

Basic Ion Exchange for Residential Water Treatment

Part 2

By Michael C. Keller

In our February issue, Keller explained the history of ion exchange, the manufacturing and softening processes, disinfection and standard removal methods. We now bring you part two, which begins with a look at efficiency factors.

Efficiency

In many parts of the country, drought has caused the water treatment industry to look for more efficient methods to soften water. California is in that process (in some counties) and has enacted laws (in other counties) requiring softeners to have an efficiency rating of 3,250 grs./lb. of salt. These laws were implemented to reduce the amount of salt being sent to the drain. This goal cannot be attained when using high salt dosages. The lower the salt dosage, the greater the efficiency of the unit (See Table 3—notice that standard resin when regenerated with 5 lbs. of salt/cu.ft. can achieve an efficiency of 4.44 kgr./lb. of salt, while 10 lbs./cu.ft. will attain only 2.9 kgr./lb. of salt).

Fine mesh resin will also increase efficiency. This is the result of better kinetics. The resin has greater surface area, so the exchange of hardness onto the resin is more efficient. Laboratory testing has shown that fine mesh resin gives approximately 10 percent more capacity than standard softening resin. The exhaustion band formed during the service cycle contains both exhausted and regenerated resin. Standard resin may have a 10-inch exhaustion band, while fine mesh resin has a 9-inch exhaustion band. For this reason, the fine mesh resin system will have one more inch of usable resin.

This is an oversimplified but accurate explanation.

Countercurrent regeneration can be a technique used to improve efficiency; however, the main benefit to countercurrent regeneration is the reduction of leakages as compared to cocurrent regenera-

tion in rinse is dependent on the system design (it must have good distribution). The reason for greater efficiency is due to the fact that the rinse water has hardness. Any reduction in rinse volume will reduce the amount of exhaustion that occurs during the rinse cycle. When less rinse water is used, less exhaustion occurs during the regeneration, so there is more capacity during the service cycle.

As stated previously, the greatest benefit to a countercurrent system is lower leakage. In a cocurrent system the brine is introduced in the same direction as the service flow. When the bed is exhausted and salt is passed through the system, top to bottom, a heel of exhausted resin is left at the bottom of the unit. A countercurrent unit which runs opposite to a cocurrent system will leave a heel of exhausted resin on top of the unit. When the system goes back on line, the heel of hardness must pass through

Table 3. Comparative evaluation—fine mesh vs. standard mesh

Regeneration level (lbs./cf @ 10%)	Standard resin operating capacity (kgr/cf) salt efficiency (kgr/lbs. of salt)	Fine mesh resin operating capacity (kgr/cf) salt efficiency (kgr/lbs. of salt)
5	22.2 / 4.44	23.9 / 4.78
10	29.0 / 2.90	31.5 / 3.15
15	31.3 / 2.09	34.0 / 2.27
20	33.6 / 1.68	36.6 / 1.83
25	35.7 / 1.43	39.0 / 1.56

Softening cycle – downflow 3 gpm/cf
Regeneration – upflow 0.5 gpm/cf
Resin bed depth – 24 inches
Operating capacity end point – 10 ppm total hardness

tion (See Table 4). With countercurrent regeneration, the brine solutions run opposite the service flow. Capacity is not increased during the actual brining of the resin; it occurs during the rinse cycle. In a cocurrent system, the total rinse can be 5-10 bed volumes or 40-80 gallons. The rinse in the countercurrent system may be as low as 2-5 bed volumes or 15-40 gallons. The reduc-

Table 4. Countercurrent water softening for high hardness and high solids

	Conventional (Cocurrent)	Countercurrent
Influent —TDS	1,500 ppm	1,500 ppm
—TH	700 ppm	700 ppm
Regenerant (NaCl)	10 lbs./cu.ft.	7.5 lbs./cu.ft.
Hardness leakage	25-30 ppm	1-2 ppm

the entire bed before exiting the unit. This procedure can reduce leakage by 90 percent or more. Residential users will generally not need to have the low leakages that countercurrent systems are capable of producing. If there were one grain of leakage, most people would never notice. However, there are many applications in commercial and industrial markets that require low hardness leakage.

