Flow Rate Through Bed

Each gallon of water that flows through the bed carries an amount of hardness with it. It is necessary to know the hardness and flow rate values because they will dictate the time of exhaustion. If a bed is loaded at 120 gpm (454 L/min) and the source water has a hardness of 14 gr/gal (240 mg/L), 1,680 gr (120 gpm × 14 gr/gal) of exchange capacity will be used each minute of operation. The operator can see that the bed will exhaust eventually and that the exhaustion time will be reached sooner if the flow rate is increased. Doubling the flow rate will theoretically exhaust the bed in half the time.

As stated, water leaving the ion-exchange vessel should have zero hardness. However, because water with zero hardness tends to corrode the system and the customers' plumbing, ion-exchange water plants must produce water that is not of zero hardness. The simplest way to do this is to bypass some of the source water around the softeners and then blend it with the zero-hardness water at a predetermined rate to achieve the desired level of finished water hardness. This predetermined rate is called the *percent bypass* and is calculated by dividing the desired finished water hardness by the source water hardness and converting that value to a percent. This number represents the approximate amount of water that should bypass the softeners. For example, if the source water hardness is 20 gpg (342 mg/L) and the desired finished water hardness is 8 gpg (137 mg/L), the percent bypass is calculated at 8/20, or 40 percent. If the plant flow is 1,000 gpm (2.2 ft^3/sec), the operator knows that 40 percent of 1,000, or 400 gpm (0.9 ft^3/sec), should bypass the softeners to get the desired results.

This bypass water will have the effect of lengthening the life of the softener. More finished water is produced during the cycle because not all of it had to be softened. The greater the desired hardness of finished water, the more efficient the plant becomes with respect to softening expense.

Regeneration

When the bed is exhausted, it must be regenerated. Because the resin has been stripped of sodium ions, these ions must be replaced. This is done by rinsing the bed with a salt solution (brine) at sufficient volume and concentration for a set time. Brine is concentrated sodium chloride (NaCl) solution, which is approximately a 25 percent concentration at 60°F (15.5°C). The specific gravity of this solution is about 1.192, which yields a working solution of about 2.479 lb of salt per gallon. The brine is usually diluted further before being applied to the softener in the regeneration cycle. As an example, if a softening unit contains 1,000 ft^3 of ion-exchange material and it has a hardness-removal capacity of 3,000 gr/ft^3, it will have a softening capacity of 3,000,000 gr. If it is assumed that 0.5 lb of salt is required per 1,000 gr of hardness removed, 3,000 × 0.5, or 1,500 lb of salt will be required to regenerate the unit. Each gallon of saturated brine contains 2.479 lb of salt; therefore, approximately 605 gal of brine solution will be required to regenerate the unit. To produce a 5 percent solution (1.03624 specific gravity), the 605 gallons of brine must be diluted to 3,480 gal.

An exhausted resin bed is first backwashed to remove any foreign particles and to restratify the bed. The diluted brine is then introduced through the bed slowly, usually for 20 to 30 minutes. The flow rate may be about 1 gpm/ft^2 (0.7 mm/sec). It is very important to provide adequate time for the regeneration effect to take place. The bed is then rinsed to remove unused brine before the unit is placed back into service.

Operating an Ion-Exchange Plant

Figure 9-5 is a schematic of an ion-exchange plant. Note that this plant treats well water that contains iron. Therefore, the plant is equipped with an aerator and iron-removal filters, which is a typical arrangement for ion-exchange plants treating water with iron problems (chapter 10). The iron must be removed before the water is passed through the exchangers; otherwise, the resin will be fouled and rendered useless.

Operators running this type of process must know the design and operating data of the plant. Designers of these plants use a much more complex set of variables, but the following examples represent a basic operational view of ion-exchange softening.

