 275.

4.1A What is the influence of temperature on the coagulation process?

4.1B How are the results of jar tests evaluated?

4.1C How can operators determine whether the coagulant dose should be increased or decreased?

4.1D How can the alkalinity of the water being treated be increased?

4.2 FLOCCULATION

Flocculation is a process of slow, gentle mixing of the water to encourage the tiny floc particles to clump together and grow to a size that will settle quickly. When the particles of floc first form they are too small to be visible to the naked eye. A floc particle of this size is also too small to settle in a reasonable time. Therefore, the process of flocculation or gentle mixing is used to bring the small particles of floc and other suspended matter into contact with each other so they will stick together and form larger particles. By the time the floc particles grow to a size of about $\frac{1}{16}$ inch (1.5 mm) diameter or larger, they are usually heavy enough to settle out in a few minutes.

Flocculation can be accomplished either by mechanical mixers or by hydraulic mixing. Mechanical mixers are preferred because their performance can be predicted and controlled more accurately. The typical mechanical flocculator consists of a set of large, slowly rotating paddle wheels. The speed of the second paddle wheel may be slower than the first and the third may be slower than the second. In this manner, the mixing becomes progressively more gentle as the water flows through the flocculation basin. Designers believe that this tapered flocculation encourages the rapid growth of larger floc particles.

Other types of mechanical flocculators exist but the purpose of all flocculators is to provide gentle mixing that will produce a quick-settling floc. The mixing must be strong enough to prevent premature settling of floc in the flocculation basin, but the mixing must not be so strong that it breaks apart the floc particles already formed. Mechanical flocculators are preferred because their operation is flexible enough to maintain the proper mixing regardless of the rate of flow through the plant and because the degree of agitation can be adjusted to suit changes in water quality.

Flocculation is sometimes attempted by means of hydraulic mixing. Hydraulic mixing occurs when water flows around obstructions or obstacles such as a series of baffles or through a series of interconnected chambers. Around-the-end baffles are commonly used to create back and forth flow through a basin. Over and under baffles are used to create an up and down rolling motion to the flow of water. Other hydraulic devices such as orifices, weirs, or vortex chambers may also be used to create hydraulic mixing.

Most hydraulic flocculators suffer from serious drawbacks. Mixing is less uniform and controllable, being too violent in one spot and too gentle in another. While hydraulic flocculators may perform well at one rate of flow, they usually give poor results at flows greater or less than that for which they are designed. Thus, they have less flexibility of operation than mechanical flocculators because the degree of mixing depends on the flow rate.

The success of flocculation is affected by only a few factors. The primary factor is the degree of mixing. If mixing is too gentle, the suspended particles will not be brought into contact with one another and there will be fewer opportunities for large clumps of floc to form. Conversely, mixing that is too violent will tear apart the floc particles and prevent them from attaining proper size. The time of mixing is also important to proper flocculation. A minimum time of mixing is necessary for flocculation to be completed. Usually, a period of 30 to 45 minutes is sufficient. To ensure that all portions of the water are retained in the flocculator for the required time, it is important to limit *SHORT-CIRCUITING.*[13] This can usually be accomplished by proper baffling or by providing several compartments in series (one after another). Three or more compartments in series are recommended. A third factor affecting flocculation is the number of particles. A relatively clear water is harder to flocculate than a turbid water containing a lot of suspended matter. The difference is that the greater number of particles in the turbid water collide with one another more often.

If flocculation is not satisfactory in producing a floc that settles quickly and clarifies the water effectively, take the following corrective steps.

1. Correct any deficiencies in the coagulation process.
2. Check the degree of mixing. Be sure the mixing is neither too gentle nor too violent.
3. Make sure that mixing is provided for an adequate time period. The flow rate through the floc basin may be too high. Are actual flows greater than design flows?
4. See that short-circuiting of flow through the basin is prevented so each portion of the water is retained as long as possible.
5. Adjust the plant to operate on a more continuous basis for longer periods of time. Frequent ON/OFF operation is harmful to flocculation because the floc settles to the bottom when the plant is off and must be resuspended when it starts again. When adjusting flows, consider previous flows, expected demands, and available storage.

For additional information on flocculation, see *WATER TREATMENT PLANT OPERATION,* Volume I, Chapter 4, "Coagulation and Flocculation," in this series of operator training manuals.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 275.

4.2A What is flocculation?

4.2B What happens if the flocculation mixing is too strong or too weak?

4.3 SETTLING (SEDIMENTATION)

Settling or sedimentation is the process of holding the water in quiet, low-flow conditions so suspended matter and particles can be settled out by gravity to the bottom of the tank and removed as sludge.

The purpose of settling is to remove as much of the floc and other suspended material as possible before the water flows to the filters. Settling is thus the final step of pretreatment prior to filtration. Settling is an economical means of clarifying water; therefore, it is usually practiced whenever the water contains even a moderate amount of suspended matter. Settling may be omitted sometimes when the water contains only a small amount of suspended matter, but settling is required when a lot of suspended matter is present.

To understand the operation of a settling tank, it is helpful to think of it as having four zones. These zones are shown in Figure 4.6. The size of each zone varies and the boundaries between the zones are vague and indefinite rather than sharp and well defined.

---

[13] *Short-Circuiting.* A condition that occurs in tanks or basins when some of the flowing water entering a tank or basin flows along a nearly direct pathway from the inlet to the outlet. This is usually undesirable since it may result in shorter contact, reaction, or settling times in comparison with the theoretical (calculated) or presumed detention times.

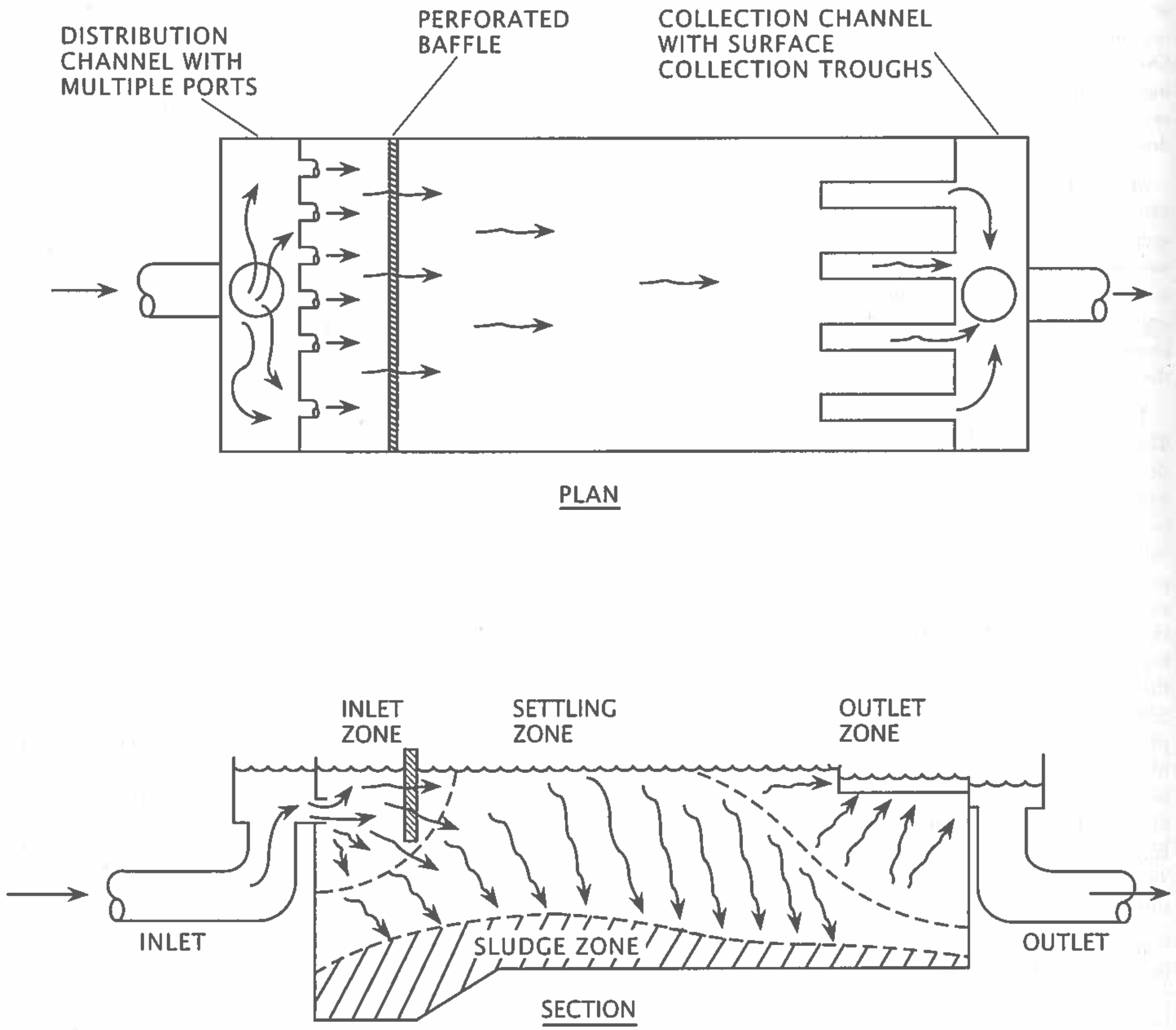


Fig. 4.6 Four zones of a settling tank

In the inlet zone, water entering the tank is distributed across the cross section of the tank and slows to a uniform flow velocity. Next, the water flows into the settling zone, which is the main part of the tank. Here, the water flows slowly through the tank and the suspended particles settle out. The settled material accumulates in the sludge zone at the bottom of the tank. At the end of the tank, the water enters the outlet zone, where it flows to the outlet, collects in suitable channels, and leaves the tank.

As the water flows through these zones in the settling tank, various factors have an important effect on the settling of suspended particles. Some of these factors are interrelated.

1. Time Provided for Settling

Commonly, a total settling time of two to four hours is provided. Related to the settling time is the flow velocity through the tank. The faster the water flows, the shorter time a particle has to settle out before the water reaches the outlet of the basin. The theoretical average flow velocity is usually limited to about one to three feet per minute (0.3 to 1 m/min). See Examples 5 and 6 on page 209.

2. Characteristics of the Suspended Matter

A dense particle of soil or sand will settle more quickly than a light floc particle. A dense, compact floc containing lots of suspended matter will settle quicker than a light, fluffy particle consisting only of alum floc. The coagulation and flocculation processes determine the settling characteristics of the floc.

3. Degree of Short-Circuiting Through the Tank

Short-circuiting occurs when some portions of water pass through the settling tank faster than others. The amount of short-circuiting depends on the shape and dimensions of the tank. For this reason, a long narrow settling tank is more effective than a short, wide tank. Short-circuiting is also affected by the inlet and outlet arrangements of the tank.

4. Tank Inlet and Outlet Arrangements

The inlet arrangement should distribute the incoming water over the full cross section of the settling tank. The water should be distributed evenly both horizontally and vertically, and high velocities and eddy currents should be avoided. This is usually done by using perforated baffles or channels with multiple openings.

The outlet arrangement should allow the water leaving the tank to be collected near the surface, but uniformly across the width of the tank. The aim is to prevent high flow velocities that will lift already settled particles and carry them out of the tank. Long weir troughs are commonly used to collect the water as well as pipes with multiple ports submerged just below the surface.

Relatively minor changes in the inlet or outlet arrangement in a settling tank can cause dramatic improvement in its settling efficiency.

5. Tank Overflow Rate

The tank overflow rate, sometimes called the surface loading rate, is determined by dividing the flow rate, Q, by the surface area of the tank. The overflow rate is normally expressed as gallons per day per square foot (GPD/sq ft or cu m/day/sq m). Typical values vary from 400 to 600 GPD/sq ft or 16 to 24 cu m/day/sq m. A lower rate is better than a higher one. See Example 6.

6. Currents in the Tank

Currents caused by flow inertia, wind action, temperature differences, and poor design can interfere with efficient settling, resuspend settled particles, and cause short-circuiting. The movement of mechanical sludge scrapers also causes currents that interfere with settling. Many small plants omit sludge scrapers to save costs.

7. Temperature of the Water

Any particle settles faster in warm water than in cold water because warmer water is less viscous (less syrupy) and offers less resistance.

8. Wind

High winds can cause surface currents to develop and cause turbulence, which will reduce settling.

The water leaving the settling tank should have a turbidity of less than five *TURBIDITY UNITS*[14] and not many floc particles should be carried out of the tank. If good settling is not being obtained, take the following actions to correct it.

1. Check the coagulation and flocculation processes to be sure they are operating as well as possible.
2. Decrease the rate of flow through the tank to lower the overflow rate and the velocity of flow, and to increase the time for settling to occur.

---

[14] *Turbidity* (ter-BID-it-tee) *Units (TU).* Turbidity units are a measure of the cloudiness of water. If measured by a nephelometric (deflected light) instrumental procedure, turbidity units are expressed in nephelometric turbidity units (NTU) or simply TU. Those turbidity units obtained by visual methods are expressed in Jackson turbidity units (JTU), which are a measure of the cloudiness of water; they are used to indicate the clarity of water. There is no real connection between NTUs and JTUs. The Jackson turbidimeter is a visual method and the nephelometer is an instrumental method based on deflected light.

3. Improve inlet conditions to reduce inlet velocity, distribute the flow uniformly, and create uniform flow velocities across the entire cross section of the tank. If more than one tank is used, make sure the flow is equally divided among the tanks as well.
4. Improve outlet conditions to eliminate excessive velocities toward the outlet. Install more weir troughs or outlet ports.
5. Remove accumulated sludge from the bottom of the settling tank.
6. Cover or screen the settling tank to diminish currents caused by changing wind and weather conditions.
7. Recycle sludge to the inlet of the settling tank to increase the number of particles in the water and improve flocculation of the settling particles.

High-rate or tube settlers were developed to increase the settling efficiency of conventional rectangular sedimentation basins. They have been installed in circular basins with successful results.

Water enters the inclined settler tubes and is directed upward through the tubes as shown in Figures 4.7, 4.8, and 4.9. Each tube functions as a shallow settling basin. Together, they provide a high ratio of effective settling surface area per unit volume of water. The settled particles can collect on the inside surfaces of the tubes or settle to the bottom of the sedimentation basin.

High-rate settlers are particularly useful for water treatment applications where site area is limited, in package-type water treatment units, and to increase the capacity of existing sedimentation basins. In existing rectangular and circular sedimentation basins, high-rate settler modules can be conveniently installed between the launders. High winds, however, can have an adverse effect on tube settlers.

Water treatment plant sludges are typically alum sludges, with solids concentrations varying from 0.25 to 10 percent when removed from the basin. In gravity flow sludge removal systems, the solids concentration should be limited to 3 percent. If the sludge is to be pumped, solids concentrations as high as 10 percent can be transported.

In horizontal-flow sedimentation basins preceded by coagulation and flocculation, over 50 percent of the floc will settle out in the first third of the basin length. Operationally, this must be considered when establishing the frequency of operation of sludge removal equipment. Also, you must consider the volume or amount of sludge to be removed and the sludge storage volume available in the basin.