Countercurrent systems can be optimized for better results. First, the system can be packed, which can be accomplished by filling the tank with resin or a combination of polypropylene beads on top of the softening resin. This will prevent the bed from turning over. The goal of this type of regeneration is to have the heel of exhausted resin on top of the bed. If the bed fluidizes, the heel of exhausted resin will be distributed throughout the whole system. Backwashing will not fluidize and expand the bed to reduce solids that have been filtered out by the bed. If iron is contained in the influent water, a reducing agent should be used to clean it frequently. Salt containing a reducing agent would be very beneficial.

Even if the countercurrent system is allowed to fluidize, it will give better results than a cocurrent system. The heel of exhausted resin will be distributed throughout the bed, but it will not be concentrated at the bottom of the bed like cocurrent regenerations. The brine in this system can be passed through the bed at such a flow rate that the bed may only expand 10-15 percent. By doing this, the heel of exhausted resin will stay at the top of the bed to a greater degree. The brine cycle can also be used as the backwash. Pulse brining will give the same effect.

Resin degradation and sampling

Softening resin can last 15-20 years or more in unstressed conditions. Chlorine and metal fouling are the primary culprits in resin degradation. There are some quick and dirty tests that can give information pertaining to resin quality. First, take a sample of resin and place it between your thumb and index finger and rub. If the resin breaks up, it has been oxidized by chlorine. There is a general rule that can be used to predict the effect of chlorine on resin life. This rule states that for each ppm of chlorine in the influent water, the resin life will be cut in half. This guideline should only be used as an estimate. For example, if there is one ppm of chlorine in the influent water, the resin will have a life expectancy of 7-12 years; two ppm of chlorine will

give a life expectancy of 3-6 years. When chlorine levels are excessive, a higher crosslinked resin can be used. There are other factors that influence the life expectancy of resin, like metal fouling. To check for metal fouling, take a small sample of resin (one ounce) and place it in a glass jar. Add muriatic acid (HCl) to a level about one inch above the resin. Let this set for about one hour. A yellow to orange color will develop. The darker the color, the heavier the iron fouling. If a blue color develops, it generally means copper fouling has occurred. These are simple tests that can give you a basic idea of the resin's condition.

If problems occur and the system is large enough, the resin can be tested by a laboratory. Standard testing includes total capacity, softening capacity, water retention, bead count and iron fouling (See Table 5). It is important to properly sample the resin bed: a grain thief can be used to obtain a representative sample of the whole resin bed. Resin can also be pulled from different levels of the bed, so a representative sample is taken for analysis. If the sample is removed from only the top of the bed, the results will more than likely show the resin to be in poor condition. Resin from the top of the bed will usually have a high degree of fines (small beads), broken beads and iron fouling. A sample from the bottom of the bed will generally be in good condition. Either way, the analysis will not be representative of the entire bed of resin.

Total capacity is a measurement of the resin's theoretical capacity. New resin has a total capacity of 1.9 to 2.0 meq/ml. Irreversible fouling or oxidation will cause this parameter to decrease. The softening capacity is more indicative of how the unit is working in the field. New resin will have a softening capacity similar to the total capacity. In the test procedure, the resin is regenerated with salt, then exhausted with calcium chloride. The difference between the total and softening capacity test procedure is that hydrochloric acid is used in the total capacity procedure. If there is a precipitated iron fouling the softening resin, the total capacity may be within specification. However, the softening capacity on the same softening resin will be poor. Salt will not remove iron fouling from the resin. If there is a difference between the softening capacity and the total capacity, it is generally due to reversible metal fouling.

Capacity lost to oxidation is unrecoverable. The water retention is the amount of water actually contained within the bead. New resin will have a

water retention of 45-48 percent. If oxidation is occurring the water retention will increase. This increase is generally due to chlorine. Chlorine will attack the crosslinking of the resin and cause it to become mushy. This kind of degradation will cause pressure drop and channeling, as well as a deterioration of the capacity.

The bead count shows the amount of whole and broken beads. The concentration of broken beads is most important. A high amount of broken beads will lead to channeling and pressure drop. A thorough, extended backwash can be used to reduce the percentage of broken beads.

The final test is for iron fouling. In this test, the amount of iron on the resin is tested in grams of Fe/cu.ft. Hydrochloric acid is the best agent to use to remedy this condition. However, as stated previously, care must be taken when using HCl. It is corrosive to the metal parts in valves and if the resin is not regenerated back to the Na form, a low pH will result in the service cycle. Other reducing agents, which are easier to handle, include sodium hydrosulfite, sodium bisulfite, citric acid and phosphoric acid. This iron test can also be used to determine other types of metal fouling, like copper and aluminum. To treat copper and aluminum fouling, phosphoric acid or hydrochloric acid needs to be used, since other reducing agents may not be strong enough to reverse metal fouling. Note that the metal fouling test only reports reversible fouling.