There are three ion-exchange softeners, each measure 6 ft (1.8 m) in diameter and have 7 ft (2.1 m) of media depth in them. The exchange capacity of the media is 15,000 gr/ft^3, and it takes 0.3 lb of salt per 1,000 gr of hardness removed to regenerate. The source water hardness is measured at 325 mg/L and the finished water hardness is 143 mg/L. One 500-gpm (1.1-ft^3/sec) high-service pump is operating. With this information, solve the following sample problems.

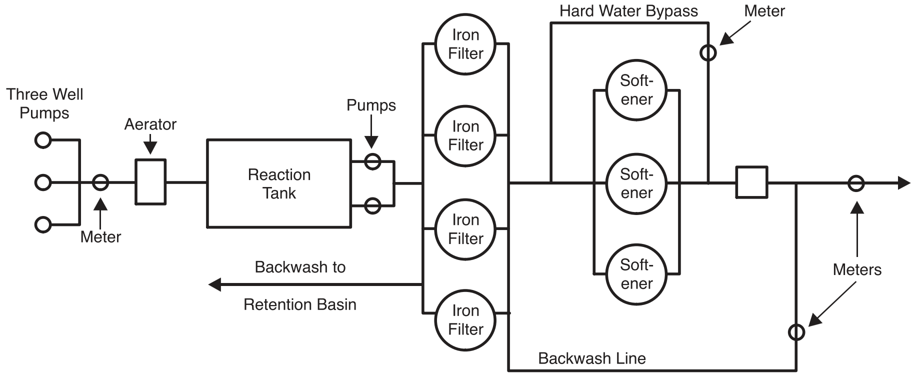

Figure 9-5 Schematic of the ion-exchange process used in the example problems

What is the total hardness-removal capacity of the plant?

The volume of media in the three exchangers is calculated as πR^2 × depth × number of units, or 3.14 × (3^2) ft × 7 ft × 3 units = 593.46 ft^3 of media. At 15,000 gr/ft^3, the hardness removal capacity would be 593.46 ft^3 × 15,000 = 8,901,900 gr removal capacity. This would also be stated as 8,901.9 kgr removal capacity. There are three units, so each unit has ⅓ of the total capacity, or 2,967,300 gr.

What is the percent bypass?

Percent bypass is calculated by dividing the finished hardness by the source hardness. In this case, it would be 143 mg/L ÷ 325 mg/L, or 0.44. Expressed as percent, this is 44 percent.

With one high-service pump operating, how many gallons per minute are bypassing the softeners?

One pump operates at 500 gpm; 44 percent of 500 gpm is 220 gpm. This is the flow rate of the water bypassing the softeners. (This also means that the rest of the water, or 280 gpm, must be going through the softeners.)

How long will one unit operate before it needs to be regenerated?

If 280 gpm are going through the softeners, it can be assumed that the flow through one softener, if balanced, is 280 gpm ÷ 3 = 93.3 gpm. Of course, meters would be installed on the influent to the softeners to help the operator balance the flow, which is desirable. A hardness of 325 mg/L is converted to grains per gallon by dividing it by 17.1. This yields a hardness of 19 gpg. Therefore, a unit is being loaded with source water at a rate of 93.3 gpm, each gallon of which carries with it 19 gr of hardness. After calculating the removal capacity of one unit to be 2,967,300 gr, divide that capacity by 19 gpg to determine that about 156,174 gal of water can be softened before exhaustion. At 93.3 gpm, it will take about 28 hours to exhaust the unit (156,174 gal ÷ 93.3 gpm/60 min/hour).

Approximately how much finished water is produced during this time?

This is a tricky, but simple, question. Regardless of the hardness being removed, if all is going well, the plant is operating at 500 gpm (ignoring backwash, plant use, etc.). Therefore, 500 gpm × 60 min/hour × 28 hours = 840,000 gal.

Assume the plant is producing 720,000 gal of finished water per day before plant usage. How many pounds of salt will be used in a 30-day month?

