Lime Softening—the Forgotten Technology: Optimization Case Studies From South Florida

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Many water treatment plants (WTPs) throughout the state of Florida have been using lime softening, primarily for the removal of color, calcium hardness, and, to a lesser extent, magnesium hardness for decades. Many of these facilities are experiencing challenges with controlling the lime softening process due to aging infrastructure, loss of engineering/operational expertise, a shift in water quality goals, and solids handling challenges.

This article includes findings and recommendations from multiple case studies across south Florida, including the City of Boynton Beach (city), related to the optimization of the lime softening process leading to a reduction in chemicals and solids generation, as well as tools to help operators meet finished water quality goals and maintain a consistent water quality.

Lime Softening Chemistry

The primary purpose of lime softening is to reduce levels of calcium and magnesium from water. Typically, effluent total hardness goals range from 80 to 120 mg/L as $CaCO_3$. The softening process requires raising the pH high enough (≥9.5) that the conversion of bicarbonate to carbonate occurs and facilitates the precipitation of calcium carbonate. The process of removing magnesium must occur at a higher pH (≥10.6) and is typically referred to as enhanced softening. Magnesium removal is not typically required in Florida due to the limited amount of magnesium in most source water and is therefore not extensively reviewed herein.

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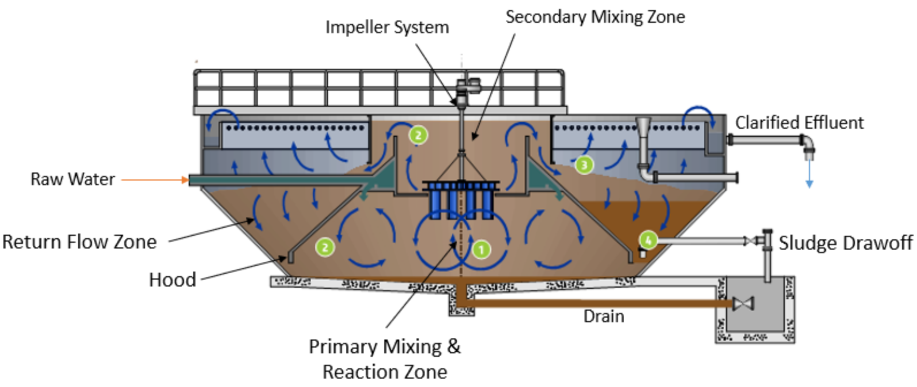

Figure 1. Typical Cross Section of a Solids Contact Clarifier *(modified from Suez Environmental)*

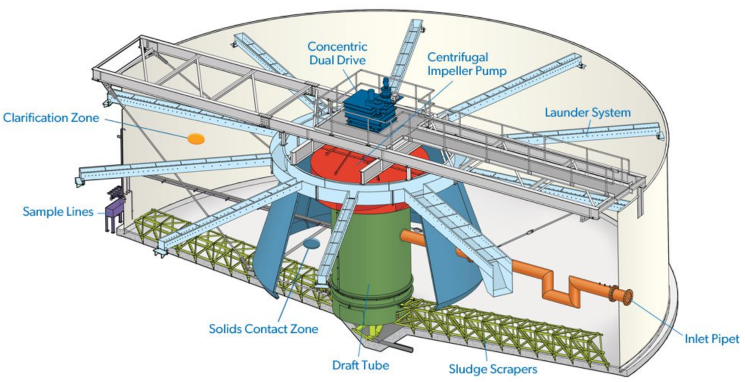

Figure 2. Typical Cross Section of a Solids Contact Clarifier *(WesTech)*

Softening for precipitation and removal of calcium requires elevated pH, which is typically accomplished by the addition of lime (Equation 1). The softened water can then be stabilized through recarbonation (the process of adding carbon dioxide) to form, then convert, carbonate to bicarbonate and minimize excessive calcium carbonate precipitation in downstream processes.