Sludge may be discharged into sludge basins or ponds for liquid-solids separation. Ultimately, the sludge may be disposed of in a landfill.

For additional information on settling, see *WATER TREATMENT PLANT OPERATION,* Volume I, Chapter 5, "Sedimentation," in this series of operator training manuals.

FORMULAS

To calculate the settling time or detention time in a basin:

1. Determine the basin dimensions and volume.
2. Measure and record the flow of water being treated.

$$\text{Basin Volume, cu ft} = (\text{Length, ft})(\text{Width, ft})(\text{Depth, ft})$$

$$\text{Basin Volume, gal} = (\text{Basin Volume, cu ft})(7.48\text{ gal/cu ft})$$

$$\text{Detention Time, hr} = \frac{(\text{Basin Volume, gal})(24\text{ hr/day})}{\text{Flow, gal/day}}$$

To calculate the basin overflow rate or surface loading:

1. Determine the basin length and width to determine the surface area.
2. Measure and record the flow of water being treated.

$$\text{Surface Area, sq ft} = (\text{Length, ft})(\text{Width, ft})$$

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

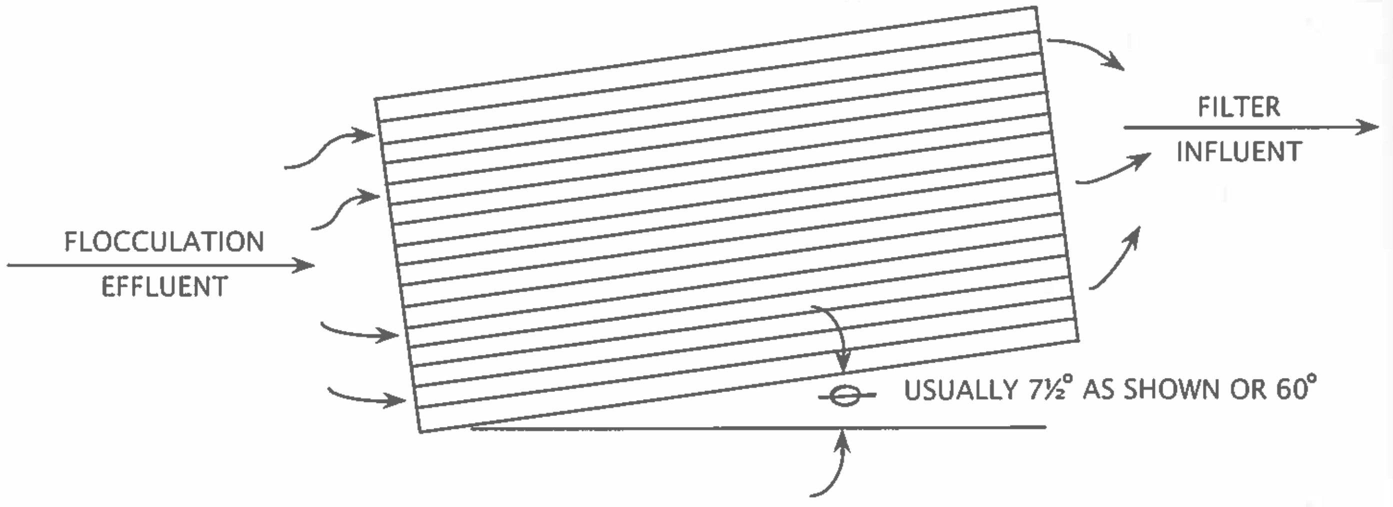


Fig. 4.7 Tube settler (installed in a rectangular or circular sedimentation basin)

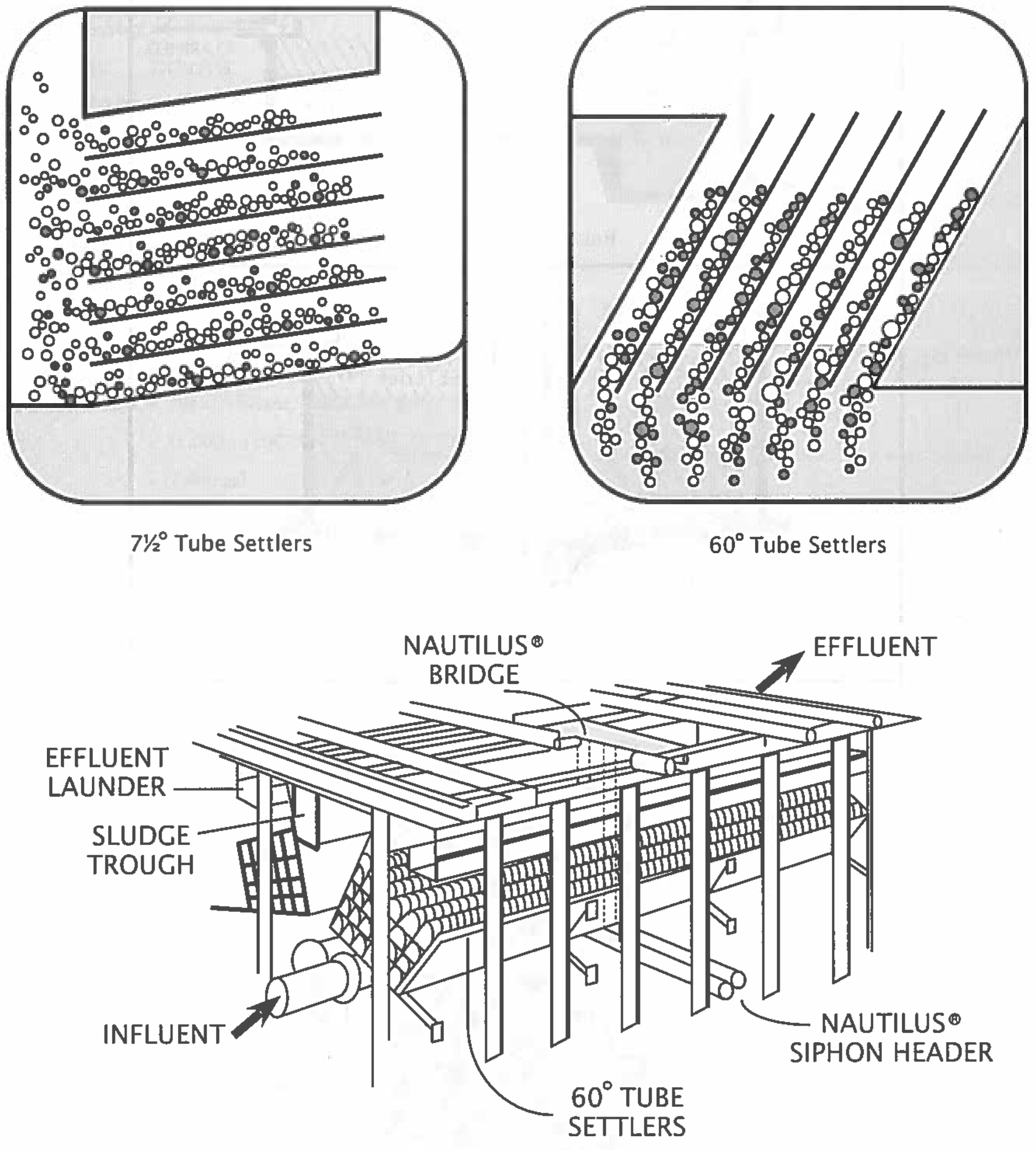
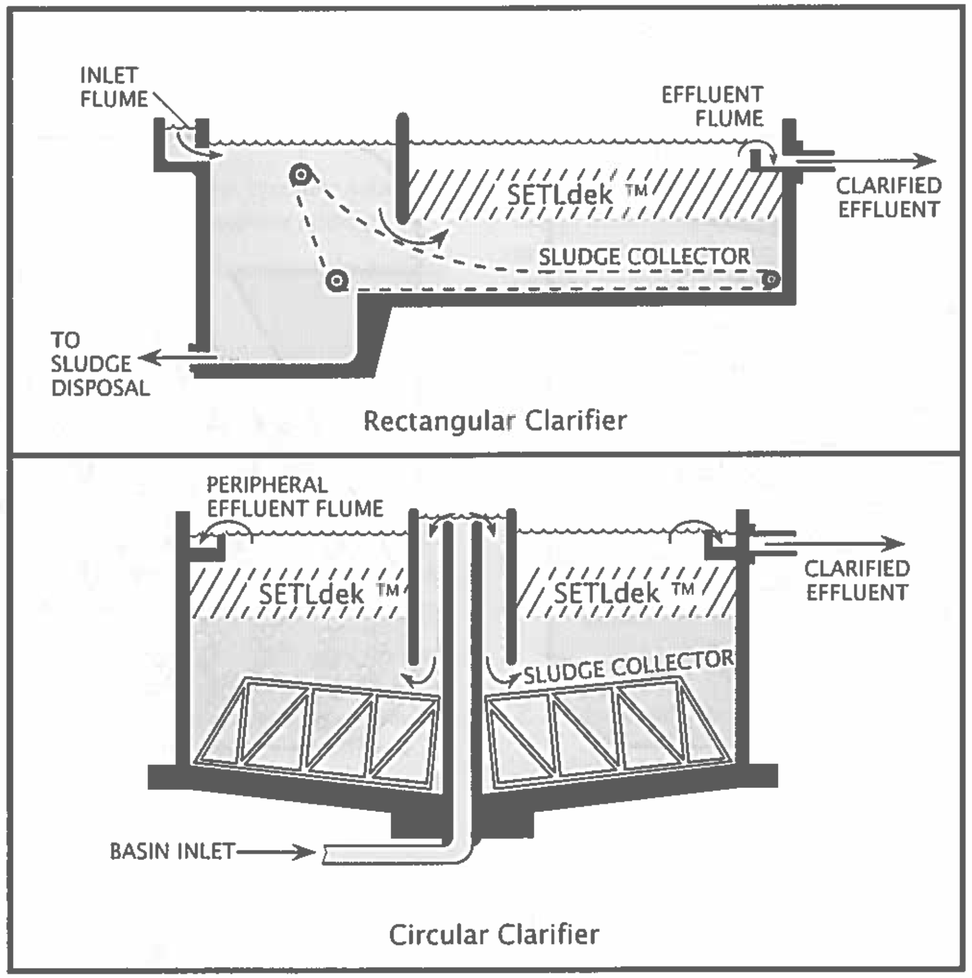
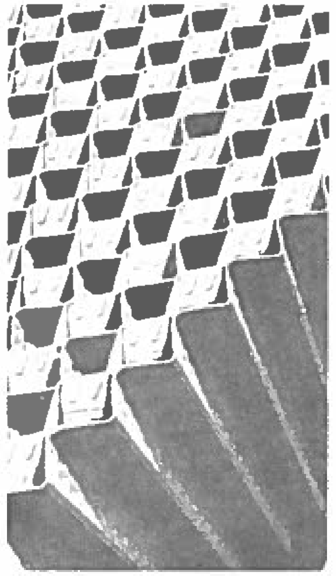


Fig. 4.8 Cutaway view of Floc/Tube clarifier

(Permission of Neptune Microfloc, Inc.)(Now Microfloc Products)





Cross-Fluted Design

Fig. 4.9 Tube settlers in rectangular and circular clarifiers
(Adapted from the Munters Corporation)

EXAMPLE 5

A rectangular settling basin 20 feet long, 10 feet wide, and with water 5 feet deep treats a flow of 60,000 gallons per day. Estimate the detention time or settling time in hours for this basin when conveying this flow.

Known		Unknown
Length, ft	= 20 ft	Detention Time, hr
Width, ft	= 10 ft	
Depth, ft	= 5 ft	
Flow, GPD	= 60,000 GPD	

1. Calculate the basin volume in gallons.

$$\text{Basin Volume, cu ft} = (\text{Length, ft})(\text{Width, ft})(\text{Depth, ft})$$
$$= (20 \text{ ft})(10 \text{ ft})(5 \text{ ft})$$
$$= 1{,}000 \text{ cu ft}$$
$$\text{Basin Volume, gal} = (\text{Basin Volume, cu ft})(7.48 \text{ gal/cu ft})$$
$$= (1{,}000 \text{ cu ft})(7.48 \text{ gal/cu ft})$$
$$= 7{,}480 \text{ gal}$$

2. Calculate the detention time or settling time in hours.

$$\text{Detention Time, hr} = \frac{(\text{Basin Volume, gal})(24 \text{ hr/day})}{\text{Flow, gal/day}}$$
$$= \frac{(7{,}480 \text{ gal})(24 \text{ hr/day})}{60{,}000 \text{ gal/day}}$$
$$= 3.0 \text{ hr}$$

EXAMPLE 6

A rectangular settling basin 20 feet long, 10 feet wide, and with water 5 feet deep treats a flow of 60,000 gallons per day. Estimate the overflow rate of the basin in gallons per day per square foot of surface area.

Known		Unknown
Length, ft	= 20 ft	Overflow Rate, GPD/sq ft
Width, ft	= 10 ft	
Depth, ft	= 5 ft	
Flow, GPD	= 60,000 GPD	

1. Calculate the surface area in square feet.

$$\text{Surface Area, sq ft} = (\text{Length, ft})(\text{Width, ft})$$
$$= (20 \text{ ft})(10 \text{ ft})$$
$$= 200 \text{ sq ft}$$

2. Determine the basin overflow rate in gallons per day per square foot.

$$\text{Overflow Rate, GPD/sq ft} = \frac{\text{Flow, gal/day}}{\text{Surface Area, sq ft}}$$
$$= \frac{60{,}000 \text{ gal/day}}{200 \text{ sq ft}}$$
$$= 300 \text{ GPD/sq ft}$$

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 275.

4.3A What is the purpose of settling?

4.3B Short-circuiting is influenced by what factors?

4.3C How does temperature influence particle settling?

4.3D Why is sludge recycled to the inlet of the settling tank?

4.4 FILTRATION

Filtration is the process of passing water through a porous bed of fine granular material to remove suspended matter from the water. The suspended matter is mainly particles of floc, soil, and debris; but it also includes living organisms such as algae, bacteria, viruses, and protozoa.

There are generally two types of filters used in water treatment. Both the gravity and pressure types are common. The traditional open gravity filter is shown in Figure 4.10. This filter is simply a tank with an open top that contains the water, the filtering media, and other filter equipment. Water enters the filter near the top and flows downward through the filtering media under the force of gravity, hence the name "gravity filter." At the bottom, the filtered water is collected in the underdrain system and flows out of the filter to the filtered water reservoir.

Slow sand filtration is a variation of the gravity filtration process. The physical structure of the filter resembles a standard gravity filter but the slow sand filter uses biological processes as well as physical straining to remove suspended particles from the water. Most small systems are now required to filter their water to comply with the Safe Drinking Water Act (SDWA) of 1986 and the Surface Water Treatment Rule (1989). Because of the importance of this technology, slow sand filtration will be discussed fully in Section 4.8 of this chapter.