Only 56 percent of that water had to be softened; so in a month, it is calculated (0.56 × 720,000 gal/day × 30 days) that approximately 12.1 mil gal flowed through the exchange units. First calculate the amount of hardness, in grains, that was removed: 12,100,000 gal × 19 gpg = 229,900,000 gr, or 229,900 kgr. Use 0.3 lb of salt per kilograins of hardness removed, so 0.3 lb/kgr × 229,900 kgr = 68,970 lb needed for the month.

How many gallons of saturated brine is this?

At about 2.5 lb/gal, 27,588 gal (68,970 lb × gal/2.5 lb) would need to be used.

Ion-Exchange Residuals

Spent brine used in the regeneration process is typically sent to a sanitary sewer. In coastal regions, water utilities may obtain permits to discharge to the ocean. Other methods that have been used to dispose of brine are discharged to evaporation ponds in arid regions or to brine disposal wells if they exist. Disposal of regenerant brine solutions used in cation radionuclide removal must be approved by regulatory agencies.

Other Softening Processes

There are several additional processes that are sometimes used to soften drinking water: electrodialysis, membrane softening, and split stream treatment (and blending strategies). Electrodialysis is discussed in some detail in chapter 10 because it is used mainly for desalination rather than exclusively for softening. Membrane softening is usually accomplished using specially designed nanofiltration membranes (reverse osmosis membranes also remove hardness). Membrane systems are discussed in detail in chapter 11. The operation and design of membrane softening systems are analogous to other membrane systems.

Split stream and blending are not separate treatment processes but rather are strategies to adjust water hardness where the opportunity exists. Some treatment processes like reverse osmosis and electrodialysis can remove calcium and magnesium almost completely for the water stream. This may result in a water that is “too soft” for the intended purpose. Some systems blend this demineralized water with unsoftened water to provide a water that meets the hardness goals. This is often termed *split treatment*. Another similar approach is to blend hard water with a softer water source before it is distributed. One example where this can be accomplished is in a system that has both surface water (soft) and groundwater (hard). The two are blended and medium hardness water is distributed to customers. Where this is possible, this can be a cost-effective approach.

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Chapter 10

Specialized Treatment Processes

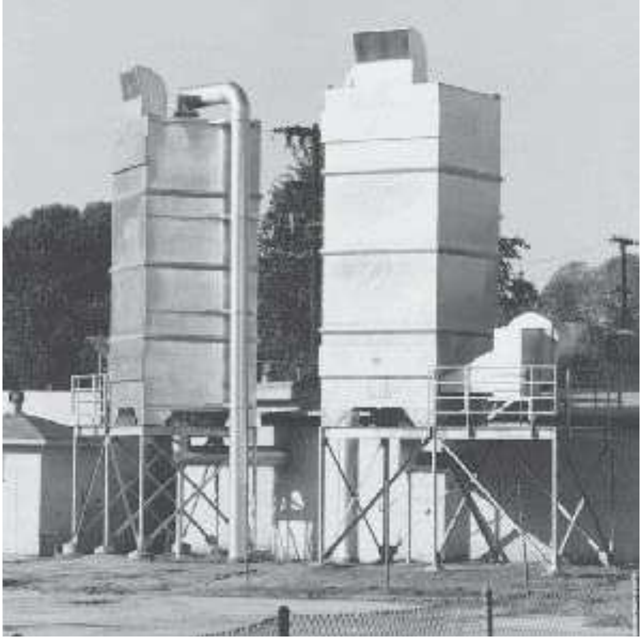
Federal and local regulations and certain site-specific conditions may require the use of specialized technologies for water treatment. The removal of regulated contaminants may indicate the use of certain targeted treatment processes. And some of these processes may be necessary in order to produce a product that is aesthetically acceptable to the customer. The descriptions included in this chapter give a brief overview of the most prevalent specialized treatment processes. The references included at the end of the chapter should be consulted for additional detailed information.

