We use lime softening extensively in certain areas of Florida and have been for over 70 years. In many communities lime softening processes do a relatively good job at removing hardness, and they do it inexpensively. Removing the hardness helps the pipe systems and keeps calcium out of customers’ water heaters.

While lime softening does struggle with organics and is not appropriate for surface waters or brackish supplies, it has proven to be an excellent solution for treatment of hard waters and has served Florida groundwater systems well for nearly a century.

Using Lime Softening Correctly

Over the past couple years, however, I have come across a number of situations where ongoing operational issues with lime softening plants have made local officials consider lime softening to be an old technology that has little value as a treatment solution today. The challenges they face seem to much to do with money; cutting costs means less lime is used, which leads to a host of problems, like poor settling, poisoned ion exchange resins, more chlorine use, cloudy water, and deposits on filter media. When the proper principles are applied, these issues are avoided. Perhaps a little review would help.

Hard water is typically caused by large amounts of calcium bicarbonate in the water, which is caused by the dissolution of limestone. By definition, hardness is the sum of all polyvalent positive ions (Hammer and Hammer, 2013). Calcium and magnesium are generally the major constituents, but iron factors in as well.

Lime reactor units (conical-shaped, open reactor vessels) are used to mix slaked lime with raw water to create a chemical reaction. Lime reacts with the calcium bicarbonate, making calcium carbonate, which settles very quickly. Then, the magnesium reacts with hydroxide (OH⁻), which also settles, thereby removing calcium and magnesium hardness, along with iron and other metals, in a clarification zone. Clear water rises to the top and the precipitating calcium carbonate and magnesium hydroxide settle to the bottom as lime sludge.

The chemistry behind lime softening is to precipitate compounds (causing hardness) by creating a chemical reaction with lime and the hardness particles (primarily calcium and magnesium) as follows:

<table>
<thead>
<tr>
<th>Hardness Constituent</th>
<th>Hydrated Lime</th>
<th>Precipitants</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂, Ca(OH)₂</td>
<td>CaCO₃, H₂O</td>
<td></td>
</tr>
<tr>
<td>Ca(HCO₃)₂, Ca(OH)₂</td>
<td>2CaCO₃ + 2H₂O</td>
<td></td>
</tr>
<tr>
<td>Mg(HCO₃)₂, Mg(OH)₂</td>
<td>CaCO₃, Mg(OH)₂ + H₂O</td>
<td></td>
</tr>
</tbody>
</table>

Because of the fast reaction that occurs, the clarifiers are small, followed by filters to remove the remaining fine, unsettled particles. If iron or hydrogen sulfide (H₂S) is present, aeration will help remove a portion of the iron and liberate H₂S (note that H₂S is biologically generated by bacteria in the groundwater).

One of the benefits of lime softening is that, as a chemical reaction, one can very quickly determine how much lime is required, if one knows the milliequivalents of carbon dioxide, calcium and magnesium bicarbonate, or sulfate, that exists in the water (Hammer and Hammer, 2013). Because calcium hydroxide (hydrated lime) ionizes in the lime softening reactor, the lime raises the pH of the water. The pH rise is critical to the speed of the reaction, the quality and quantity of the sludge, and the clarity of the water going to the filters.

Figure 1 shows the alkalinity diagram; when the pH is greater than 10, carbonate (CO₃²⁻) will dominate. The CO₃²⁻ and OH⁻ are the form of alkalinity that settles, so the pH is critical; however, as the magnesium
hydroxide begins to settle, the pH starts to be reduced, which will slow the settling of the calcium carbonate. Bicarbonate (HCO₃⁻) then dominates.

While HCO₃⁻ reacts with calcium, it does not settle, which is the normal condition in raw water supply. This is why the concept of lime softening works most efficiently when the pH is raised to around 10 via milliequivalent calculations; otherwise, settling will be hindered.

