



Tech Brief

Lime Softening

A NATIONAL DRINKING WATER CLEARINGHOUSE FACT SHEET

Summary

Hard water can cause scaling problems in water heaters and soap does not lather well in hard water. Therefore, some water utilities soften water to improve its quality for domestic use. Lime softening is best suited to groundwater sources, which have relatively stable water quality. The combination of variable source water quality and the complexity of the chemistry of lime softening may make lime softening too complex for small systems that use surface water sources.

Although lime softening has been used successfully by groundwater systems serving fewer than 3,000 people, it is unlikely to be suitable for treating groundwater in systems serving 500 or fewer people unless those systems have some form of contract or satellite operation that would enable a trained operator to monitor the treatment process. Prefabricated lime softening equipment is available for small systems. Also, there is an American Water Works Association Standard for quicklime and hydrated lime (ANSI/AWWA B202-93) that provides purchasers, manufacturers, and suppliers with the minimum requirements, including physical, chemical, packaging, shipping, and testing requirements.

Either hydrated lime [$\text{Ca}(\text{OH})_2$] or quicklime (CaO) may be used in the softening process. The choice depends upon economic factors, such as the relative cost per ton of the two materials as well as the size and equipment of the softening plant. Hydrated lime is generally used more in smaller plants because it stores better and does not require slaking (producing a chemical change in lime by combining it with water) equipment. On the other hand, quicklime costs less per ton of available calcium oxide and is thus more economical for use in large plants.

Softened water has high causticity and scale-formation potential; hence, recarbonation is employed to reduce pH and mitigate scaling of downstream processes and pipelines. Onsite combustion generation of carbon dioxide (CO_2) or liquid CO_2 is the most common source of carbon dioxide for recarbonation.

What is hard water?

“Hardness” in water is primarily the result of concentrations of calcium and magnesium. Thus, some water utilities remove calcium and magnesium to soften the water and improve its quality for domestic use. Other ions that produce hardness include iron, manganese, strontium, barium, zinc, and aluminum, but these ions are generally not present in significant quantities. Therefore, total hardness is usually defined as the sum of magnesium and calcium hardness in milligrams per liter (mg/L), as calcium carbonate (CaCO_3). Total hardness can also be differentiated into carbonate and noncarbonate hardness. Carbonate hardness is the portion of total hardness present in the form of bicarbonate salts [$\text{Ca}(\text{HCO}_3)_2$ and $\text{Mg}(\text{HCO}_3)_2$] and carbonate compounds

(CaCO_3 and MgCO_3).

Noncarbonate hardness is the portion of calcium and magnesium present as noncarbonate salts, such as calcium sulfate (CaSO_4), calcium chloride (CaCl_2), magnesium sulfate (MgSO_4), and magnesium chloride (MgCl). The sum of carbonate and noncarbonate hardness equals total hardness.

What may be “hard” water in one area may be perfectly acceptable water in another area. In general, the degree of hardness is classified as follows:

Hardness	mg/L as CaCO ₃
Soft	0 to 75
Moderate	75 to 150
Hard	150 to 300
Very hard	Above 300

Source: Water Treatment Plant Design, 1998.

For most applications, total hardness of 120 mg/L or less and magnesium hardness of 40 mg/L or less appear to be acceptable design criteria for softening facilities.

How does the lime-softening process work?

In the lime-softening process, the pH of the water being treated is raised sufficiently to precipitate calcium carbonate and, if necessary, magnesium hydroxide. The normal pH of water is between 6.5–8.5. In small systems, lime softening is typically practiced by adding hydrated lime to raw water to raise the pH to approximately 10. This removes calcium carbonate, essentially limestone. If magnesium removal is also required, the pH during softening needs to be closer to 11. Lime-softening systems need not be pilot tested for small systems using groundwater sources. Jar testing to determine appropriate process pH and chemical doses is sufficient. Doses of these chemicals should not change greatly over time unless the groundwater is subject to periodic infiltration by surface water that changes in quality. Lime-softening systems do need to be pilot tested if used on surface water sources with variable quality.

What pretreatment is used?

The principal types of pretreatment used before lime softening are aeration and presedimentation.