AERATION

Aeration, or air stripping, is used to make water stable and used for disinfection, precipitation of inorganic contaminants, and air stripping of volatile organic compounds (VOCs) and nuisance-causing dissolved gases. The most commonly used types of aeration are diffused air, surface aerator, spray, and packed-tower systems (Figure 10-1). These systems remove or minimize the offending contaminants by stripping them out of the water (in the case of gases) or by oxidizing them (e.g., iron and manganese).

Diffused-air or bubble aeration involves contacting gas bubbles with water in order for the gases to transfer to the water. Operators use this technology to strip VOCs from the water, apply ozone, oxidize with O_2, or recarbonate with CO_2. The most common arrangement for this process consists of perforated tubes or porous plates situated at the bottom of the reactor tank. This allows for maximum contact time of the gas bubbles as they rise through the water. The point of application is dependent on the purpose of the process. For example, lime precipitative softening plants that use recarbonation may add CO_2 to the effluent of the clarifiers just prior to filtration, while operators using ozonation for disinfection may add CO_2 to the raw water. The use of ozone technology is covered further in chapter 8.

Surface aerators are used primarily for oxygen absorption and to strip gases and volatile contaminants.



Source: US Filter.

Figure 10-1 Forced draft aerator used to strip organic chemicals from source water

ADSORPTION (GAC)

Adsorption involves the accumulation of a substance at the interface of two phases, such as a solid phase and a liquid phase. An example of this process is the collection of taste- and odor-causing compounds in water on the surface of activated carbon particles. Ion-exchange resins can also be used as interfaces to adsorb *organic* compounds. The use of ion exchange to remove *inorganic* compounds is discussed in chapter 9.

Granular activated carbon (GAC), perhaps the most commonly recognized solid-phase adsorption method used in public water treatment, is a good adsorber because of its surface chemistry and its surface area. In fact, GAC particles are actually honey-combed, with cracks and fissures. This property gives the particle a very large surface-area-to-mass ratio. These fissures are capable of capturing (adsorbing) many small organic molecules over extended periods of time. GAC particles, tailored to adsorb different types and sizes of organic molecules, can be specified for different purposes. GAC with small pore openings can be used to trap low–molecular-weight organics, and the larger pore–sized GAC particles can be used to trap the high–molecular-weight organics. This same property can, of course, allow the GAC to be fouled or prematurely used up if care is not taken.

GAC is made from raw materials such as lignite, wood, peat, and bituminous coal. The manufacturing process involves heating the material to temperatures near 700°C in the absence of air or to 800° to 900°C in steam and CO_2. The process and raw materials used determine the characteristics of the final product. GAC is often used as a cap for granular filters and serves the dual purpose of particulate removal and particulate adsorption.

There are several important concepts that operators must know about GAC. Empty-bed contact time (EBCT) is a design parameter used to predict performance. It is the detention time of the water that flows through a bed at a given flow rate. The higher the flow rate, the lower the EBCT for a fixed bed depth. For source water of a given quality, there is a minimum depth of GAC that will prevent breakthrough of the adsorbate. All GAC beds remove adsorbates in an area called the *mass transfer zone*. The zone must be deep enough to provide sufficient contact time as the water filters down through it. If there is insufficient zone depth or if the design flow rate is exceeded, breakthrough of adsorbate will occur. Therefore, an EBCT that provides adequate opportunity for water/GAC contact is necessary.

Breakthrough will also occur when the bed is exhausted. As the bed removes adsorbate, the available adsorption sites on the GAC become saturated. After a time, the GAC cannot accept any more adsorbate and it must be replaced or reactivated. For source waters with different kinds of adsorbates, it is common for a GAC bed to become exhausted selectively for each. For example, a GAC bed may begin to pass disinfection by-products long before it passes tastes and odors.

Taste-and-Odor Control

The control of disagreeable tastes and odors in public water supplies is normally accomplished by oxidation or adsorption processes. In addition, certain odors caused by volatile gases can be stripped from the water by aeration, as discussed in a previous section.