Again, it is important to obtain a representative resin sample testing. Resin from the top of the bed will have higher amounts of broken and fine beads along with higher amounts of iron fouling. A good representative sample can be acquired by sticking a PVC pipe down through the entire bed. (See Chubb Michaud's article "Sampling Quality and the Quality of the Sample—The key to good resin management is good sampling," *WC&P* November 2004.)

Resin should be stored in an area that will prevent it from freezing. Frequent freezing and thawing causes resin to break down physically. If resin freezes once or twice, it should not be negatively affected. Resin is sold in the fully swollen moist form and should not be allowed to dry out. Upon wetting, the resin may fracture, causing broken beads to form. In many cases, ion exchange resins that have lost significant amounts of moisture, appearing dehydrated, do still have sufficient water in the interstitial spaces to prevent any severe physical breakdown. If the resin is dehydrated, it is best

Table 5. Typical softening resin analysis

Total capacity	
meq/ml	1.9
meq/gm	4.5
Softening capacity	
meq/ml	1.6
meq/gm	4.31
Water retention , percent	52
Bead count , percent	
Whole	93
Cracked	4
Broken	3
Iron fouling	
GM Fe/cu.ft. as Fe	11

to rehydrate it in a salt solution overnight; this will reduce the osmotic shock that might otherwise occur, also allowing the resin to swell back to its original volume slowly thereby releasing any occluded air. A thorough backwashing should be performed to remove any broken and fine beads. Dehydration should not effect the resin's capacity to remove hardness.

If the resin is going to be put into shutdown, the above recommendations should be followed. The resin should also be placed into a brine solution; this will prevent the resin from freezing and reduce the potential for biological growth. If extremely cold temperatures are possible, a solution of propylene glycol can be used to store the softening resin. Propylene glycol can be purchased from any RV dealer, since it is used to winterize mobile homes and trailers. Propylene glycol is usually a food grade product.

When the system is started up, the unit should be regenerated twice to remove all of the antifreeze. Use only propylene glycol. The unit can also be stored in a saturated brine solution. The brine will decrease the likelihood of freezing and will reduce the potential for any bacterial growth. This treatment is also good for areas where the temperature is warm. If any bacterial growth is noticed (e.g. odor, pressure drop, etc.), the system should be disinfected. (See Keller's article on iron removal in *WCP*, June 2004).

Disinfection of water softeners

Most water treated by municipal facilities uses some type of disinfectant. Disinfected water will generally not contribute to bacterial build-up on the softening bed. This problem can occur when the water is untreated.

In the event that biological growth is a problem, disinfection may be re-

quired. Bacteria can grow within the bed; if the growth is significant, the bed may clump together. When disinfection is required, the entire system must be treated, not just the softening bed. Bacterial hide-out can occur in any part of the water system. Most disinfection processes utilize oxidants, which will eventually break down ion exchange resin. Unfortunately, this is a necessary evil if there is bacterial contamination. If the bed is clumped together the unit may need to be physically broken up, as well as treated with an oxidant. This can be performed with an air lance or by stirring the resin with a broom handle.

It should be mentioned that bacteria could cause the rotten egg odor associated with hydrogen sulfide (H_2S). Sulfate reducing bacteria can grow in the water distribution system and attack sulfate ions that are present in the water, reducing them to hydrogen sulfide. This is why the water supply may not have a rotten egg odor but the water at the faucet does. Disinfection of the entire system should help alleviate this problem.

Sodium hypochlorite, commonly known as bleach, is an inexpensive and excellent oxidant that can be purchased at your local store. Generally, bleach has an available chlorine content of 5.25 percent.

To disinfect a house system with a well, a solution of bleach (5.25 percent) is poured into the well. A 100-ppm solution of bleach is adequate to kill the bacteria. Use Table 6 to determine how much bleach is required to achieve a 100-ppm solution.

If the well casing dimensions are not known, it is better to over-chlorinate. This will only increase the amount of time required to purge the well of chlorine. Chlorine should remain in the water distribution for six to eight hours, or overnight if possible. It is desirable to bypass the water softener when disinfecting the well and the house. Contact with high concentrations of bleach for an extended period of time is detrimental to the resin.