Aeration may be used to remove carbon dioxide from the source water before softening. This is only applicable to groundwaters where carbon dioxide concentrations are relatively high. Lime removal of carbon dioxide in source water adds to operation costs because of chemical expenses and increased calcium carbonate residuals.

Induced draft or open tray aeration is often used and may reduce the carbon dioxide level to 10 mg/L or less. Aeration also oxidizes iron and manganese; clogging of the aeration tray is a problem.

Presedimentation is used primarily by those plants treating high turbidity surface waters.

What are the monitoring and operating requirements?

Regulatory monitoring requirements for lime softening plants depend on whether the source water is surface water or groundwater. Process monitoring requirements should focus on measurement of pH, hardness, and alkalinity for plants treating groundwater. In addition, filtered water turbidity monitoring is needed at the plants treating surface water for compliance purposes, as well as to manage filter operation.

One of the difficult aspects of lime softening is the operation and maintenance of lime feeders and lines carrying lime slurry to the point of application. In addition, plant operators must understand lime softening chemistry. Measurement of pH must be accurate, and the operator must know that the pH meter is properly calibrated. Failure to maintain the proper pH in softened water prior to filtration at a lime softening plant could result in precipitation or excess lime in the filter beds and formation of calcium carbonate deposits within the filters.

What are the chemical requirements?

The amount of lime required to remove carbonate hardness and magnesium can be calculated using the following equation:

$$\text{CaO (lb/mil gal)} = 10.6 \text{ CO}_2 \text{ (mg/L)} + 4.7 [\text{alkalinity (mg/L)} + \text{magnesium hardness (mg/L)} + X]$$

Where CaO is 100 percent pure, CO₂ is expressed as CO₂, alkalinity is expressed as CaCO₃, and X is the required excess hydroxide alkalinity in mg/L as CaCO₃. The magnesium hardness shown is the amount to be removed by softening, and not the amount present. Desired excess alkalinity can be determined from the magnesium hydroxide solubility relationship: it is typically in the range of 30 to 70 mg/l and is often estimated at 50 mg/L expressed as CaCO₃.

What are other softening alternatives?

The selection of lime, lime-soda ash, or caustic soda softening is based on cost, total dissolved solids criteria, sludge production, carbonate and noncarbonate hardness, and chemical stability. Water containing little or no noncarbonate hardness can be softened with lime alone. However, water with high noncarbonate hardness may require both lime and soda ash to achieve the desired finished water hardness. Softening with lime or lime-soda ash is generally less expensive than caustic softening. Caustic soda softening increases the total dissolved solids of treated water, while lime and lime-so-

da ash softening often decrease total dissolved solids. Caustic soda softening produces less sludge than lime and lime-soda ash softening. Caustic soda does not deteriorate during storage, while hydrated lime may absorb carbon dioxide and water during storage, and quicklime may slake in storage causing feeding problems. The final selection is generally based on cost, water quality, and owner and operator preference.

What are the benefits of softening?

Potential benefits of softening water at a central treatment plant include the following:

- reducing dissolved minerals and scale-forming tendencies,
- reducing consumption of household cleaning agents,
- removing radium 226 and 228,
- removing arsenic and uranium,
- removing heavy metals,
- supplementing disinfection and reducing algal growths in basins,
- removing certain organic compounds and reducing total organic carbon (TOC),
- removing silica and fluoride,
- removing iron and manganese,
- reducing turbidity of surface waters in conjunction with the hardness precipitation process,
- increasing the Langelier Saturation Index, useful for corrosion control under some conditions, and
- possibly removes Giardia Lamblia cysts.

Are there concerns about soft water?

In most cases, for consumer use, relatively soft water is preferable; however, it does have several disadvantages.

Excessively soft water can cause corrosion in pipes. This corrosion can shorten the service life of pipes and household appliances and can result in toxic materials, such as lead and cadmium, being dissolved in drinking water. The decision to soften a water supply depends completely on the community. Drinking water regulations do not generally require softening.

What about lime softening residuals?