The second common type of filter is the pressure filter (Figure 4.11). The pressure filter is completely enclosed in a watertight tank and the water is forced through the filter under pressure created by an elevated source, a pump, or other pressure source. When a bed of granular filtering media is used, the water enters the top of the filter tank and flows vertically

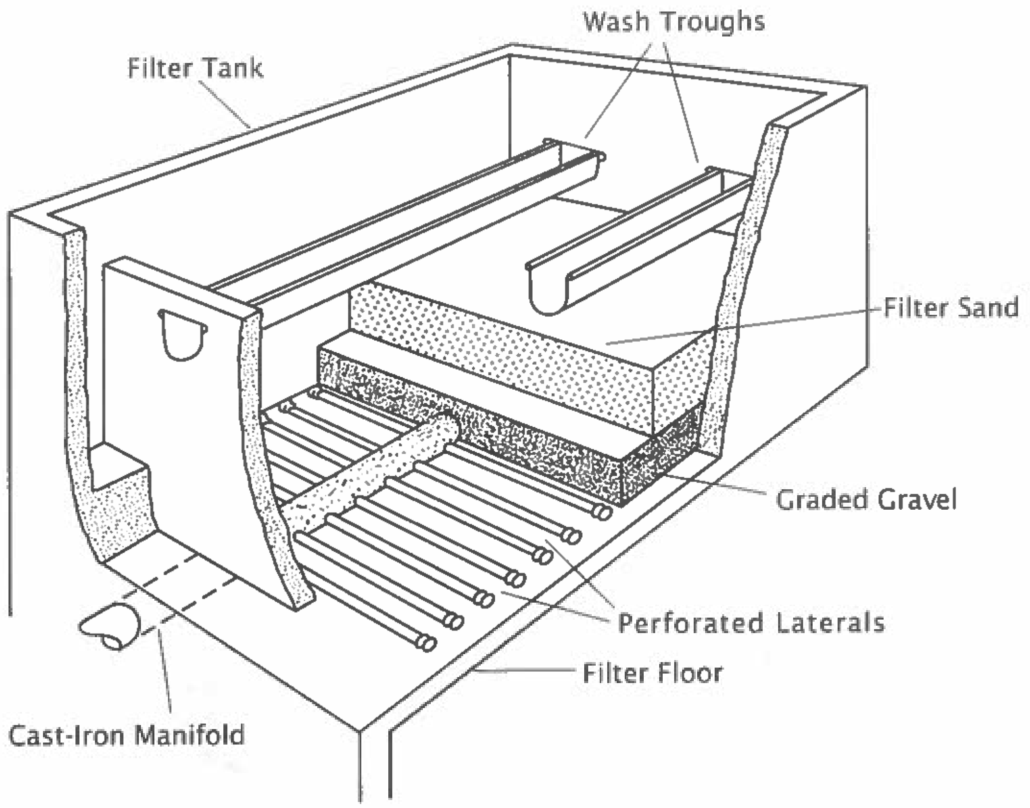


Fig. 4.10 Cutaway view of typical open gravity sand filter
(Reprinted from *WATER TREATMENT PLANT DESIGN*, by permission. Copyright 1969, the American Water Works Association)

downward as it does in a gravity filter. The underdrain system is also similar. Some types of pressure filters, called "precoat filters" (Figure 4.12), use *DIATOMACEOUS EARTH*[15] (DE) temporarily deposited on fabric or wire screen elements to accomplish the filtering action. Thus, the interior arrangement of a pressure filter can vary considerably from one manufacturer to another. Pressure filters frequently offer lower installation and operation costs in small filtration plants; however, they are generally somewhat less reliable than gravity filters (depending upon pressure). Some states do not recommend the use of pressure filters for treating surface waters.

Filtration is the final step in the overall solids removal process, which usually includes the pretreatment processes of coagulation, flocculation, and sedimentation. The configuration of these processes, or mode of operation, varies from plant to plant with respect to which steps are included in the process. Three modes (or methods) are common: conventional, direct, and diatomaceous earth. A fourth mode, slow sand filtration, is practiced in smaller plants in the United States, and is an acceptable method for purposes of meeting regulatory requirements.

Conventional Filtration: This mode of water treatment is suited for water sources where quality is highly variable or is high in suspended solids, and large volumes of water are required. This process is used in most municipal treatment plants in the United States. A conventional filtration plant commonly operates at filter rates of 2 to 3 GPM/sq ft, but can function up to 10 GPM/sq ft. This mode includes complete pretreatment (coagulation, flocculation, and sedimentation), and provides a great amount of flexibility and reliability in plant operations. A chemical application point just prior to filtration permits the application of a filter-aid chemical (such as a nonionic polymer) to assist in the solids removal process, especially during periods of pretreatment process upset, or when operating at high filtration rates.

Direct Filtration: Direct filtration is the same as conventional filtration except that sedimentation is omitted. Direct filtration is considered a feasible alternative to conventional filtration, particularly when source waters are low in turbidity, color, plankton, and coliform organisms. Filtration rates are usually in the range of 2 to 5 GPM/sq ft. As in conventional filtration, a chemical application point just prior to filtration permits the addition of a filter-aid chemical. Many direct filtration plants provide rapid mix, short detention without agitation (30 to 60 minutes) followed by filtration. Other direct filtration plants practice what is known as "in-line" filtration, which is the same as direct filtration without separate flocculation. With in-line operation, chemical filter aids are added directly to the filter inlet pipe and are mixed by the flowing water.

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[15] *Diatomaceous* (DYE-uh-toe-MAY-shus) *Earth*. A fine, siliceous (made of silica) earth composed mainly of the skeletal remains of diatoms.

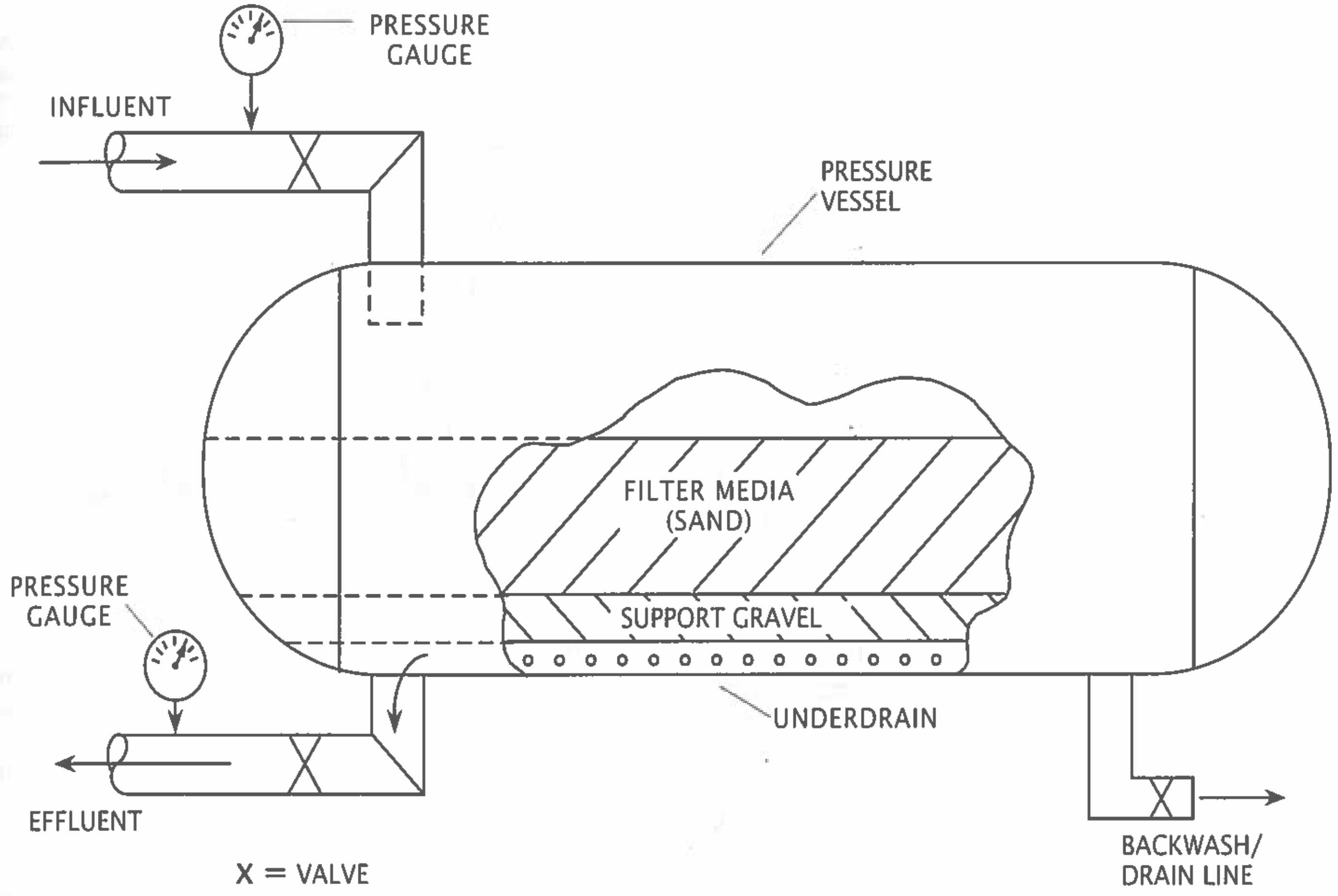

Fig. 4.11 Pressure filter

Diatomaceous Earth: In diatomaceous earth (precoat) filtration, the filter media is added as a *SLURRY*[16] to the water being treated; it then collects on a septum (a pipe conduit with porous walls) or other appropriate screening device as shown in Figure 4.12. After the initial precoat application, water is filtered by passing it through the coated screen. The coating thickness may be increased during the filtration process by gradually adding more media—a body feed. In most water treatment applications, diatomaceous earth is used for both the precoat and body-feed operations.

Diatomaceous earth filtration is primarily a straining process, and finds wide application where very high particle removal efficiencies (high clarity water) are required, such as in the beverage and food industries. Precoat filters can be operated as gravity, pressure, or vacuum filters. They are also commonly used in swimming pool installations due to their small size, efficiency, ease of operation, and relatively low cost. Use of these filters is limited in larger water treatment plants because of operational considerations such as flow rates and sludge (used diatomaceous earth) disposal requirements.

Slow Sand: In slow sand filtration, water is drawn downward through the filter media (sand) by gravity as it is in the gravity filtration process. However, this is generally where the similarity between these two filtration processes ends. In the slow sand filtration process, particles are removed by straining, *ADSORPTION*,[17] and biological action. Filtration rates are extremely low (0.015 to 0.15 GPM/sq ft or 0.01 to 0.1 liters per sec/sq m

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[16] *Slurry*. A watery mixture or suspension of insoluble (not dissolved) matter; a thin, watery mud or any substance resembling it (such as a grit slurry or a lime slurry).

[17] *Adsorption* (add-SORP-shun). The gathering of a gas, liquid, or dissolved substance on the surface or interface zone of another material.

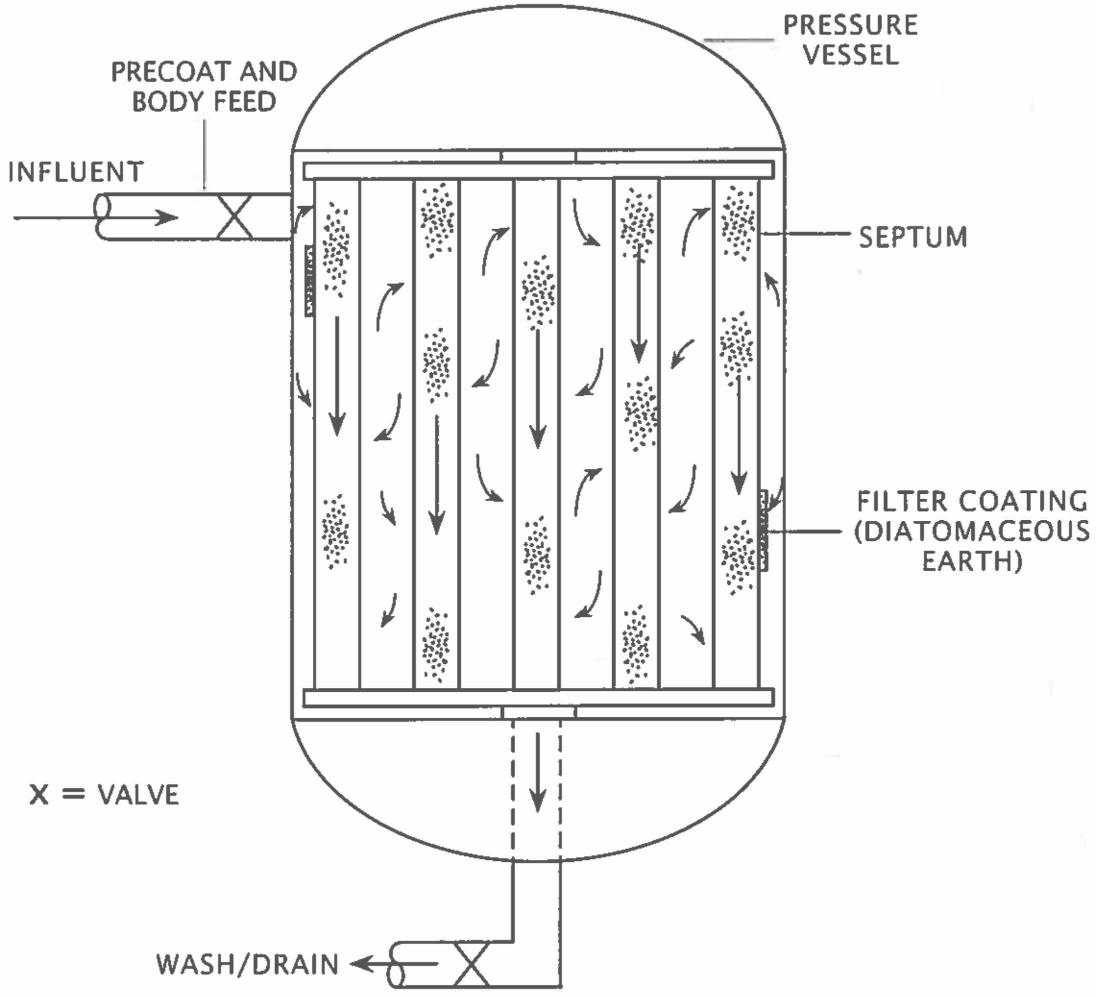

Fig. 4.12 Precoat filter

or 0.01 to 0.1 mm/sec). This process usually does not require pretreatment for most surface waters. The majority of the particulate material is removed in the top few inches of sand, so this entire layer must be physically removed, rather than backwashed, when the filter becomes clogged. This filtration process has found limited application due to the large area required and the need to manually clean the filters, but its efficiency in removing or inactivating disease-causing organisms has sparked interest in the process.

Chemical coagulation is absolutely essential for effective filtration except when using the slow sand process. Filters using a granular filter media will not effectively remove fine suspended matter unless coagulation treatment is provided. Without coagulation, the filter will operate only as a strainer that removes the large, coarse particles while the fine particles of suspended matter will easily flow right between the grains of filter media and pass through the filter without being removed. Only proper coagulation can make a granular media filter perform effectively to clarify the water.