Equation 1: $Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2CaCO_3 \downarrow (solid) + H_2O \qquad pH \geq 9.5$

As shown, this process relies heavily on the presence of carbonate, which is one of the species that composes alkalinity. If the amount of calcium exceeds the amount of alkalinity in a water source (this can be compared easily when everything is reported as $CaCO_3$), the softening reaction will run out of carbonate before complete calcium removal and can lead to low finished water alkalinity. This is undesirable due to the lack of buffering capacity and the potential for nitrification to depress pH in the distribution system and resulting corrosive water.

Solids Contact Clarifier Operation

Configuration and operation of the solids contact clarifier (SCC) have a significant impact on overall plant performance. Figures 1 and 2 show a typical cross section of a SCC for two different manufacturers. In general, influent raw water flow is introduced into the center cone (area under the hood) where it's mixed by a mechanical mixer with lime and previously formed recirculated solids, which allows for the primary mixing and a surface for the softening reaction to occur. The mixer keeps the solids in suspension and resuspends the solids that settle in the return flow zone and where the rake (if included) can transport them back into the center cone, where they can be resuspended. Polymer can be added in the primary or secondary mixing zone to encourage solids agglomeration via bridging.

The upflow rate (also called rise rate) and the solids recirculation capacity are of primary importance to a well-functioning SCC. The 2012 Ten States Standards recommend a maximum upflow rate for SCCs used for softening of 1.75 gal per minute (gpm)/ft^2; however, historically, many WTPs in Florida can operate at higher upflow rates (Figure 3), which provides an opportunity to increase process capacity. Higher rates are acceptable because these installations, like most in Florida, only remove calcium carbonate and are not influenced by magnesium hydroxide, which requires lower rise rates. (For example, the steel industry precipitates magnesium hydroxide only and utilizes rise rates of 0.2 gpm/ft^2. This demonstrates the poor settleability of magnesium hydroxide.)