The same 100-ppm concentration is also used to disinfect the water softener. The first step to clean the softening resin is to fully regenerate it to the sodium form with salt. This will help prevent any metals, such as iron, from precipitating and fouling the bed. It will also help remove metals like copper that can act as a catalyst with chlorine and increase the rate of resin degradation. Placing four ounces of bleach per cubic foot into the brine well and putting the unit into regeneration performs the actual disinfection. It is advantageous to interrupt the brining cycle

for one to two hours once there is a chlorine odor in the effluent. This will allow greater contact time for more complete disinfection. It is normally recommended that the system then be put through a completely regeneration cycle with salt only. This will help remove any debris that may have broken loose during the disinfection process.

As stated previously, bleach is an oxidizing agent that will degrade the resin. This procedure should only be pursued when needed, with the understanding that the resin life will be shortened. Be certain the pH of the water is eight or higher. Bleach can cause a higher degree of degradation in an acidic environment than in an alkaline environment. Any metals on the resin or in the bleach solution can act as a catalyst and increase the amount of degradation that occurs with this treatment.

There are other biocides on the market that can be used as disinfecting agents, such as chloromelamine. Any chlorine donor will cause degradation, though chloromelamine is not as detrimental as free chlorine. There are non-oxidizing agents on the market that should be effective; however, they must meet FDA regulations. As with any chemical, care should be taken and the manufacturer's instructions must be followed.

It is a better practice to eliminate bacterial problems prior to installation of the softening system. This will help prevent the use of an oxidant on the resin causing the softener to have a shorter life.

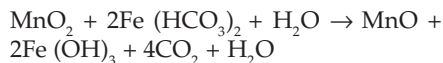
Storage

Ion exchange resins can have a long shelf life when properly stored. Resin should be packaged in a container that will not allow it to dehydrate. The rehydration process should occur over a several-hour period, preferably overnight. The resin should then be backwashed thoroughly to remove any broken beads generated during the rewetting process. Cation resin should be stored at a temperature between 40° F and 120° F; anion resin should be stored at a temperature of 40° F and 120° F in the chloride (Cl) form and at a temperature of 40° F to 95° F in the hydroxide (OH) form.

Other methods of iron removal

Manganese dioxide (MnO_2) is a naturally occurring mineral that can be mined from the ground, or manufactured synthetically. It works as a catalyst to promote the oxidation of iron. Basically, iron and oxygen are attracted to the manganese dioxide, where they are retained

long enough to react, causing precipitation. This material can also precipitate iron if there is no oxygen present in the water. This reaction occurs when MnO_2 is reduced to MnO and ferric hydroxide is precipitated. The chemical reaction follows:



During the backwash, the surface of this material is scoured, removing the MnO . This exposes fresh MnO_2 which is used to oxidize iron. Simple backwashing is all that is needed to regenerate manganese dioxide. No chemicals are required to regenerate this material. Manganese dioxide should work well on clear water iron, as well as red water iron.

Manganese dioxide does have some drawbacks. First, MnO_2 weighs approximately 120 lbs./cu.ft. The backwash flow must be sufficient to expand the bed a minimum of 30 percent, although 50 percent is optimal. This is generally accomplished with a flow of 15-18 gpm/sq.ft. Remember that backwashing is a critical step with the product, since this is how the bed is rejuvenated. Second, manganese dioxide works most efficiently at a pH of 6.5 to 9. If the pH falls below this specification, pH adjustment is required. Finally, manganese dioxide should not be used on water that has bacterial or organic iron. There is an annual attrition rate of up to five percent under normal operating conditions.

Birm is another type of manganese dioxide. It has a silicon dioxide core coated with manganese dioxide. This makes Birm much lighter than its ore counterpart, less than 50 lbs./cu.ft. The benefit of this type of product is that it can be backwashed at a flow rate of 8-122 gpm/cu.ft. Birm requires dissolved oxygen in the water for the precipitation of iron, where the manganese dioxide ore does not. Birm relies on its ability to act as a catalyst between iron and oxygen. It has a limited amount of MnO_2 available, so it does not have the ability to supply oxygen through a redox reaction. The oxygen content should be at least equivalent to 15 percent of the total iron content. If the oxygen content is less than 15 percent, aeration is required. Birm is recommended on levels of iron less than 10 ppm. It can be utilized on higher concentrations, but the frequency of regeneration (backwashing) becomes excessive. Birm has a capacity of approximately 400-500 grains/cu.ft. It can treat up to 800 gallons of water containing 10 ppm Fe as $CaCO_3$. Birm should not be used on

water containing oil or hydrogen sulfide and organic matter should not exceed five ppm. As with any product, consult the manufacturer for operational guidelines.