Sand is the most frequently used filtering media for treatment of domestic water. The sand should be a hard material like quartz so it will not erode and crumble or easily dissolve in water. The depth of sand may vary from 20 to 30 inches (50 to 75 cm). A depth of 24 inches (60 cm) is common but some filters of special design may have only 6 to 12 inches (15 to 30 cm) of sand.

Raw sand from just any source is not suitable for filter media. This sand usually is not the right size and it is not properly "graded," that is, the different sizes are not present in the correct proportion. Therefore, filter sand must be prepared by screening the raw sand through a set of sieves and mixing the sand retained on each size sieve in the proper proportion. When this mixing operation is completed, the sand should consist of grains ranging in size from about 0.2 to 1.2 millimeters.

Anthracite is the second most frequently used filtering media. Anthracite is hard coal. Ordinarily, anthracite is prepared by crushing the coal and sieving it to achieve the proper gradation. Properly graded anthracite will consist of grains ranging in size from about 0.5 to 3.0 millimeters.

Anthracite may be used as the only filtering media but it is more commonly used along with sand. When the two materials are used together, the filter is called a "dual media" filter. In the dual media filter, about 6 to 10 inches (15 to 25 cm) of sand is placed on the bottom and 18 to 24 inches (45 to 60 cm) of anthracite is placed on top. Since the sand is about two and a half times heavier than water and anthracite is only about one and a half times heavier than water, the two materials stay separated and in the same relative positions (anthracite on top and sand on the bottom) even after backwashing.

Sometimes, a layer of crushed *GARNET*[18] media is used at the bottom of the filter in addition to the sand and anthracite. In this case, the filter is called a "mixed media" filter.

Small filters containing replaceable cartridge-type elements are sometimes used in homes or very small treatment plants. When the elements become plugged with dirt, they must be discarded and replaced since they cannot be cleaned and reused. The cost of replacement elements is often a significant expense.

The underdrain system of the filter is at the bottom beneath the filtering media. This system has several important functions:

1. To support the filtering media and prevent the media from passing out the bottom of the filter
2. To collect the filtered water and convey this water out of the filter when the filter is in normal operation
3. To uniformly distribute the backwash water across the filter bed and provide uniform upward flow

Of these three functions, the most important is uniform distribution of the backwash water.

The underdrain system usually consists of two parts, the gravel layers and the water conduits. The gravel layers, which are on top, usually consist of several layers of different size gravel. The uppermost layer of gravel, which is in contact with the sand, may be $\frac{1}{16}$ to $\frac{1}{8}$ inch (1.5 to 3 mm) in diameter and about three inches (75 mm) thick. There may be as many as six different layers of gravel, each larger in size than the one above. The bottom layer may be as large as 1 $\frac{1}{2}$ to 2 $\frac{1}{2}$ inches (35 to 65 mm) in diameter. The total depth of the gravel layers may vary from 12 to 24 inches (30 to 60 cm).

The bottom part of the underdrain system consists of the water conduits for collection of the filtered water and distribution of the backwash water. These conduits may consist of a large central header pipe with numerous small pipe laterals branching off the header. The header-lateral underdrain system is more common in older or smaller filters. Newer and larger filters most often use an underdrain system consisting of a false bottom constructed of porous stone plates or perforated hollow blocks of vitrified clay.

A rate-of-flow control valve orifice is normally placed in the effluent line from each filter. The purpose of this valve is to somewhat equalize the flow among all the filters and to prevent excessive rates of filtration by limiting the rate of flow through each filter to a predetermined value. The rate-of-flow controller also is used to maintain a constant flow through a given filter during the entire filter run. As the head loss through the filter builds up, the controller opens up to maintain a constant flow.

The rate of filtration, usually expressed in gallons per minute per square foot of filter area (GPM/sq ft), is an important characteristic of any filter. The slow sand filters built in the past operated at a filtration rate of about 0.05 GPM/sq ft (0.034 mm/sec or 0.034 liter per sec/sq m). When rapid sand filters were developed, they were usually designed to operate at a filtration rate of two GPM/sq ft (1.4 mm/sec or 1.4 liters per sec/sq m), approximately 40 times faster. Modern filters using dual media and improved design can operate at rates ranging from three to five GPM/sq ft (2 to 3.4 mm/sec or 2 to 3.4 liters per sec/sq m). In a very few cases, filters have been designed and operated successfully at rates ranging from six to eight GPM/sq ft (4 to 5.4 mm/sec) or even as high as 10 GPM/sq ft (6.8 mm/sec or 6.8 liters per sec/sq m), but these filters are rare.

Successful operation of filters at high rates requires the following conditions:

1. Good design by a knowledgeable engineer or consultant
2. Use of dual or mixed media
3. Surface wash apparatus to assist cleaning of the media during backwash
4. Use of polymers or other filter aids

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[18] *Garnet.* A group of hard, reddish, glassy, mineral sands made up of silicates of base metals (calcium, magnesium, iron, and manganese). Garnet has a higher density than sand.

5. Turbidimeters that continuously monitor the performance of the filters
6. Competent operators on duty continuously whenever the plant is operating
7. Excellent pretreatment (coagulation, flocculation, and settling) to properly condition the water prior to filtration

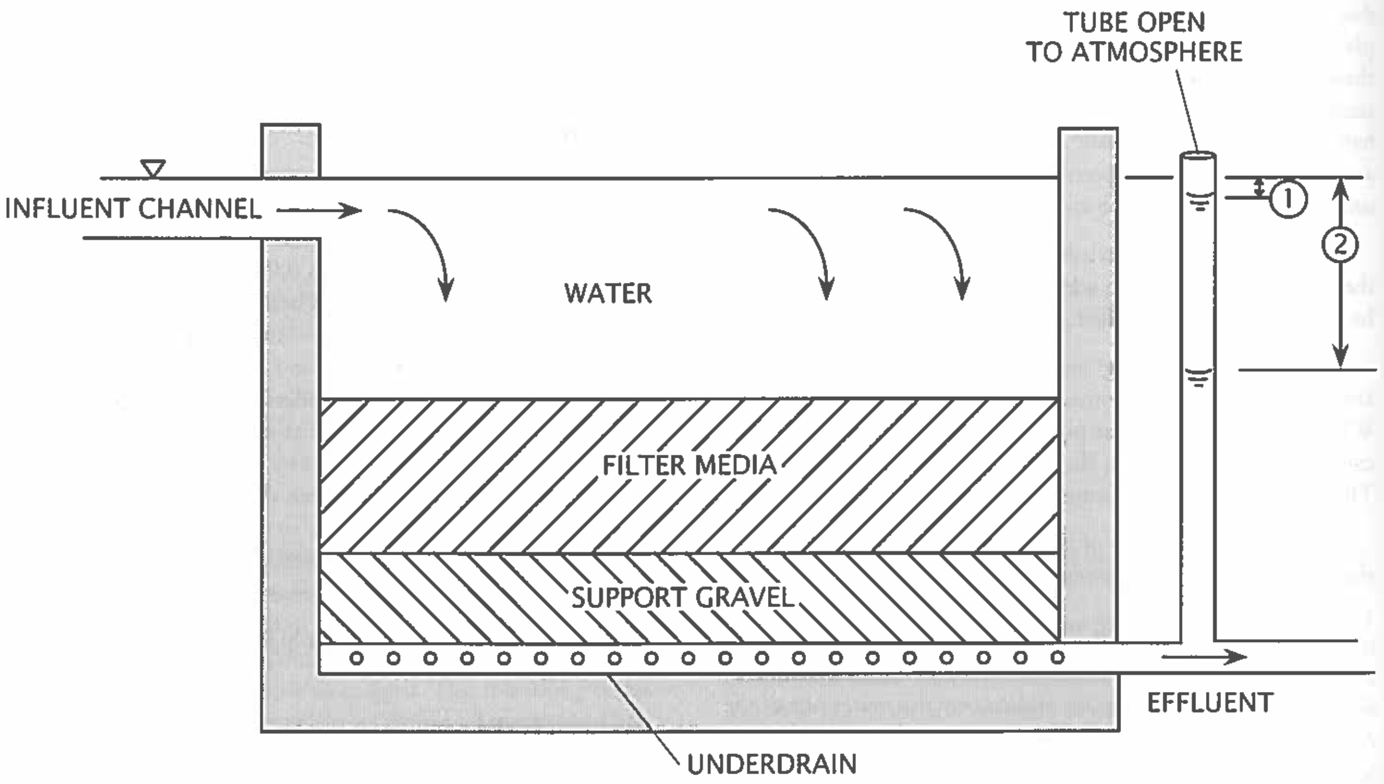
Since these conditions usually do not prevail in small water treatment plants, the rate of filtration should usually be restricted in small filters, or ones of poor design, to no more than about two GPM/sq ft (1.4 mm/sec or 1.4 liters per sec/sq m). See Example 7 on page 219.

As a filter operates, it continuously removes suspended matter from the water passing through it. Eventually this matter clogs the openings through the filter and the flow of water is reduced. Another sign of a dirty filter is breakthrough of excessive turbidity in the filtered water.

When a filter is operating properly, the head loss through the filter media will build up gradually (Figure 4.13). The actual head loss is measured by a filter head loss gauge that is monitored by the operator. The head loss should never be as great as the distance from the water surface to the top of the filter media.

The rate of head loss buildup is an important indicator of filter performance. Sudden increases in head loss might be an indication of surface sealing of the filter media (lack of depth penetration). Early detection of this condition may permit you to make appropriate process changes such as adjustment of the chemical filter-aid feed rate or adjustment of filtration rate.

When the filter becomes dirty (high head loss) it must be cleaned by backwashing. This is a process of reversing the direction of flow through the filter to flush the dirt out of the media. The backwash water enters the underdrain system at the bottom of the filter and flows upward through the filter media. The flow of backwash water is regulated to a rate that will separate the individual grains of media and suspend them in the flow of water. When the media is thus expanded, the grains scrub each other and the dirt particles are flushed out. Backwashing continues until the filter is clean; usually about five to ten minutes are required.



NOTE: If a tube open to the atmosphere was installed in the filter effluent, then

1. Head loss through filter at start of run, and
2. Head loss through filter before start of backwash cycle.

Fig. 4.13 Head loss through a filter

In gravity filters, the backwash water is collected at the top of the filter in troughs that drain it away to waste. In pressure filters, the backwash water is piped to waste by manipulating the proper valves.

The backwash water supply system should provide a maximum upward flow rate of 15 to 20 GPM/sq ft (10 to 13.6 mm/sec or 10 to 13.6 liters per sec/sq m). This is common for sand media. The actual flow rate required for satisfactory backwash will depend on the size and specific gravity of the media and the temperature of the water. Thus, a lower flow rate will be necessary for anthracite than for sand. And, a lower flow rate will be necessary when the water is cold than when it is warm. In any case, backwash flow must be adequate to lift the individual grains of filter media and expand the filter bed so the foreign matter collected in the bed can be flushed out. Separating the grains of media allows them to scrub each other clean of the coating of floc or dirt. Typically, the filter bed will be expanded to 120 to 150 percent of its normal depth. However, the operator must be careful that the flow rate is not so high that the filter media itself is flushed out of the filter and lost during backwashing. See Example 9.

The frequency of backwashing may vary from a few hours to a few days depending on how quickly the filter plugs or on the quality of the filtered water. The filter head loss gauges indicate how quickly the filters are plugging and when they need backwashing. Under unfavorable conditions, when there is lots of suspended matter in the water being filtered, the filter will plug rapidly and may require backwashing several times a day. At other times, when the water to be filtered contains only small amounts of suspended matter, the filter will plug slowly and it may operate from several days up to a week before backwashing is required.

However, backwashing is also required whenever the filtered water quality becomes unacceptable. If the turbidity of the filtered water suddenly increases above the level permitted by standards, backwashing is necessary even though flow through the filter is not seriously affected by plugging.

Operators of small filter plants try to achieve the longest possible filter runs, try to use the minimum amount of backwash water, and try to produce the best possible filtered water quality (turbidities of less than 0.1 turbidity unit is a recommended target). For good operation, you should not have to use more than two percent of your filtered water for backwashing. Depending on the quality of the source water, daily backwashing may be often enough. In some cases, filters may be operated two or three days without backwashing, but longer periods are not recommended.

Surface wash jets are used on filters to improve the efficiency of backwashing. Surface wash is especially good for dual media and mixed media filters. The water jets may be either on a fixed grid or on a rotating arm suspended above the surface of the filtering media. Compressed air is sometimes supplied with the water to the jets. The purpose of the surface wash jets is to provide additional agitation to break up any crust or *MUDBALLS*[19] that may form at the surface of the filter bed and to improve cleaning of the media. Surface washing can be very helpful and should be used whenever available. Therefore, if a permanent system of surface wash jets is not provided, the operator should use a handheld hose with a fire nozzle to apply a powerful blast of water to the top of the filter media. The blast of water should be applied to the exposed media before and when the backwash water first starts to flow to assist cleaning of the media.

Only fully treated water should be used for filter backwashing. Untreated or partially treated water should not be used because it will contaminate the filter media and underdrain system, and it may leave the filter more dirty after backwashing than it was before. In gravity filter plants, the treated water for backwashing may be supplied by gravity flow from a backwash water storage tank or by special backwash pumps that draw water from the clear well. A third alternative for backwash water supply is gravity flowback from the distribution system itself.

In pressure filter plants, the backwash water is most commonly produced by the filters themselves as it is used. In this mode of operation, the treated water produced by three of the pressure filters is used to backwash the fourth. The filters are backwashed in sequence, one after another, until all are clean. This scheme requires the plant to be out of production while the filters are backwashing, but normally this is not a serious drawback. Figure 4.14 shows the in-service and backwash flows for a pressure filter plant.

The waste backwash water is usually very muddy and it must be disposed of properly. The backwash water may be simply flushed to waste into the nearest stream or drainage ditch. This practice is considered a source of pollution and is not recommended. Disposal to a sanitary sewer system is sometimes possible. Many small plants can simply retain the backwash water in a small pond where it will evaporate or seep into the ground. If an evaporation pond is not practical, the backwash water can be contained in a tank or basin until the heavy material settles. Then, the clear water can be drawn off and recycled to the inlet of the treatment plant for pretreatment. The settled sludge is periodically removed to a landfill for disposal.