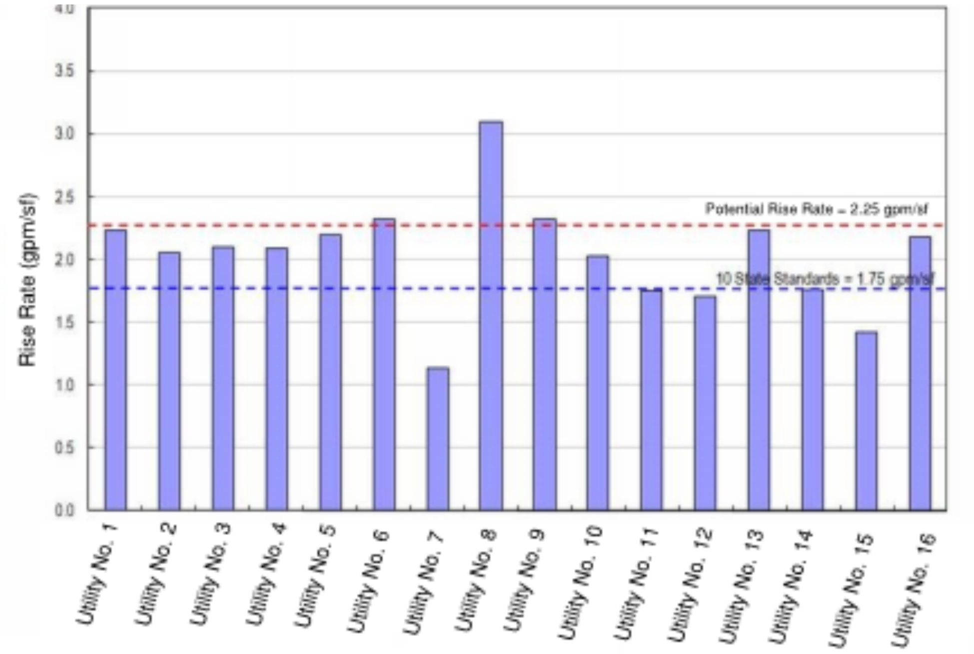

Figure 3. Upflow Rates for Solids Contact Clarifiers Across Florida

The recirculation of solids, which is the single most important factor, and a high inventory of solids should be maintained to provide a large surface area for the precipitation of calcium carbonate (the calcium carbonate reaction has a preference for precipitation on surfaces). Increasing the recirculation ratio (via increasing mixing speed and corresponding pumping capacity) lifts solids off the bottom of the SCC, promotes the formation of larger and more-uniformly-sized particles that settle rapidly, and prevents precipitation of fine calcium carbonate particles in the bulk liquid, which results in poor settled water turbidity and carryover to downstream processes.

Figure 4 shows the center cone solids for two mixing speeds. In this case, 100 percent speed resulted in improved settled water quality, less torque on the rake, and provided good mixing for the representative center sampling.

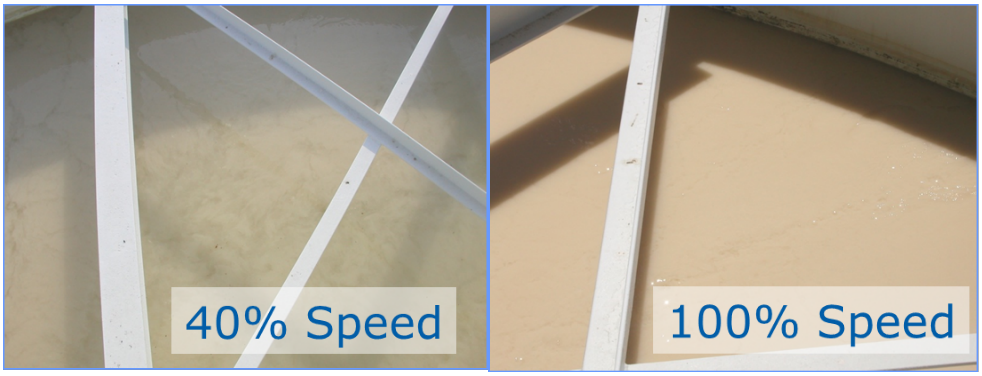

Figure 4. Center Cone Solids at Varying Mixer Speeds (Recirculation Ratios)

One misconception with SCC operation is that elevated rake torque levels should be mitigated by wasting solids. This can lead to excessive wasting and a reduction in the solids inventory, which will subsequently reduce the settleability of the solids and increase the settled water turbidity. Instead, utilities should consider increasing the speed of the turbine or center cone mixer. By increasing the speed, the solids are lifted off the rake and the torque is significantly reduced, without losing the solids inventory.

Part of the key to minimizing rake torque is to build larger solids, which will settle out more quickly in the clarification portion of the basin. Solids that settle out closer to the center of the rake will result in less torque (torque is the load times the moment arm—better settling decreases the moment arm).

Water Quality Considerations and Lime Dose

An SCC is a unit process specially designed for the softening reaction and works on the theory of maintaining a solids inventory to provide a surface area for the softening reaction to occur. Influent water quality and target pH of the lime softening process influence the operational approach of an SCC. The SCC operation historically needed to consider the desired finished water hardness, amount of magnesium hydroxide precipitation, and color removal goals. Many Florida utilities have installed color removal technologies, which allow a "decoupling" of hardness removal from color removal and also allow for reconsideration of overall goals of the SCC.

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For example, the city installed a magnetic ion exchange (MIEX) system as a pretreatment to its lime softening process at its East WTP. The MIEX system removes organic compounds and the corresponding color from the raw water (from an average color of 27 color units reduced to an average of four color units) before softening. This allows the city the ability to dial in a finished water hardness (instead of softening the entire flow stream to achieve color removal) and potentially bypass a portion of the flow around the softening process without sacrificing finished water color goals.