There are two strategies that can be used to produce water that is free of tastes and odors. The utility can take measures to prevent or reduce the likelihood that offending compounds will reach the source water or, once in the water, the utility can take measures to remove them. The choice may depend on economic factors and/or plant capabilities. Most plant operators would agree that prevention is a better practice than removal after the fact, but it is not always practical.

The test for taste and odor is called the *threshold odor test*. It is an attempt to classify the characteristics, including intensity, of the particular odor that is found in a water supply. The test compares successive dilutions of finished water to odor-free water. The secondary maximum contaminant level (SMCL) for odor is 3 TON (threshold odor number). Operators normally try to keep this value as low as possible, because odors tend to erode consumers' confidence in the water supply. When customers lose confidence, they may seek alternative and less reliable or unsafe supplies of water.

One method for taste- and odor-treatment that is used in conventional treatment plants is to apply a GAC cap to a granular media filter. The detention time is short because the cap is usually only 6–24 in. deep. In a dual-media or multi-media filter, GAC can be added to the top of the filter or it can replace the anthracite layer. Filter flow rates and head loss characteristics must be considered. Several treatment plants have reported a successful implementation of this approach. Some have used this process to remove DBPs or DBP precursors to acceptable levels.

IRON AND MANGANESE REMOVAL

Iron and manganese are naturally occurring minerals found in rocks and soil and are usually found in an insoluble form. However, as rainwater percolates into soils, dissolved oxygen is removed by the decomposition of organic materials. As oxygen levels decrease, the water becomes capable of dissolving iron and manganese. This is why many groundwaters have iron. Manganese is found more rarely, but when it is present, it is usually along with iron.

Iron and manganese do not present public health concerns. They do, however, create considerable aesthetic and operational problems when present in water supplies. As soluble iron and manganese become oxidized, they transform from colorless compounds to turbid yellow and black suspended solids that can stain sinks and fixtures and clog water mains. In some cases, iron or manganese will cause odor problems when they react with other chemicals. Water plants the sources of which contain these minerals are usually equipped with treatment devices that remove the minerals before water is distributed to the public.

Because iron and manganese can cause problems, the US Environmental Protection Agency (USEPA) has set the SMCL for iron at 0.3 mg/L. Customers seem to notice a taste from iron if the level reaches 0.5 mg/L. An SMCL has also been set for manganese at 0.05 mg/L. Manganese stains on laundry are very stubborn, and most operators strive to eliminate manganese altogether.

Iron and manganese in water are controlled at the treatment plant using the following methods:

- Precipitation and filtration
- Ion exchange
- Sequestration

As mentioned in chapter 9, the lime-softening process also removes iron and manganese quite effectively. However, this process is not used solely for iron and manganese treatment but in combination with softening.

Precipitation Processes for Iron and Manganese Removal

In precipitation, soluble forms of iron and manganese are oxidized to convert them to insoluble forms. When completely converted to an insoluble form, they can be effectively settled and filtered. To be oxidized, the iron must come into contact with air or oxygen or the iron and manganese must be chemically oxidized using chlorine, ozone, potassium permanganate, or chlorine dioxide.

Aeration oxidizes iron in water that has a pH greater than 6.5, and aeration is also useful for manganese oxidation when the pH is less than 9.5. Long contact times may be necessary to complete the process. Water can be aerated by forcing compressed air through it or by allowing water to cascade down over trays, effectively allowing for thin sheets of water to be exposed to the air. The trays become coated with iron and manganese hydroxide over time, which promotes further removal of the metals. A reaction tank or vessel is usually provided downstream of the aeration equipment. This tank is designed for a suitable detention period so that complete oxidation of the metals can take place. Detention times of 20 minutes to 1 hour are common.