A broad category in iron treatment is the oxidation process. The following are types of oxidation and precipitation methods:

1. Ozonation
2. Aeration (Oxygen)
3. Chlorination

The addition of any of these chemicals will cause clear water iron to precipitate. The precipitated iron is allowed to settle in a retention tank and the effluent water is finally passed through a filter. This filter is necessary to pick up any of the suspended particles that did not settle in the retention tank. Table 7 shows the amount of oxidant required to react with one ppm of iron. Ozonation and chlorination can also be used as disinfecting agents.

Ozone is created when electrical current is passed through the air. A portion of O_2 molecules split, forming elemental oxygen, which reacts with O_2 molecules to form O_3 .

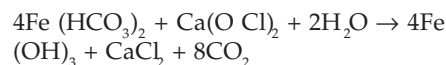
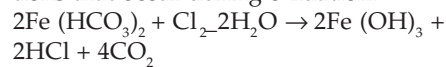
$$2Fe(HCO_3)_2 + O_3 + H_2O \rightarrow 2Fe(OH)_3 + 4CO_2 + O_2$$

Ozone is an extremely strong oxidizing agent, which reacts very quickly with any oxidizable material in the water, including iron. Ozone is so reactive that it is difficult to maintain a residual. Because of this, incomplete oxidation may result. One benefit of ozone is that it will not impart taste or odor into the water. Ozone may not be as effective as an oxidant in water bearing tannins. It will, however, effectively treat bacterial iron.

Aeration is another process by which iron can be oxidized. In this process, oxygen-filled air is bubbled up through the water and if there is adequate retention time, iron will precipitate. The required retention time increases as pH and temperature decrease. To some degree, these two parameters effect all of the oxidation processes. Following the aerator, a settling tank and/or filter should be utilized to remove the precipitated iron. A coagulant may have to be added at this point to increase the size of the particles for effective settling/filtration. This process is usually used as a pretreatment. Unreacted iron and/or colloidal iron can be polished by another process downstream. There are aeration systems that incorporate all of this technology into one package.

Chlorination is another extremely effective oxidant. It can be fed into a system as sodium hypochlorite, calcium hy-

pochlorite, or chlorine gas. Sodium hypochlorite is usually the oxidant of choice, since it is relatively inexpensive and readily available. These chemicals work on the same principle that OCl ions (hypochlorite) both disinfect and oxidize. The following equations show the reactions that occur during oxidation:

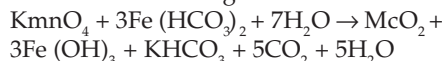


The treated water then passes into a retention tank where the iron will precipitate and settle out. A coagulant may be helpful in the retention tank to produce a particle sufficient in size to enhance the settling properties of the precipitated iron. Be sure the coagulant is not overfed, as this could foul the water treatment equipment downstream. The chlorine compound is fed into the influent water in a concentration high enough to allow for a residual chlorine content of one to four ppm when the water leaves the retention tank. Generally, a 30-minute retention time is sufficient to allow for the reaction to occur; however, a longer time may be required. Following the retention tank, an activated carbon filter is necessary to dechlorinate the water as well as filter a portion of the suspended iron. Whether a carbon filter or some other type of filter is used, frequent backwashing is critical to remove precipitated iron from the bed.

A side effect of chlorination is the formation of trihalomethane, a known carcinogen. When chlorine reacts with tannins in water, trihalomethane can be formed. Caution must also be taken to keep chlorine tablets dry. They can react with a small amount soft water, causing an exothermic reaction that may result in fire. Remember, this is an oxidant and oxygen fuels fire. Chlorine will add taste and odor to water. From a health standpoint, this is no problem, but aesthetically it is unappealing. As stated previously, chlorine can be removed by activated carbon.