The city retained Carollo to help optimize the lime softening process to minimize chemical and residuals disposal costs. Bench-scale testing was completed using a standard jar test apparatus with six square, 2-liter jars for a number of testing conditions. Figure 5 shows the water quality of existing (full-scale) operations of the city's East WTP with no blend, compared to bench-scale results for two potential blends of 8.3 and 25 percent (meaning that 8.3 to 25 percent of the raw [MIEX-treated] water would be bypassed around the SCCs and blended with lime-softened water).

As shown, higher alkalinity and total hardness goals can be achieved with blends up to 25 percent, with minimal impact on finished water total organic carbon (TOC). Due to concerns with the Langlier Saturation Index (LSI)/calcium carbonate precipitation potential (CCPP) of the 25 percent blend, the city felt most comfortable wth the 8.3 percent blend. The percent bypass of the softening system directly correlates to reduction in lime use and solids production/handling costs. The pH range results were within the acceptable range for this facility.

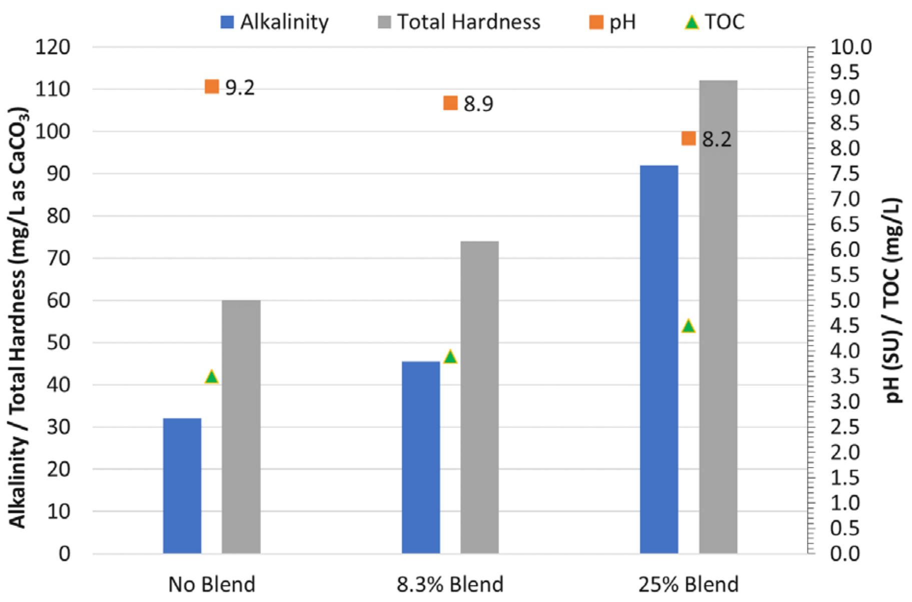

Figure 5. Blended Water Quality Results From East Water Treatment Plant *(City of Boynton Beach)*