The performance of a filter must be monitored frequently or continuously if possible. Several different manufacturers supply turbidity meters (turbidimeters) that can continuously measure the turbidity of the treated water produced by a filter. Turbidimeters are also available for testing individual water samples collected on a grab basis; however, the continuous-reading instruments are much better for monitoring the performance of a filter because they give a rapid indication of any momentary change in quality. This rapid indication feature is indispensable when a polymer is used as a filter aid or when the operator

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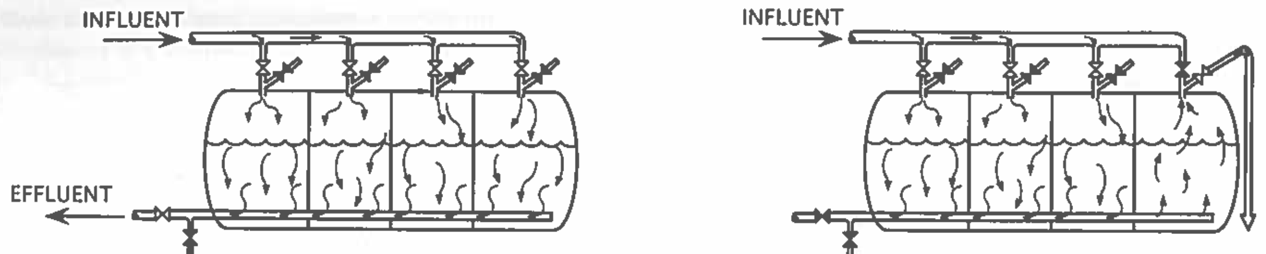
[19] *Mudballs.* Material, approximately round in shape, that forms in filters and gradually increases in size when not removed by the backwashing process. Mudballs vary from pea-sized up to golf-ball-sized or larger.

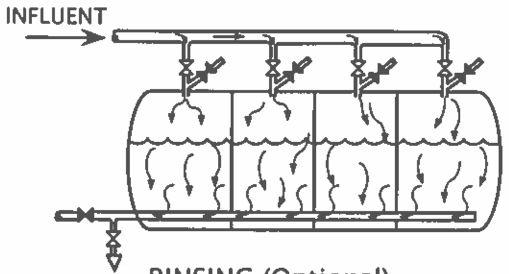


IN SERVICE

The influent water is distributed to each filter compartment, passes evenly through the media, is collected by the underdrain system, and leaves the filter through the effluent valve.

BACKWASHING

The effluent valve is closed. At the same time, the influent valve to one compartment is automatically closed. The backwash outlet valve to that compartment is opened. The influent water continues to filter downward through the remaining three compartments and upward through the fourth. This is repeated sequentially until the entire filter has been washed.



RINSING (Optional)

Before the filter is returned to service, a rinse valve is opened allowing rinsing of the entire filter to waste. At the completion of this step, the effluent valve is opened as the rinse valve closes, returning the unit to service.

Fig. 4.14 In-service and backwash flows for a four-compartment pressure filter

(Permission of Watermasters, Inc., Burlingame, CA)

wishes to detect the rapid rise of turbidity in the filtered water, which indicates breakthrough and the need to backwash.

If a turbidity instrument is not available, the operator should still make an effort to monitor the performance of the filters. A reliable judgment can often be made by simply observing the water in the clear well reservoir that receives the water from the filter. If the bottom of the reservoir is clearly visible through the full depth of water, the turbidity is probably very low. If the water is faintly cloudy and hazy, filter performance is probably substandard. A bright light beam shown through the water is usually a great help in judging the clarity. If the operator routinely observes the water every day, enough experience is soon gained to detect a change for the worse just by visual observation.

A properly operated filter plant should easily produce treated water with a turbidity of less than 1.0 turbidity unit and it should usually be less than 0.5 turbidity unit. A filtered water turbidity as low as 0.1 turbidity unit is achieved regularly by many filter plants that are well designed and operated properly. A filter plant that cannot consistently produce water with a turbidity of less than 1.0 turbidity unit is defective either in its design or in its operation, and measures should be undertaken to correct the problem.

Most filters have similar operation and maintenance needs. If the filters are not performing satisfactorily, check the following points and make appropriate corrections.

1. Verify that the coagulation, flocculation, and settling processes are performing as efficiently as possible. The turbidity of the settled water going to the filters should not exceed 5.0 turbidity units.
2. The rate of filtration should not exceed the design rate. Check the rate of flow controller on each filter to make sure they are preventing excessive filtration rates in any one filter.

3. The filter may need backwashing. Filters must be backwashed frequently, preferably every day. The backwash must effectively clean the filter media. Otherwise, mudballs will form in the media and eventually plug the filter completely. Maintain a permanent record of the backwash frequency and duration for each filter. Check the rate of backwashing to make sure it will adequately expand the media and flush out the dirt.

4. The filter must be operated so the rate of flow changes slowly. A rapid increase in the filter rate will very likely cause the filter to produce poorer quality water. For this reason, frequent ON/OFF operation of the filter should be eliminated. In addition, rapid operation of the backwash water valve can cause serious damage to the underdrain system. The backwash valve must always be opened very slowly.
5. The media must be inspected frequently to determine that it is in good condition. Gravity filters can be inspected easily through the open top, but pressure filters must be opened or taken apart to visually inspect the media. This should be done at least yearly and more often if necessary. Examine the media for loss in depth, mudballs, caking, surface cracks, and mounding or unevenness. Remove the mudballs and replace or replenish the media as required.
6. Determine the condition of the underdrain system by observing the filters during filtering and backwashing. If the gravel layers are upset or the underdrain conduits are broken, the media will escape through the bottom of the filter and appear in the filtered water. Substantial amounts of sand in the filter effluent pipe or filtered water reservoir (clear well) indicate definitely that the underdrain system needs repair.

   If gravel appears near the surface of the media or if the surface of the media is mounded instead of level, the underdrain system should be repaired and new gravel and media installed. Sand boils or other evidence of uneven upward flow during backwashing are further evidence of underdrain problems.
7. Accurate gauges must be provided to measure the loss of head or the pressure loss between the inlet and the outlet of the filter. These gauges give a good idea of how clean the filter is and when it needs backwashing. After a filter has been backwashed, the loss of head through the filter will gradually increase as particles are removed from the water being filtered. These particles will plug the spaces in the filter material and cause the head loss to increase. The operator should maintain a permanent record of the head (pressure) loss in each filter at the beginning and end of each filter run. Variations from past readings indicate a problem.
8. Consider feeding a polymer filter aid at the inlet to the filters. Very small dosages of the proper chemical can often make a startling improvement in the efficiency of filtration.
9. When checking pressure filters with multicells, inspect the plates inside the filters for cracks and breaks.

Figure 4.15 shows the installation of the small treatment plant loaded on the pickup shown in Figure 4.1. This plant consists of four vertical pressure filters. Pre- and postchlorination are used for disinfection. Alum is the coagulant. The filters are used to remove turbidity. In some installations, this same type of plant is used to remove iron and manganese by changing the media.

For additional information on filtration, see *WATER TREATMENT PLANT OPERATION,* Volume I, Chapter 6, "Filtration," in this series of operator training manuals.

FORMULAS

To calculate the filtration rate for a rapid sand filter:

1. Determine the dimensions of the filter and surface area.
2. Measure and record the flow of water being treated.

$$\text{Surface Area, sq ft} = (\text{Length, ft})(\text{Width, ft})$$

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

$$\text{Flow, gallons/min} = \frac{(\text{Water Drop, ft})(\text{Surface Area, sq ft})(7.48\ \text{gal/cu ft})}{\text{Time, min}}$$

In this formula, Water Drop, ft, times Surface Area, sq ft, gives the volume of water in cubic feet. Multiplying by 7.48 gal/cu ft converts cubic feet to gallons. Dividing the volume in gallons by Time, min, gives the flow in gallons per minute.

$$\text{Filtration Rate, GPM/sq ft} = \frac{\text{Flow, gal/min}}{\text{Surface Area, sq ft}}$$

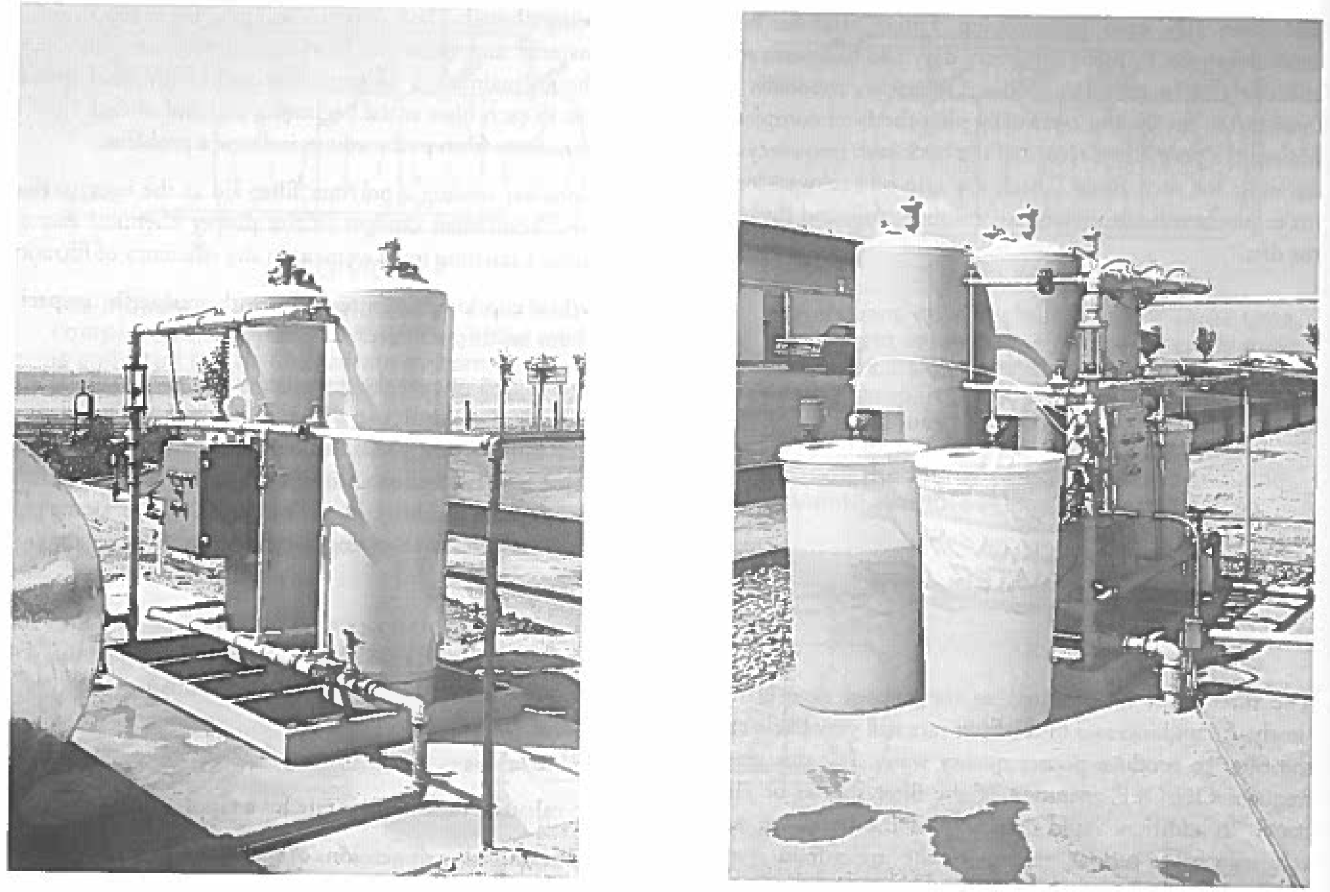
To determine the backwash flow rate for a gravity sand filter:

1. Determine the dimensions of the filter and surface area.
2. Measure and record the flow rate of the backwash water.

$$\text{Backwash Rate, GPM/sq ft} = \frac{\text{Flow, gal/min}}{\text{Surface Area, sq ft}}$$

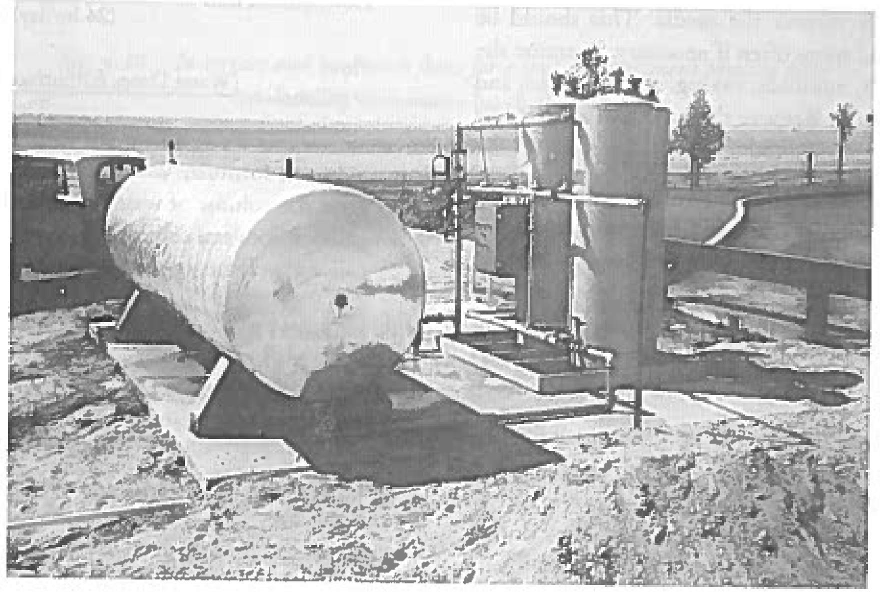
To determine the percent of water used for backwashing, divide the gallons of backwash water by the gallons of water filtered and multiply by 100 percent.

$$\text{Backwash, \%} = \frac{(\text{Backwash Water, gal})(100\%)}{\text{Water Filtered, gal}}$$



Pressure Filters

Chemical Containers



Hydropneumatic Tank

Fig. 4.15 Small pressure filtration plant
(Permission of Watermasters, Inc., Burlingame, CA)

EXAMPLE 7

A water treatment plant treats a flow of 2 MGD. There are two sand filters and each filter has the dimensions of 20 feet long by 20 feet wide. Determine the filtration rate in gallons per minute per square foot of filter. *NOTE:* Each filter treats a flow of 1 MGD.

Known	Unknown
Length, ft = 20 ft	Filtration Rate, GPM/sq ft
Width, ft = 20 ft	
Flow, MGD = 1 MGD	

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 MGD to GPM.

$$\begin{aligned}\text{Flow, gal/min} &= \frac{(\text{Flow, MGD})(1{,}000{,}000/\text{Million})}{(24\text{ hr/day})(60\text{ min/hr})}\\ &= \frac{(1\text{ MGD})(1{,}000{,}000/\text{Million})}{(24\text{ hr/day})(60\text{ min/hr})}\\ &= 694\text{ gal/min}\end{aligned}$$

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

$$\begin{aligned}\text{Filtration Rate, GPM/sq ft} &= \frac{\text{Flow, gal/min}}{\text{Surface Area, sq ft}}\\ &= \frac{694\text{ gal/min}}{400\text{ sq ft}}\\ &= 1.7\text{ GPM/sq ft}\end{aligned}$$

EXAMPLE 8

To check on the valve position of a controller in a filter, the influent valve to the filter was closed for five minutes. During this time period, the water surface in the filter dropped 1.25 feet (1 ft 3 in). The surface area of the filter is 400 square feet. Estimate the flow in gallons per minute.