Chemicals are commonly used for oxidation and can eliminate the need for double pumping and for the reaction vessel. Chlorine, chlorine dioxide, and potassium permanganate are the oxidants of choice. These powerful chemicals can be used to produce insoluble forms of iron and manganese and, in the case of potassium permanganate, can reduce the disinfectant/disinfection by-product levels because no chlorine is added at the front of the plant.

All of these processes require the removal of the iron and manganese floc that is formed. At higher concentrations of the metals, sedimentation is specified, followed by filtration. If pH in the sedimentation basin is low, lime may be used to raise the pH to levels that are more favorable for precipitation. Filtration alone can be used after oxidation if the concentration of the metals is below about 5 mg/L.

Ion Exchange

Ion exchangers can remove iron and manganese, along with other metals, if the proper exchange resin is used. Where hardness is low and there are no precipitates to foul the bed, this process is specified for waters with low iron content. Otherwise, the process is not usually economical.

Manganese Greensand Filtration

This process is commonly used for the removal of iron, manganese, and hydrogen sulfide from groundwater. The manganese greensand (glauconite) is a naturally occurring material that can be classified to produce an excellent filtration media having a sieve analysis of 18 x 60 mesh with a resulting effective size of 0.3–0.35 millimeters (mm) and a uniformity coefficient of 1.60 or less.

To optimize the process, the material is first coated with manganese oxide. This stabilizes the material and imparts a special oxidation-reduction property that is effective for removing iron, manganese, and small amounts of hydrogen sulfide. The filter media must be regenerated when their capacity to remove iron and manganese is reached. Regeneration is accomplished either continuously (CR) or intermittently (IR).

Continuous regeneration is usually used when iron is mostly being removed. An oxidant, either chlorine or potassium permanganate ($KMnO_4$), is fed continuously ahead of the greensand filters. The oxidized iron is captured on the filter sand. IR is used mainly for manganese removal. The greensand is treated with oxidant (usually permanganate) when the filter capacity is reached. This intermittent treatment occurs while the filter is off-line.

Operating conditions may vary and optimization is site specific. However, as a starting point, the pH is usually adjusted so as to be in the 6.2–6.8 range. Alkalinity is ideally >120 mg/L as $CaCO_3$. When iron alone is treated, chlorine is fed at about 1.0–1.2 times the iron concentration. For water containing both manganese and iron, most plants feed chlorine followed by permanganate. Chlorine is fed, in this case, at about 1.0 the iron concentration and 2.0 the manganese concentration. This is followed by a small permanganate feed that is controlled by the faint pink color in the water just before the greensand filter.

Backwashing the greensand filters must be performed periodically to remove captured iron and manganese particles and to restore the filter rate capacity. To enhance filter performance and improve backwash efficiency, the greensand filters are often capped with anthracite filter media. It is common for the filters to have an 18-in. anthracite cap over 18–30 in. of greensand (depending on the regeneration method and the amount of iron and manganese being removed).

Operating a greensand process can be tricky and often careful monitoring of pH, chlorine, permanganate, iron, manganese, and hydrogen sulfide levels is necessary. Sufficient training and instruction regarding proper operation of the chemical feed systems and filter operation are necessary to achieve optimum results.

Sequestration

If the source water is low in iron and manganese (<1.0 mg/L combined) and contains no dissolved oxygen, sequestration may be used to treat for iron and manganese. Sequestration is the process by which iron and manganese are kept in solution by adding chemicals, such as polyphosphates or silicates. In this way, the iron and manganese are not removed but rather prevented from being oxidized and made insoluble. Bacterial slimes sometimes occur in systems that sequester because the iron is still available. Care must be taken to maintain adequate chlorine residual to minimize this problem.

FLUORIDATION OF WATER

Fluoride is a mineral that occurs naturally in all water sources, even in the oceans. It is never encountered in the free state but rather in combined form.

When fluoride levels in water are held constant at about 1.0 mg/L, the incidence of dental cavities is reduced. Because of this fact, public water supplies are usually fluoridated to optimum levels. In 2006, the Centers for