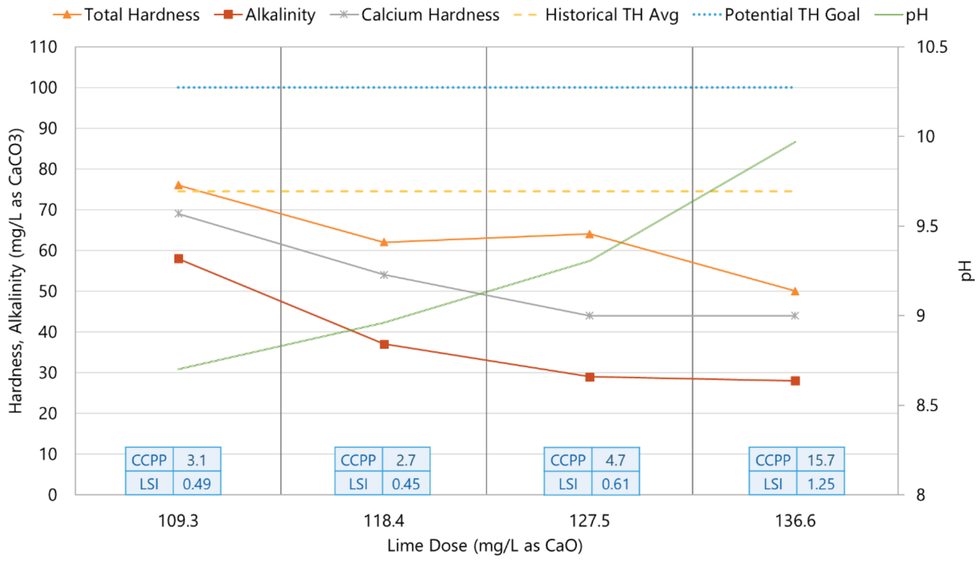

Figure 6. Settled Water Quality Results From East Water Treatment Plant at Varying Lime Doses

Some utilities in Florida have witnessed continued softening through the processes downstream of SCCs, including filtration, which can limit filter run times, reduce overall water efficiency, change media characteristics, and cause damage to underdrains.

A utility located in south Florida has experienced this since it currently adjusts pH with carbon dioxide after filtration. It was determined that the filter influent and effluent pH before carbon dioxide addition were relatively high. Since the process water pH is not adjusted before filtration, it's likely that the softening reaction is still occurring, resulting in calcium carbonate deposition onto the filters. This theory was substantiated by the fact that filter influent pH is ~10.6 and effluent pH is ~8.9-9.3, thereby showing that the softening reaction is still occurring through the filters since the pH decreases (e.g., due to precipitation of calcium carbonate and resulting in a reduction in dissolved carbonate and pH shift).

Utility staff suspected that there was significant underdrain clogging due to calcification, resulting in ineffective backwashing. As calcium carbonate precipitates in the filter, the headloss through the media and underdrain increases, thereby reducing filter run times. It was recommended that the location of the carbon dioxide injection be moved to just before filtration to lower the influent filter pH, stop the softening reaction, and prevent calcium carbonate deposition onto the filters and in the underdrain system.

The American Water Works Association (AWWA) recommends that filters remove no more than 10 mg/L as $CaCO_3$ of hardness across the filters, as this is indicative of detrimental calcium carbonate precipitation in the filters. It's also the experience of the authors that a filter that has experienced severe precipitation of calcium carbonate can be remediated by processing settled water that is aggressive, allowing for a slow redissolution of

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calcium carbonate. Trying to do this by treating the filters with acids or proprietary cleaning chemicals is largely unsuccessful and can cause damage to the filters.

A lime dose directly relates to lime softening pH and overall solids production (adding calcium when adding lime, which also needs to be removed with the influent calcium). Figure 6 shows water quality results of four lime doses (expressed as CaO) tested at the bench scale for the city. The East WTP's current average lime dose is 127.5 mg/L as CaO. (Note: water quality results from bench-scale testing of the 127.5 mg/L dose were similar to grab samples collected from the full-scale plant.)

As expected, as the dose increased to 136.6 mg/L as CaO, settled water pH increased and hardness decreased; however, no significant improvement in hardness reduction was achieved compared to the current average dose. The corresponding CCPP and LSI were also considered and are shown for each dose. A CCPP from 4 to 10 mg/L is preferred for settled water stability, and at lower lime doses this value decreases below this range. For this WTP, these results indicated that a settled water pH of 9.5 should be targeted to provide a stable settled water, which can be achieved at lime doses around 127.5 mg/L, depending on raw water quality.

For these reasons, it was not recommended that the lime dose be lowered. It also should be noted that the lower the hardness of the softened water, the more bypass that can be allowed, which yields greater cost savings than an overall lime dose reduction. Bypassing should also consider CCPP, LSI, and alkalinity of the finished water to confirm slightly precipitating conditions and a well-buffered, noncorrosive water to protect the distribution system.