Known	Unknown
Time, min = 5 min	Flow, GPM
Water Drop, ft = 1.25 ft	
Surface Area, sq ft = 400 sq ft	

Calculate the flow in gallons per minute.

$$\begin{aligned}\text{Flow, GPM} &= \frac{(\text{Water Drop, ft})(\text{Surface Area, sq ft})(7.48\text{ gal/cu ft})}{\text{Time, min}}\\ &= \frac{(1.25\text{ ft})(400\text{ sq ft})(7.48\text{ gal/cu ft})}{5\text{ min}}\\ &= 748\text{ GPM}\end{aligned}$$

EXAMPLE 9

Estimate the backwash rate for the filter in Example 7 if there are two backwash pumps capable of delivering 4,000 GPM each. The total backwash flow is 8,000 GPM.

Known	Unknown
Surface Area, sq ft = 400 sq ft	Backwash Rate, GPM/sq ft
Backwash Flow, GPM = 8,000 GPM	

Calculate the backwash rate in gallons per minute per square foot of surface area.

$$\begin{aligned}\text{Backwash Rate, GPM/sq ft} &= \frac{\text{Backwash Flow, gal/min}}{\text{Surface Area, sq ft}}\\ &= \frac{8{,}000\text{ GPM}}{400\text{ sq ft}}\\ &= 20\text{ GPM/sq ft}\end{aligned}$$

EXAMPLE 10

During a filter run, the total volume of water filtered was 1.20 million gallons. When the filter was backwashed, 18,000 gallons of water was used. Calculate the percent of filtered water used for backwashing.

Known	Unknown
Water Filtered, gal = 1,200,000 gal	Backwash, %
Backwash Water, gal = 18,000 gal	

Calculate the percent of water used for backwashing.

$$\begin{aligned}\text{Backwash, \%} &= \frac{(\text{Backwash Water, gal})(100\%)}{\text{Water Filtered, gal}}\\ &= \frac{(18{,}000\text{ gal})(100\%)}{1{,}200{,}000\text{ gal}}\\ &= 1.5\%\end{aligned}$$

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 275.

4.4A What is included in the suspended matter removed by filtration?

4.4B Why do anthracite and sand stay separated during and after backwashing?

4.4C What is a mixed media filter?

4.4D Under what conditions will mudballs form in filters?

4.5 DISINFECTION

The purpose of disinfection in domestic water treatment is to kill or inactivate any disease-causing organisms that may be present. There are several types of disease-causing organisms and each type has different characteristics that are important to understand.

1. Bacteria

   Bacteria are microscopic organisms. Individual bacteria are usually so small they are invisible to the naked eye. Therefore, it is impossible to tell if bacteria are present simply by looking at the water. A glass of water may be sparkling clear and appear to be pure but actually contain millions of bacteria.

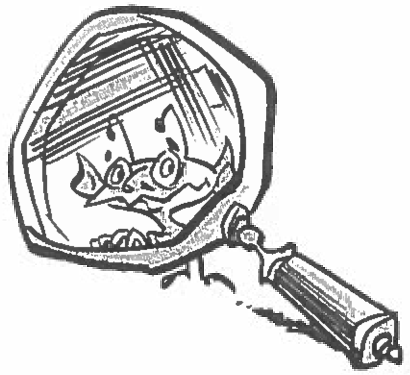
   Most bacteria are harmless but a few types cause serious illness and even death in humans. Some bacterial diseases transmitted by drinking contaminated water include typhoid fever, paratyphoid fever, bacillary dysentery, and cholera.

2. Viruses

   Virus agents are very small organisms, much smaller than bacteria, and they too can cause serious illness in humans. Infectious hepatitis and possibly poliomyelitis are two viral diseases that can be transmitted by contaminated drinking water. So-called "sewage poisoning," acute intestinal upset caused by drinking sewage-contaminated water, may also be caused by viral agents.

3. Protozoa

   Protozoa are microscopic animals that are also too small to be detected by the naked eye. Among the waterborne diseases they cause are amoebic dysentery, giardiasis (jee-are-DYE-uh-sis), and cryptosporidiosis.



These three types of organisms (bacteria, viruses, and protozoa) differ in their resistance to chlorine, the most common disinfectant. The bacteria are readily killed by the chlorine residual (0.2 to 0.5 mg/*L*) normally maintained in domestic water from a treatment plant. Most viruses are significantly more resistant to chlorine than are bacteria. Therefore, higher chlorine concentrations and longer contact times are necessary to kill viral agents. The protozoa are the most resistant to chlorine. They normally are not killed by the concentrations of chlorine ordinarily used in water treatment. Therefore, operators must rely on the processes of coagulation, flocculation, settling, and filtration for physical removal of protozoa rather than depend on disinfection to kill the organisms.

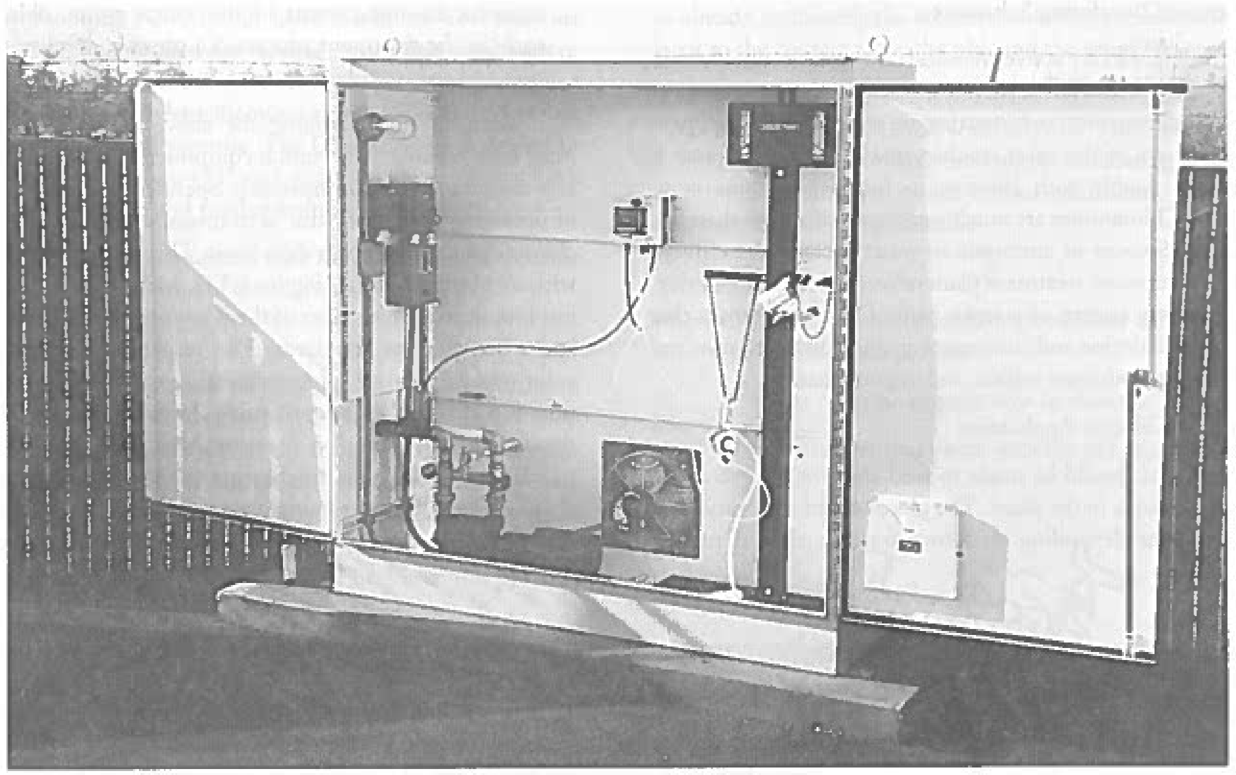
The processes of coagulation, flocculation, settling, and filtration can remove a high percentage of the disease organisms from a water supply. However, the operator cannot rely on these processes for 100 percent removal of disease organisms. Disinfection must be applied to all surface water sources to ensure that the water will be entirely safe and free of harmful organisms. Groundwater sources from properly constructed wells and springs may be free of contamination and may not require disinfection.

Nearly all domestic water supplies are disinfected with chlorine, although iodine, ozone, and ultraviolet radiation are also used occasionally. Chlorine is available in several forms. Gaseous chlorine can be purchased as liquid chlorine in steel cylinders. As chlorine gas is removed from the cylinder, the liquid chlorine evaporates and produces more gas. Chlorine can also be purchased in the form of liquid bleach, a solution of sodium hypochlorite in water. Laundry bleach, available from grocery stores, is 5.25 percent chlorine and commercial strength bleach, available from swimming pool suppliers or chemical companies, is usually 12.5 percent chlorine. Chlorine compounds in a solid form, granular or tablets, can also be purchased from swimming pool suppliers and chemical companies. These compounds of chlorine contain calcium hypochlorite. Calcium hypochlorite in solid form contains 65 percent available chlorine. This means that if you add 10 pounds of calcium hypochlorite to water, you are actually adding 6.5 pounds of chlorine (10 lbs × 0.65 = 6.5 lbs). Chlorine dioxide (ClO_2) is another form of chlorine used to disinfect drinking water. All forms of chlorine are hazardous chemicals that can cause serious injury and damage if they are not stored and used properly.

The form of chlorine used at the treatment plant will determine the type of chlorine feeder that is needed. If chlorine gas is used, it must be fed through a "chlorinator." The chlorinator not only controls and measures the flow of chlorine gas but also dissolves it in water so it can be safely injected into the water supply (Figure 4.16).

If chlorine in the form of liquid bleach (sodium hypochlorite) or a granular compound (calcium hypochlorite) is used, it is mixed with water to make a hypochlorite solution. Then, this solution is injected into the water supply by a chemical solution feed pump called a "hypochlorinator."

Small water plants most frequently use hypochlorite forms of chlorine because these are safer to handle and the feeder pumps are relatively inexpensive. Larger plants use chlorine gas because it is less expensive than hypochlorites and because gas chlorinators are usually more reliable and require less attention by the operator than a hypochlorinator.



NOTE: Chlorine cylinders are placed on the scales at the right and secured by the chains.

Fig. 4.16 Small chlorination system

(Permission of Watermasters, Inc., Burlingame, CA)

The following factors have an important effect on disinfection of water with chlorine.

1. Concentrations of Chlorine

   The higher the chlorine concentration, the faster and more complete will be the disinfection.

2. Time of Chlorine Contact

   The longer that water is in contact with chlorine, the greater will be the degree of disinfection achieved. Short-circuiting of flow through basins and tanks must be avoided because it can drastically shorten the time of chlorine contact. Clear wells, which store treated water, are used to provide adequate contact time.

3. The pH of the Water

   The pH determines whether the chlorine is in the form of hypochlorous acid, a powerful disinfectant, or in the form of hypochlorite ion, which is a much weaker disinfectant. For best results, the pH should be less than 7.5.

4. Water Temperature

   Chlorine requires more time to kill organisms in cold water than in warm water. A decrease in the water temperature from summer to winter may require twice the contact time to achieve the same degree of disinfection.

5. Degree of Mixing

   Any organisms not exposed to chlorine will not be killed. Therefore, mixing of the chlorine and the water must be rapid and complete to ensure that chlorine comes in contact with all the organisms present.

6. Clarity of the Water

   Organisms that are encased in a covering of suspended particles, mud, or trash may be so protected from the chlorine that the chlorine never penetrates to the organisms. It is important to remove as much suspended matter as possible so it does not shield organisms from chlorine or consume the chlorine before it is effective in killing the organisms.

7. Presence of Interfering Substances

Chlorine is a very active chemical and it reacts quickly with many substances. These chemical reactions can consume the chlorine or convert it to forms that are poor disinfectants. Ammonia is one of the most troublesome substances because it combines readily with chlorine to form chloramine compounds. Chloramines are much weaker disinfectants than free chlorine. Sources of ammonia in water include the effluent from a wastewater treatment plant or seepage from the subsurface leaching system of a septic tank. Other substances that react with chlorine and consume it include dissolved iron and manganese, hydrogen sulfide, and organic matter.

8. Points of Chlorine Application

Provisions should be made to feed chlorine at several different locations in the plant. The place of feed may vary from time to time depending on source water quality. If natural organics are not present in the source water, chlorination early in the treatment process can provide effective disinfection and reduce chlorine costs.

In addition to controlling the above factors, the operator must have reliable chlorination equipment and it must be properly maintained and competently operated. An important part of operating the chlorinator is to measure the concentration of chlorine in the water on a daily basis. This measurement is made with a chlorine test kit (Figure 4.17). Many brands of chlorine test kits are available. Most of them consist of a clear sample vial and a set of color standards. The reagent, which produces a color whose intensity is proportional to the chlorine concentration, is added to the vial containing the water sample. The color that forms in the sample is then compared with the known color standards to determine the chlorine concentration. Previously, a chemical solution containing orthotolidine reagent, which produces a yellow color with chlorine, was used in all chlorine test kits. Orthotolidine (OT) is still used in the low-cost chlorine test kits that are supplied for testing swimming pool waters. However, for testing domestic water supplies a reagent called DPD (diethyl-p-phenylene diamine) is much preferred because it is more accurate and versatile. The DPD method is subject to fewer interferences than OT and it accurately measures both free available chlorine and total chlorine residuals.

Fig. 4.17 Chlorine test kit
(Permission of HACH Company)

Operators must be acquainted with the three types of chlorine residuals that can be found in treated water.

1. Free

Free available chlorine residual includes that chlorine in the form of hypochlorous acid (HOCl) and hypochlorite ion (OCl^-). Hypochlorous acid is the most effective disinfectant form of chlorine. Hypochlorite ion is much less effective as a disinfectant than hypochlorous acid. The pH of the water determines whether the free chlorine is in the form of hypochlorous acid or hypochlorite ion. The lower the pH, the greater the percent of hypochlorous acid.

2. Combined

Combined available chlorine residual includes that chlorine in the three chloramine forms (monochloramine, dichloramine, and nitrogen trichloride), which are produced when chlorine reacts with ammonia. Combined chlorine requires up to 100 times the contact time or at least 25 times the chlorine concentration to achieve the same degree of disinfection as free available chlorine.

3. Total

The total chlorine residual is the sum of the free residual and the combined residual.

Chlorine residual test kits measure the free available chlorine residual and the total chlorine residual. The combined available chlorine residual is the difference. For example, a test kit could measure the free chlorine residual as one mg/*L* and the total chlorine residual as three mg/*L*. The combined available chlorine residual would be two mg/*L* (3 mg/*L* – 1 mg/*L* = 2 mg/*L*).

Operators should strive to maintain a free chlorine residual to accomplish disinfection and to avoid depending on the much weaker combined chlorine residual. Thus, in performing a chlorine residual test, the small system operator should make sure that the test result indicates only the free chlorine residual concentration.

Operators of small treatment plants frequently ask, "What chlorine residual should I maintain to guarantee that the finished water is adequately disinfected?" This is a very important question and one that must be answered correctly. But it is impossible to give a simple answer covering all situations because, as already explained, the required chlorine concentration is related to the contact time, the pH, and the water temperature.