Using the hardness and alkalinity of the water, one can determine the milliequivalents of calcium and magnesium bicarbonate that exist in the raw water, which can easily be used to determine the lime dose required for treatment. This can be confirmed with Imhoff cones.

**A Tale of Four Plants**

One of the better-operated lime plants in south Florida uses 1800 lbs/million gallons (MG) based on a hardness of 260 mg/L. This plant has minimal carryover, and has run the sand filters with no bed expansion (caused by the particles increasing in size) for over 20 years (replacing the media only because of an underdrain failure).

Another plant, in the same area, with a hardness of 168 mg/L, uses 1380 lbs/MG and runs just as well. The fact that the carryover from the lime softening reactor is minimal indicates good settling and proper lime dose, as verified by milliequivalent calculations.

Compare these two plants with two others that have ongoing issues, including filter expansion and solids/turbidity issues in the water distribution system, and consider their lime use.

The first used 570 lbs/MG of lime and reported 10 years of turbidity in the distribution system. Based on the use of milliequivalent calculations, 1350 lbs/MG of lime should be used. The operators claimed cases where the plant could not treat the water correctly, but had not adjusted the lime feed. The city where this plant is located was looking at spending tens of millions of dollars to replace the lime plant as a result.

The second plant reported using 700 lbs/MG of lime. Based on the use of milliequivalent calculations, 1400 lbs/MG of lime should be used. The chief operator at the plant reduced the lime feed to save money. The second plant's operator saved money on lime, but fixing the plant and the distribution system cost the utility about $20 million.

Consider the impact of too little lime. When the pH does not reach 10, the reaction is incomplete and creates a series of cascading failures as a result. First, sludge settles poorly (less solids, more liquid); compare Figures 2 and 3. Since the sludge settles poorly, there is more of it, so disposal costs more.

The second problem is that, if lime sludge does not settle, it will move from the lime softening reactors to the filters. As is known from the lime reaction in spiracors, the sand (and, we have found, the anthracite) in the filters acts as a catalyst for the calcium bicarbonate. Hence the sand particles accumulate the calcium carbonate and the particles get bigger, resulting in bed expansion.

The intent of the filter media is to remove fines via grain size. Sand and anthracite are specified to remove certain-size particles. If the grain sizes get larger, small particles will not be removed and filter efficiency is reduced, meaning solids can wash through the filters more easily. Turbidity then results.

Figure 4 shows the filter of a properly operated lime softening plant, and Figure 5 shows a comparison of anthracite and the media removed from a filter that did not use enough lime (note it is no longer black due to the calcium carbonate carryover that covered it). In the worst case, the particles can cement together, which will completely undermine the filtration process. Instead of filter media removing particles, the particles will travel through the channels that occur—just like in the Biscayne aquifer.

Filters need to be periodically backwashed to address plugging, which needs to be done more often if there is carryover. At one plant, the operation staff noted that backwashing takes place at a frequency exceeding 150 hours. This is a long time for lime softening systems and most backwash is done at lesser intervals (under 100 hours; the two better-operated ones at 50 hours) to lessen the impact of plugging.

**Lime Softening Plants Work**

To celebrate lime softening, I have included photos of some of the many lime softening plants that I have visited over the years. Despite some of these plants being over 50 years old (one is over 70), they continue to work well. Sure, they need periodic maintenance, but the most-common operational issues appear to be the reduction of lime usage for cost or other reasons. That will compromise the treatment veracity and can create cascading issues that might indicate plant problems.

Lime softening remains a solution for groundwater treatment from limestone aquifers in Florida. So let’s take another look at our lime plants and make sure they are being operated as intended.

We should celebrate this process and its cost-effectiveness.
Florida Lime Softening Plants

Lauderhill Village of Palm Springs Spiractors Davie Lime Plant

Hollywood Spiractors North Lauderdale Palm Beach County

Margate Hallandale Beach Pembroke Pines

Dania Beach shown empty. The calcium carbonate sticks to the side and protects the metal.

Dania Beach full.