As mentioned, the softening process relies on the presence of alkalinity. In cases where alkalinity in the source water is limited, increased lime doses above what is needed for the reaction can actually lead to increased hardness (since lime is $Ca[OH]_2$), as shown in Figure 7. Therefore, it may be prudent to determine if a utility is inadvertently on the uptick of the chart (starting at 160 mg/L) and overdosing lime. The actual lime dose that this could occur at is unique to each utility, and finished water goals can be achieved by lowering the lime dose or adding soda ash (more carbonate) or caustic soda (no calcium addition) if the higher pH is necessary.

Solids Handling

The lime softening process generates calcium carbonate solids in the SCCs that need to be removed intermittently to maintain a desired concentration of solids within the softeners. The management of the percent solids in the center cone of an SCC is the key to producing excellent settled water quality. A common misconception about SCC operation is that the solids level needs to be above the outlet of the center cone (solids blanket mode of operation); however, this is not required and can be detrimental to settled water quality.

Solids (residuals) blowdown frequency has a direct impact on the solids inventory. Insufficient blowdown frequency leads to solids buildup within the SCC and places an increased strain on the internal equipment (such as the rake), which can potentially plug up the solids blowdown lines. Contrarily, if solids blowdown is too frequent, then valuable surface area provided by the solids are lost, which can contribute to compromised settled water quality because smaller particles form and carry over.

A utility in south Florida previously monitored percent solids from the primary mixing zone instead of the center cone, which did not provide valuable information on the solids inventory. Measuring the percent solids by volume within the center cone can help determine if the correct solids inventory is occurring, with 6 to 12 percent solids (by volume) being the target for most SCCs. If not in the ideal range, then modifying operations, including blowdown frequency and mixing speed, could improve the solids inventory and settled water quality. It should be noted that there are many SCCs in Florida that cannot handle the desired solids inventory due to poor mixer performance or limitations of the rake. Utilities should realize that some SCCs will not work correctly due to these limitations.

Lime Slaking and Handling

Effective and efficient lime softening relies on proper activation (assuming that the utility needs to slake the lime) of the lime. This is a process where pebble lime reacts with water to form calcium hydroxide and generates heat. Controlling this reaction (high heat without boiling) is important because the reactivity of slaked lime is dependent on surface area (more area for reaction) and maintaining a small particle size (small particles stay in suspension longer). Both higher surface area and smaller particle size are facilitated by high slaking temperatures.

Faster-reacting lime raises the pH and generates calcium carbonate more quickly, which results in limiting undesirable precipitation (in locations such as downstream piping, filters, etc.) and maximizing lime efficiency. Inefficient slaking can actually lead to higher lime usage and increased solids. Properly controlled slaking temperature provides optimum lime reaction conditions with small particles that have high surface areas and results in adequate surface area for reaction and slow settling lime particles.

Newly affordable infrared cameras provide a cost-effective tool that can be used to safely check the slaking temperature. The ideal slaking temperature range is between 190 and 200°F (although the slaking temperature should be based on the efficiency of the slaking and eliminating localized boiling). Operating temperatures below this range result in inefficient lime use, which is shown in Figure 8.