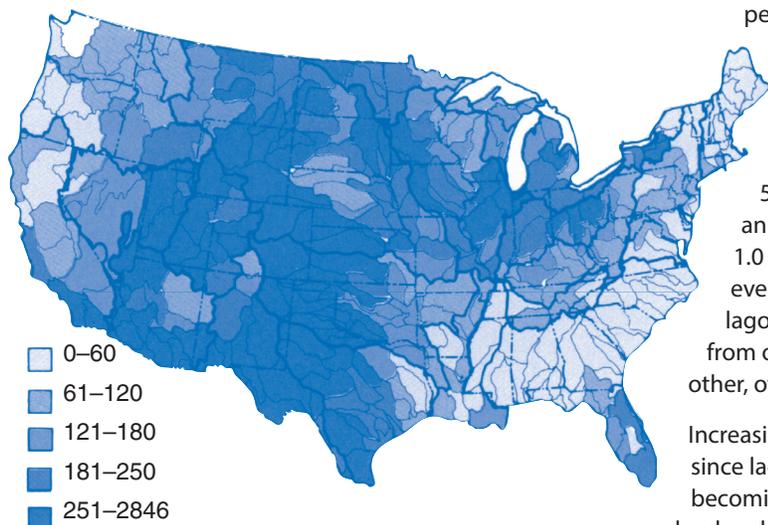
All water softening plants, large or small, are now required to refrain from directly discharging any wastes—liquid or solid—into rivers or streams. Where abandoned stone quarries, sand and gravel pits, or coal mines are available nearby, it may be possible to dispose of the sludge for many years without any serious difficulty. In areas where there are abandoned coal-strip mines, pumping the sludge into these areas may be a logical and convenient solution. If acid waters are leaching out of the mine into the watershed, as many such mines do, the waste sludge can help in abating serious stream pollution by neutralizing the acid water. Such neutralization may offer a great potential savings in material treatment cost to the state.

Selection of lime, lime-soda ash, or caustic soda chemical precipitation process must adequately address the disposal of generated sludges. Ultimate disposal of lime or caustic sludges now includes options, such as discharge to sanitary sewers, drying lagoons, and land application.

In some cases, sludge is discharged directly into a community's sewage system. Such a discharge must be done with the approval of the municipal sewage department, since not all systems can accommodate this alkaline waste, at least in the volume produced. In other instances, the discharge of such sludge could prove beneficial in neutralizing other acid trade wastes entering the same system. A few small plants are permitted to discharge directly into the community's storm sewer system, although this method has been phased out in most cases.

Lagooning is another practical solution. If the sludge can be dried to approximately 50 percent moisture content in lagoons, the annual requirement will be approximately 0.5 to 1.0 acre-feet per 100 mg/L hardness removed for every million gallons per day (MGD). Also, multiple lagoons used on a fill and let dry sequence, or filling from one end and withdrawing or decanting from the other, often result in better drying of the sludge.

Increasing ingenuity is necessary for sludge disposal, since lagooning, one of the most common practices, is becoming less frequent due to the dearth of available land and soaring land costs. Therefore, other methods are being increasingly employed.



Hardness as CaCO₃, mg/L

Courtesy of the U.S. Geological Survey, Report 78-200



An attractive method for a water plant located in a farming area is to use land application of the sludge on farm fields where the soil pH is too low for optimal plant growth. In addition to providing a desirable pH for plant growth, lime-softening sludge is generally a pure source of calcium carbonate with varying small amounts of magnesium hydroxide and provides an effective source of liming material for farmers. It has a neutralizing value for soil acids in excess of most agricultural liming materials.

Where can I find more information?

Information in this fact sheet was primarily obtained from the following sources:

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- (2) American Water Works Association. 1984. Introduction to Water Treatment. Principles and Practices of Water Supply Operations.
- (3) National Lime Association at <http://www.lime.org/>.
- (4) National Research Council. 1997. Safe Water From Every Tap: Improving Water Service to Small Communities. National Academy Press. Washington D. C.
- (5) Technology Transfer Handbook: Management of Water Treatment Plant Residuals. American Association of Civil Engineers Manuals and Reports on Engineering Practice N0.88, AWWA Technology Transfer Handbook, U.S. EPA/625/R-95/008.
- (6) American Water Works Association. 1990. Water Quality and Treatment: A Handbook of Community Water Supplies. Fourth Edition.
- (7) American Water Works Association and American Society of Civil Engineers. 1998. Water Treatment Plant Design. McGraw-Hill. New York, NY.
- (8) Vigneswaran, S., C. Visvanathan. 1995. Water Treatment Processes: Simple Options. CRC Press. New York, NY.