Manganese greensand or glauconite is a mineral that is mined in the eastern part of the U.S. The base material is composed of alumino-silicate, which is treated with manganese chloride and then regenerated with potassium permanganate ($KMnO_4$). Upon exhaustion, the greensand is backwashed to remove precipitated iron from the bed. $KMnO_4$ is then passed back over the bed to oxidize the MnO to MnO_2 . This type of regenera-

tion is known as intermittent. Iron is precipitated directly by the greensand in a redox reaction. Iron up to 10-15 ppm can be treated in this fashion. KmnO_4 can also be fed continuously ahead of the bed. In this type of regeneration, iron is precipitated prior to the bed as well as by the bed. The oxidation process that causes iron to precipitate prior to the bed can be seen in the following reaction:



This process is normally used in larger systems that will be monitored. Some type of filtration media should be used prior to the bed to filter most of the precipitated iron. This will help prolong the service run, since this should reduce the pressure drop on the bed of greensand. Generally, when pressure drop exceeds 10 psi the unit is backwashed. The backwash flow should be sufficient to expand the bed by 40 percent.

The minimum recommended pH for this process is 6.2. Water with an acidic pH will strip the MnO_2 coating, making the greensand useless. When this occurs, the greensand must be replaced. Chlorine

Table 7. Chemical requirements for the oxidation of iron

Oxidant	Amount required to oxidize 1 ppm iron
Oxygen (O_2)	0.14 ppm
Chlorine (Cl_2)	0.62 ppm
Ozone (O_3)	0.86 ppm
Potassium permanganate (KMnO_4)	0.91 ppm

NOTE: This shows the stoichiometric amount of oxidant required to react with 1 ppm iron. In practice, the actual amount required can be greater since there are agents in the water that might also react with the oxidizer besides the iron.

injection can be used on either type of regeneration, especially if hydrogen sulfide and manganese are present. H_2S and Mn will consume a disproportionate amount of KmnO_4 compared to iron. Iron requires approximately one ppm of permanganate, while H_2S and Mn require six ppm and two ppm respectively. Chlorine will help oxidize hydrogen sulfide and manganese as well as the iron, allowing KmnO_4 to go further. When chlorination is used in conjunction with manganese greensand, the use of permanganate can be lowered drastically. Potassium permanganate is not easy to work with. It will stain just about anything it contacts. If it is overfed, the water will have a pink to purple color. It should also be noted that KmnO_4 is toxic and expensive.

When iron has precipitated it must

Table 6. Computing bleach requirements

Depth of water in the well (ft.)	Well diameters		
	6 inches	8 inches	10 inches
10	8 oz.	8 oz.	8 oz.
20	8 oz.	16 oz.	32 oz.
30	16 oz.	32 oz.	48 oz.
40	16 oz.	32 oz.	64 oz.
80	32 oz.	64 oz.	112 oz.
150	80 oz.	129 oz.	192 oz.

be physically filtered from the water. Sand, anthracite, activated carbon, garnet or a multimedia filter should adequately remove the precipitated iron. The space between the particles of media is the mechanism for physical removal. In a filter bed, the actual filtration occurs at the top if it is operated in a downflow fashion. Perhaps the most important characteristic of a filter media is the particle size. The size of the media dictates the size of the particle that can be removed. Size will also impact the flow rate and pressure drop; the smaller the particle size, the greater the pressure drop and the lower the flow rate. Media with a smaller particle size will utilize a smaller portion of the bed than does media with a larger particle size. A larger particle size distribution will allow for greater penetration of solids into the bed; therefore, a greater portion of the bed will be used. In the filtration of iron, the particle size of the media must be small enough to remove the precipitated iron. This will be a judgment call, involving some trial and error.

Neutralizing filters have also been used in iron removal. Magnesium oxide and calcium carbonate are used to increase pH in acidic water. By increasing the pH the iron can more readily precipitate. The iron is then filtered out in the bed. Simple backwashing is required to keep the bed from plugging with precipitated iron. This media is sacrificial and occasional replacement is required (more so than other iron removal processes).

Calcium carbonate, sometime referred to as limestone or marble chips, can be used by itself or in combination with magnesium oxide. This helps prevent the magnesium oxide from becoming an agglomerate. Magnesium oxide is more soluble and will increase pH at a faster rate. When used in conjunction with calcium carbonate, the filter will increase low (four to six) pH water more effectively than calcium carbonate alone.

Iron removal involves both art and science. Equipment design is critical, but the most important factor is what type of iron is being treated. This dictates what

iron removal process is most likely to be effective.

About the author

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This article is Part 2 in a series. Watch for Part 3 in an upcoming issue.