A reference book, *HANDBOOK OF CHLORINATION AND ALTERNATIVE DISINFECTANTS*[20] by George Clifford White, describes a workable method for calculating the required chlorine concentration under various conditions. The calculation uses the following formula:

$C \times T = A$

where C = the free available chlorine residual concentration in milligrams per liter

T = the chlorine contact time in minutes

A = a number that varies with the pH as shown in Table 4.1

TABLE 4.1 RELATIONSHIP BETWEEN pH AND A

pH Range	A (For Cold Water, 0 to 5°C)
7.0–7.5	12
7.5–8.0	20
8.0–8.5	30
8.5–9.0	35

For example, suppose in a particular small water plant that the minimum chlorine contact time from the point of chlorine injection to the entrance of the distribution system is 30 minutes. Then, for the formula, T = 30. The pH of the water was found to be 7.2 and the water temperature during the winter months is usually just above freezing, say 1° or 2° Celsius. Then,

---

[20] *HANDBOOK OF CHLORINATION AND ALTERNATIVE DISINFECTANTS*, Fourth Edition, by George Clifford White. Obtain from John Wiley & Sons, Inc., Customer Care Center (Consumer Accounts), 10475 Crosspoint Boulevard, Indianapolis, IN 46256. ISBN 0-471-29207-9. Price, $275.95, plus $5.00 shipping and handling.

from Table 4.1, the value of A in this case is 12. Substituting these values in the formula we obtain:

$$C \times T = A$$

$$C \times 30 = 12$$

Solving for C,

$$C = \frac{A}{T}$$

$$C, \text{mg}/L = \frac{12}{30}$$

$$= \frac{4}{10}$$

$$= 0.4 \text{ mg}/L \text{ Free Chlorine Residual}$$

This calculation tells us that good disinfection of the water supply will be accomplished under the existing conditions by maintaining a free chlorine residual of at least 0.4 mg/*L* for the 30-minute contact time. Notice that a stronger chlorine residual would be required if the pH were increased, say to 8.3. Then, A = 30.

$$C \times T = A$$

$$C \times 30 = 30$$

or

$$C = \frac{30}{30}$$

$$= 1.0 \text{ mg}/L \text{ Free Chlorine Residual}$$

The efficiency of the disinfectant is measured by the time, T, in minutes of the disinfectant's contact in the water and the concentration, C, in mg/*L* of the disinfectant residual measured at the end of the contact time. The product of these two parameters (C × T) provides a measure of the degree of pathogenic inactivation. The required CT value to achieve inactivation depends on the organism in question, type of disinfectant, pH, and temperature of the water supply. Table 4.2 shows the combinations of disinfectant, pH, and temperature that will produce 99.9 percent *Giardia lamblia* (a disease-causing organism) inactivation.

TABLE 4.2 CT VALUES REQUIRED FOR 99.9% *GIARDIA LAMBLIA* INACTIVATION

Disinfectant	pH	10°C	15°C	20°C	25°C
Free Chlorine[a]	6	79	53	39	26
	7	112	75	56	37
	8	162	108	81	54
Ozone	6–9	1.4	0.95	0.72	0.48
Chloramines	6–9	1,850	1,500	1,100	750

[a] with 1 mg/*L* free chlorine residual

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

Sometimes, you may increase the chlorine dose setting on your chlorinator and the chlorine residual may actually drop (Figure 4.18, *BREAKPOINT CHLORINATION*).[21] This can happen when ammonia is present. Also, under these conditions, you may receive complaints that your water tastes like chlorine. The solution to this problem is to increase the chlorine dose even more. For additional information on breakpoint chlorination, see Chapter 5, "Disinfection." You are at the proper setting if:

1. You are maintaining the chlorine residual from the above calculations.
2. An increase in the chlorinator setting will produce a calculated chlorine dose increase of 0.1 mg/*L* and the resulting actual chlorine residual increases by 0.1 mg/*L*.
3. Chlorine residual tests at the far end of the distribution system produce chlorine residuals of at least 0.2 mg/*L*.
4. Coliform test results from throughout the distribution system are negative.

Another important part of chlorinator operation is keeping adequate records. The records must be legible and kept in an organized format. They should be written down in a permanent manner that can be preserved indefinitely for future reference. Records scribbled with a dull pencil on assorted scraps of paper are worthless and suggest incompetence.

The records should show the date and time the chlorinator was inspected, the flow rate of the water being treated, the total gallons of water treated, the feed rate of the chlorinator, the pounds of chlorine used, the calculated chlorine dosage, the chlorine residual concentration in the water as measured with the test kit, and the operator's name. The operator can conveniently tabulate this vital information on a standard record sheet similar to those in Tables 4.3 and 4.4.

Chlorinators not in service require more maintenance than those in service. The operator must be alert to spot failures and repair the equipment quickly because lack of disinfection is not, of course, acceptable. If possible, the operator should have a spare chlorinator on hand that can replace the failing unit. If not, the treatment plant must be shut down until the chlorinator is repaired. If the plant must operate without a chlorinator, consumers must be notified to boil all drinking water. The operator should save the manufacturer's operation manual for reference and keep repair parts in stock at all times. Contacts should be established with the chlorinator supplier or manufacturer so that service and parts can be obtained quickly. A program of periodic maintenance on chlorination equipment will prevent the vast majority of chlorinator failures. Regular disassembly and cleaning of the chlorinator and replacement of critical parts is recommended insurance against a breakdown.

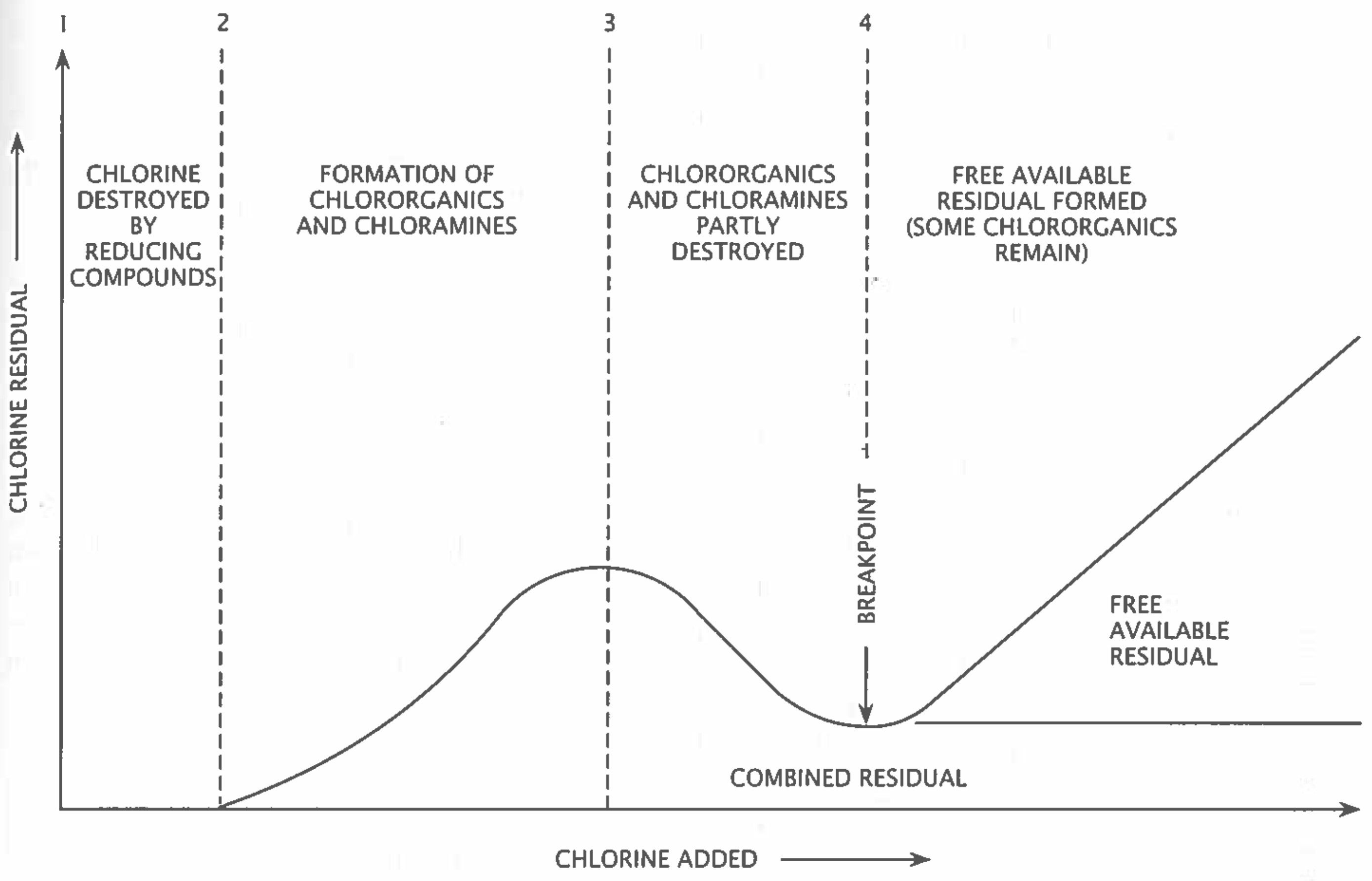


Fig. 4.18 Breakpoint chlorination curve

If a gas chlorinator is not feeding properly, the operator should check the items listed below.

1. The chlorine feed rate may not be properly adjusted. Reset it to the desired level.
2. The chlorine gas supply may be interrupted. The gas cylinder may be empty or the gas valve on the cylinder may be closed. Also, the chlorine tubing from the gas cylinder to the chlorinator may be plugged.
3. Are you trying to draw too much chlorine gas from the cylinder? If the withdrawal rate is too high, the liquid chlorine will not evaporate fast enough. High velocities of chlorine gas in the chlorine supply line will remove heat and cause a frost to form on the line. This can cause the chlorine gas to *RELIQUEFY*.[22] This liquid chlorine can plug the supply line and no more chlorine gas will flow. Operators refer to this condition as a "frozen" chlorine supply line. Be very careful because if you disconnect the supply, the liquid chlorine can evaporate again and send liquid chlorine shooting out the end of the disconnected line.
4. The chlorinator may not be drawing a vacuum. Check the water supply to the injector for adequate flow and make sure the injector is not plugged with debris.
5. The internal mechanism of the chlorinator may be malfunctioning. A broken diaphragm, a weak spring, or a leaking gasket will cause a malfunction. Replace the necessary parts and clean the chlorinator thoroughly using the cleaning solvents recommended by the manufacturer.

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[21] *Breakpoint Chlorination.* Addition of chlorine to water or wastewater until the chlorine demand has been satisfied. At this point, further additions of chlorine will result in a free chlorine residual that is directly proportional to the amount of chlorine added beyond the breakpoint.

[22] *Reliquefaction* (re-lick-we-FACK-shun). The return of a gas to the liquid state; for example, a condensation of chlorine gas to return it to its liquid form by cooling.

TABLE 4.3 CHLORINATION RECORD FOR GAS CHLORINATOR

CHLORINATION RECORD
FOR
GAS CHLORINATOR

REPORT NO. ____________
WATER SUPPLIER ____________
SYSTEM NAME ____________ SYSTEM NO. ____________
FOR WEEK OF ____________ THRU ____________ 20 ___
OPERATOR ____________

DAY	DATE	TIME	CHLORINE RESIDUALS, mg/L #1	#2	#3	WATER PRODUCTION PLANT OPERATING RATE—GPM	WATER METER READING, GALLONS	GALLONS OF WATER TREATED	CHLORINATION TREATMENT CHLORINATOR FEED RATE, LBS/24 HRS	WEIGHT OF CHLORINE AND CONTAINER	WEIGHT OF EMPTY CONTAINER	WEIGHT OF CHLORINE REMAINING	POUNDS OF CHLORINE USED	AVG. CHLORINE DOSE FOR PAST DAY (CALCULATED) NOTE 1	INSTANTANEOUS CHLORINE DOSE (CALCULATED) NOTE 2
COLUMN NUMBER			1	2	3	4	5	6	7	8	9	10	11	12	13
SUN															
SAT															
FRI															
THUR															
WED															
TUES															
MON															
READINGS FORWARD															
WEEKLY TOTALS →															

REPORT SUBMITTED BY:

REMARKS:

SIGNATURE

NOTE 1:

$$\text{AVG. CHLORINE DOSE, mg/}L = \frac{(\text{LBS OF CL}_2\text{ USED})(120{,}000)}{\text{GAL OF WATER TREATED}} = \frac{(\text{COL 11})(120{,}000)}{(\text{COL 6})}$$

NOTE 2:

$$\text{INSTANTANEOUS CHLORINE DOSE, mg/}L = \frac{(\text{CHLORINATOR FEED RATE})}{(.012)(\text{PLANT OPERATING RATE, GPM})} = \frac{(\text{COL 7})}{(.012)(\text{COL 4})}$$

TABLE 4.4 OPERATION RECORD FOR SODIUM HYPOCHLORINATOR

(See Table 4.5 for instructions.)

OPERATION RECORD FOR SODIUM HYPOCHLORINATOR

REPORT NO. ____________
WATER SUPPLIER ____________
SYSTEM NAME ____________ SYSTEM NO. ____________
FOR WEEK OF ____________ THRU ____________ 20 ___
OPERATOR ____________

ITEM A.	STRENGTH OF BLEACH USED	5.25%	12.5%	1.0%
ITEM B.	POUNDS OF CHLORINE PER GALLON	0.44 LBS	1.04 LBS	0.083 LBS

ITEM C. SIZE OF CHLORINE SOLUTION TANK: ____________ GALLONS
ITEM D. SIDEWALL DEPTH OF SOLUTION TANK: ____________ INCHES
ITEM E. STRENGTH OF SOLUTION: EACH GALLON OF BLEACH IS ADDED TO ______ GALLONS OF WATER
ITEM F. GALLONS OF BLEACH IN A FULL TANK OF SOLUTION: ____________ GALLONS
ITEM G. POUNDS OF CHLORINE IN ONE INCH OF SOLUTION DEPTH: ____________ POUNDS PER INCH DEPTH

$$\frac{(\text{GAL. BLEACH IN FULL TANK})(\text{POUNDS CHLORINE/GALLON})}{(\text{SIDEWALL DEPTH OF SOLUTION TANK})} = \frac{(\text{ITEM F}) \times (\text{ITEM B})}{(\text{ITEM D})}$$

DAY	DATE	TIME	CHLORINE RESIDUALS, mg/L #1	#2	#3	WATER PRODUCTION PLANT OPERATING RATE—GPM	WATER METER READING, GALLONS	GALLONS OF WATER TREATED	CHLORINATION TREATMENT FEEDER SETTING	INCHES OF SOLUTION IN TANK	INCHES OF SOLUTION USED	POUNDS OF CHLORINE USED (ITEM G) TIMES (COLUMN B)	AVERAGE CHLORINE DOSE, mg/L NOTE 1	QUARTS OF BLEACH TO BE ADDED NOTE 2
COLUMN NUMBER			1	2	3	4	5	6	7		8	9	10	11
SUN														
SAT														
FRI														
THUR														
WED														
TUES														
MON														
READINGS FORWARD														
WEEKLY TOTALS →														

REPORT SUBMITTED BY:

SIGNATURE

NOTE 1:

$$\text{AVG CHLORINE DOSE, mg/}L = \frac{(\text{LBS OF CHLORINE USED}) \times (120{,}000)}{(\text{GAL OF WATER TREATED})} = \frac{(\text{COL 9})(120{,}000)}{(\text{COL 6})}$$

The 120,000 converts gallons of water treated to million pounds of water, which gives pounds of chlorine used per million pounds of water or milligrams of chlorine per liter of water.

NOTE 2:

$$\text{QUARTS OF BLEACH TO BE ADDED} = \frac{(\text{INCHES SOLN. USED}) \times (4) \times (\text{GALLONS OF BLEACH IN A FULL TANK})}{(\text{SIDEWALL DEPTH OF SOLUTION TANK})} = \frac{(\text{COL. 8}) \times (4) \times (\text{ITEM F})}{(\text{ITEM D})}$$

TABLE 4.5 INSTRUCTIONS FOR COMPLETING TABLE 4.4, "OPERATION RECORD FOR SODIUM HYPOCHLORINATOR"

ITEM A and ITEM B—Circle the strength of chlorine bleach and the corresponding value for pounds of chlorine per gallon that is purchased for mixing the chlorine solution.

ITEM C—Record the capacity of the chlorine solution tank in gallons.

ITEM D—Record the sidewall depth of the solution tank when it is full.

ITEM E—Record the number of gallons of water that are added to each gallon of bleach for preparing chlorine solution.

ITEM F—Using the information in Item E, calculate the gallons of bleach in a full tank of solution.

ITEM G—Calculate the pounds of chlorine in one inch of solution depth in the tank. For example, assume that a 30-gallon solution tank is used and that the chlorine solution is made by mixing 4 gallons of water with each gallon of 5.25% household bleach (Clorox or Purex). Therefore, the full 30-gallon tank will contain 6 gallons of bleach. Since each gallon of 5.25% bleach contains 0.44 pounds of chlorine, 6 gallons of bleach contain (6) × (0.44) = 2.64 pounds of chlorine. If the tank has a sidewall depth of 36 inches, there are (2.64) + (36) = 0.073 pounds of chlorine in each inch of solution depth in the tank.

Columns 1 through 7 in the daily record form are self-explanatory.

COLUMN 8—Measure the inches of chlorine solution used from the tank and record it in Column 8.

COLUMN 9—Calculate the pounds of chlorine used by multiplying the inches of chlorine solution used (Column 8) times the pounds of chlorine in one inch of solution depth (Item G). Record the answer in Column 9.

COLUMN 10—Calculate the average chlorine dose by multiplying the pounds of chlorine used (Column 9) times 120,000 and divide by the gallons of water treated (Column 6). Record the answer in Column 10.

COLUMN 11—To refill the solution tank, proceed as follows. Multiply the inches of solution used from the tank (Column 8) times four. Then, multiply that answer times the gallons of bleach that are in the tank when it is full, in the example above, 6 gallons. Divide this answer by the total sidewall depth of the solution tank (36") to obtain the number of quarts of bleach that should be added to the tank. Enter the answer in Column 11. After the bleach is added, fill the tank to the top with clean water. This procedure will maintain the chlorine solution in the tank at a uniform strength.

$$\frac{\text{Inches of Solution Used} \times 4 \times \text{Gallons of Bleach in a Full Tank}}{\text{Sidewall Depth of Solution Tank}} = \frac{\text{Column 8} \times 4 \times \text{Item F}}{\text{Item D}}$$

If a hypochlorinator is not feeding properly, check these points.

1. Adjust the hypochlorinator to feed the desired dosage.
2. The hypochlorite solution may be used up.
3. The intake tubing in the hypochlorite solution tank may be plugged with sediment.
4. The diaphragm in the hypochlorinator may be ruptured.
5. The inlet and outlet poppet valves in the hypochlorinator may be malfunctioning.
6. The drive belt may be broken or slipping.
7. The electrical supply to the hypochlorinator may be interrupted.
8. The feed line from the hypochlorinator to the injection point may be plugged or broken.
9. There may be excessive backpressure at the point of injection that the hypochlorinator cannot overcome.
10. The hypochlorite solution may freeze in the tubing and other small conduits through which it flows. Provide an insulated, heated enclosure for the equipment.

The biggest problem with hypochlorinators is that they can develop calcium deposits if you are using calcium hypochlorite. Hypochlorinators can be cleaned with a weak acid (vinegar or muriatic acid). If you have only one hypochlorinator, turn off the water being disinfected so no unchlorinated water can enter your clear well or distribution system. Pump the acid through the entire pump (hypochlorinator or chemical feed pump, they are the same) and into a waste or drain line. This procedure allows for the cleaning of all feed lines, valves, and equipment. If this procedure is followed on a regular or routine basis, the pump will never have to be taken apart for cleaning.

If the operator has problems achieving adequate disinfection of the water or maintaining a chlorine residual, one or more of the following problems could be the cause.

1. The chlorinator is not feeding. Inspect the equipment and determine that the chlorinator is operating properly.
2. The chlorine dosage is inadequate. Readjust the chlorinator to feed the proper dosage. Never mix more than a two- or three-day supply of hypochlorite solution. Hypochlorite solutions lose their strength in time and this fact has the effect of changing the feed rate.
3. The contact time is too short. Relocate the point of chlorine injection to increase the contact time. Eliminate short-circuiting of flow through the plant.
4. Suspended matter in the water is preventing effective disinfection. Improve clarification treatment so that turbidity is minimal.
5. The chlorine is being consumed by organic matter, dissolved gases or minerals, or by sludge in basins and pipelines. Increase the chlorine dosage, clean sludge from basins and storage tanks, and flush sediment from the distribution system.
6. The chlorine is being destroyed by exposure to sunlight in an uncovered storage tank. Provide a cover for the storage tank or rechlorinate the water as it leaves the tank.

For additional information on disinfection, see *WATER TREATMENT PLANT OPERATION,* Volume I, Chapter 7, "Disinfection," in this series of operator training manuals.

FORMULAS

To estimate the actual average chlorine dose in milligrams per liter for a gas chlorinator:

1. Determine the weight of chlorine used.
2. Measure and record the amount of water treated.

$$\begin{aligned}\text{Average Chlorine Dose, mg}/L &= \frac{\text{Chlorine Used, lbs/day}}{(\text{Water Treated, MGD})(8.34\text{ lbs/gal})}\\ &= \frac{\text{lbs Chlorine}}{\text{M lbs Water}}\\ &= \frac{\text{mg Chlorine}}{\text{1 M mg Water}}\\ &= \text{mg Chlorine/Liter Water, or}\end{aligned}$$

$$\begin{aligned}\text{Average Chlorine Dose, mg}/L &= \frac{(\text{Chlorine Used, lbs/day})(1{,}000{,}000/\text{M})}{(\text{Water Treated, gal/day})(8.34\text{ lbs/gal})}\\ &= \frac{(\text{Chlorine Used, lbs/day})(120{,}000)}{\text{Water Treated, gal/day}}\\ &= \text{mg Chlorine/Liter Water}\end{aligned}$$

NOTE: Chlorine used in pounds and water treated in gallons or million gallons must be for the same time interval, but not necessarily for 24 hours. The time period could be 20 hours, 27 hours, or even 2 days.

To estimate the instantaneous chlorine dose in milligrams per liter for a gas chlorinator:

1. Record the chlorinator feed rate setting.
2. Measure and record the flow rate for the water being treated.

$$\text{Flow Rate, MGD} = \frac{(\text{Flow, gal/min})(60\text{ min/hr})(24\text{ hr/day})}{1{,}000{,}000/\text{M}}$$

$$\begin{aligned}\text{Instantaneous Chlorine Dose, mg}/L &= \frac{\text{Chlorinator Feed Rate, lbs/day}}{(\text{Flow, MGD})(8.34\text{ lbs/gal})}\\ \text{or} &= \frac{\text{Chlorinator Feed Rate, lbs/day}}{(\text{Flow, GPM})(0.012)}\end{aligned}$$

To select the chlorinator feed rate setting in pounds of chlorine per 24 hours (lbs/day):

1. Determine the desired chlorine dose.
2. Measure and record the flow rate for the water being treated.

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

To estimate the actual average chlorine dose in milligrams per liter of a hypochlorinator system:

1. Determine the dimensions and volume of the hypochlorite solution container.
2. Determine the number of gallons of water added to each gallon of hypochlorite (bleach) in the solution tank.
3. Measure and record the amount of water treated.

$$\text{Total Chlorine, lbs} = (\text{Chlorine, lbs/gal})(\text{Bleach, gal})$$

$$\text{Chlorine Used, lbs} = \frac{(\text{Total Chlorine, lbs})(\text{Chlorine Used, in})}{\text{Depth of Tank, in}}$$

$$\begin{aligned}\text{Average Chlorine Dose, mg}/L &= \frac{(\text{Chlorine Used, lbs})(1{,}000{,}000/\text{Million})}{(\text{Water Treated, gal})(8.34\text{ lbs/gal})}\\ &= \frac{\text{lbs Chlorine}}{\text{M lbs Water}}\\ &= \frac{\text{mg Chlorine}}{\text{M mg Water}}\\ &= \text{mg Chlorine/Liter Water}\end{aligned}$$

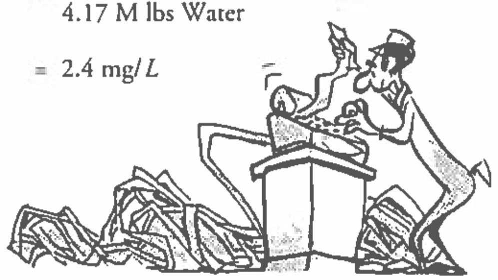
EXAMPLE 11

Estimate the average chlorine dose in mg/*L* for a chlorinator that used 10 pounds of chlorine to treat 500,000 gallons (0.5 million gallons) of water.

Known		Unknown
Chlorine Used, lbs	= 10 lbs	Average Chlorine Dose, mg/*L*
Water Treated, M Gal	= 0.5 M Gal	

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

$$\begin{aligned}\text{Average Chlorine Dose, mg}/L &= \frac{\text{Chlorine Used, lbs}}{(\text{Water Treated, M Gal})(8.34\text{ lbs/gal})}\\ &= \frac{10\text{ lbs Chlorine}}{(0.5\text{ M Gal Water})(8.34\text{ lbs/gal})}\\ &= \frac{10\text{ lbs Chlorine}}{4.17\text{ M lbs Water}}\\ &= 2.4\text{ mg}/L\end{aligned}$$



EXAMPLE 12

Estimate the instantaneous chlorine dose in mg/*L* if the chlorinator feed rate is set at 12 pounds per 24 hours and the flow is 300 gallons per minute.

Known	Unknown
Chlorine Feed, lbs/day = 12 lbs/day	Instantaneous Chlorine Dose, mg/*L*
Flow, GPM = 300 GPM	

1. Convert the flow from GPM to MGD.

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

$$= \frac{(300\text{ gal/min})(60\text{ min/hr})(24\text{ hr/day})}{1{,}000{,}000/\text{Million}}$$

$$= 0.432\text{ MGD}$$

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

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

$$= \frac{12\text{ lbs/day}}{(0.432\text{ MGD})(8.34\text{ lbs/gal})}$$

$$= 3.3\text{ mg}/L$$

EXAMPLE 13

Estimate the actual average chlorine dose in milligrams per liter from a hypochlorinator. The depth of hypochlorite solution dropped 10 inches while treating 100,000 gallons of water. The strength of bleach used is 5.25 percent and contains 0.44 lb of chlorine per gallon of bleach. For every gallon of bleach added to the container, four gallons of water are added. The full mark on the container is at 50 gallons (10 gallons of bleach and 40 gallons of water). When the container is full, there are 50 inches of hypochlorite solution.

Known	Unknown
Chlorine Used, in = 10 in	Average Chlorine Dose, mg/*L*
Water Treated, gal = 100,000 gal	
Bleach, lbs/gal = 0.44 lb/gal	
Bleach Used, gal = 10 gal	
Depth of Tank, in = 50 in	

1. Calculate total chlorine in container in pounds.

$$\text{Total Chlorine, lbs} = (\text{Chlorine, lbs/gal Bleach})(\text{Bleach, gal})$$

$$= (0.44\text{ lb/gal})(10\text{ gal})$$

$$= 4.4\text{ lbs}$$

2. Determine the chlorine used in pounds.

$$\text{Chlorine Used, lbs} = \frac{(\text{Total Chlorine, lbs})(\text{Chlorine Used, in})}{\text{Depth of Tank, in}}$$

$$= \frac{(4.4\text{ lbs})(10\text{ in})}{50\text{ in}}$$

$$= 0.88\text{ lb}$$

3. Estimate the average chlorine dose in mg/*L*.

$$\text{Average Chlorine Dose, mg}/L = \frac{(\text{Chlorine Used, lbs})(1{,}000{,}000/\text{Million})}{(\text{Water Treated, gal})(8.34\text{ lbs/gal})}$$

$$= \frac{(0.88\text{ lb})(1{,}000{,}000/\text{Million})}{(100{,}000\text{ gal})(8.34\text{ lbs/gal})}$$

$$= 1.1\text{ mg}/L$$

QUESTIONS

Write your answers in a notebook and then compare your answers with those on pages 275 and 276.

4.5A List the various methods used to disinfect domestic water supplies.

4.5B List the common forms of chlorine available to disinfect water supplies.

4.5C What does a chlorinator do?

4.5D What substances found in water react with and consume chlorine?

4.5E List the two types of chlorine residuals that can be measured with test kits.

4.5F Calculate the desired free chlorine residual for a water with a pH of 7.6 when the water is 5°C. The contact time is 25 minutes.

End of Lesson 1 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 1 of 2 Lessons)

At the end of each lesson in this chapter, you will find some discussion and review questions. The purpose of these questions is to indicate to you how well you understand the material in the lesson. Write the answers to these questions in your notebook.

1. Why do small water treatment plants often not perform satisfactorily?
2. Why might prechlorination be recommended?
3. What happens if the coagulant dosage is either too high or too low?
4. If you suspect that the coagulation treatment is substandard or if excessive dosages of coagulant are required, it could be due to a change in the quality of the source water. What could cause a change in source water quality?
5. What would you do if a flocculation process is not satisfactorily producing a floc that settles quickly and clarifies the water effectively?
6. List the factors that influence the performance of a settling basin.
7. Successful operation of filters at high rates requires what conditions?
8. If a filter is not performing satisfactorily, what would you do?
9. Why do small water treatment plants frequently use hypochlorite forms of chlorine instead of chlorine gas?
10. List the factors that have an important effect on disinfection of water with chlorine.
11. How is the time, T, measured to calculate CT values?
12. How would you determine if the chlorinator setting is high enough?
13. How would you try to prevent chlorinator failures?