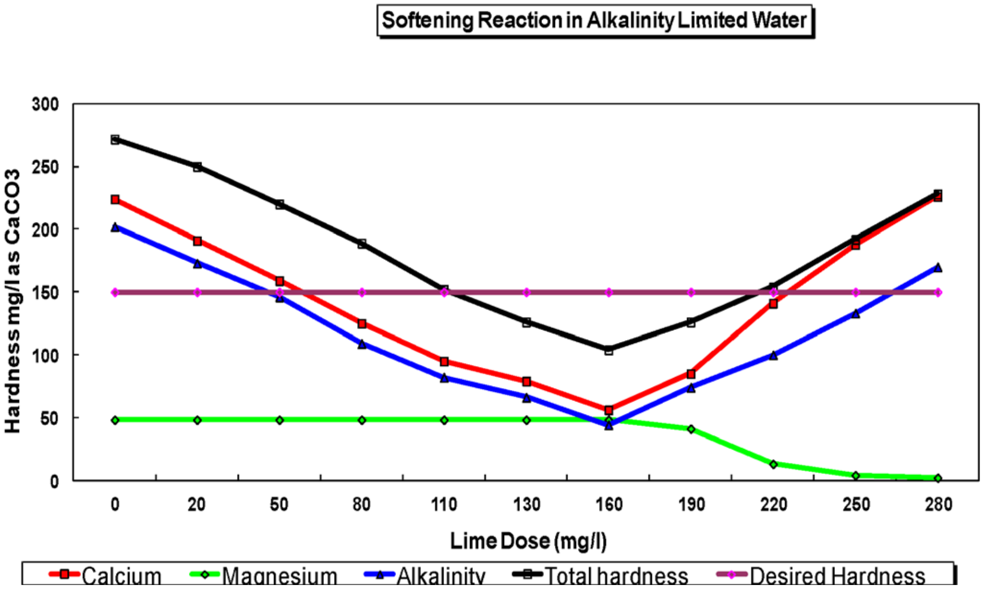

Figure 7. Water Quality for Increasing Lime in an Alkalinity Limited Water

Operational modifications to control slaking include modifying the water-to-lime ratio to help control temperature. Slaking temperature, reaction time, and lime-to-water ratio also depend on the quality of lime and the starting water temperature; therefore, slaking temperature should be checked with each new load of lime (laboratory test procedures are available). The dilution water that is used to slake the lime typically has carbonate, which will react with the calcium in the lime and result in deposition. Utilities could also consider use of a lime slurry condition agent if the plugging of lime equipment is frequent, or, if severe enough, could consider an air stripping unit that converts the carbonate to carbon dioxide and then strips out the carbonate from the dilution water, resulting in no precipitation in the lime systems. There are also polyphosphate-based chemicals that can be added to the lime slurry to reduce deposition and maintenance of feed lines.

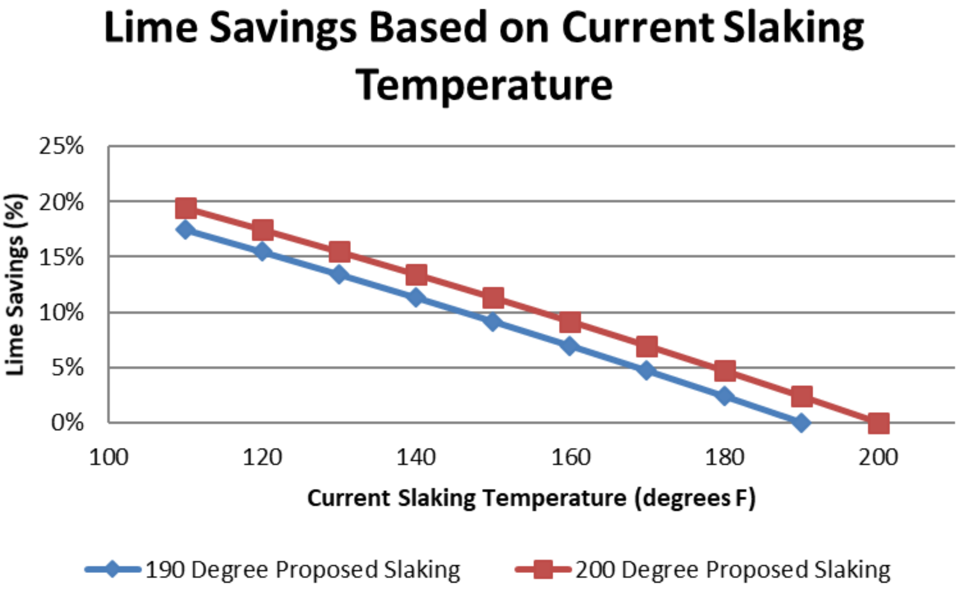

Figure 8. Potential Lime Savings Based on Potential Slaking Temperature Versus Current Slaking Temperature

Conclusion

Many utilities throughout the state of Florida use the lime softening process to reduce hardness and color. Due to the complexity of the softening process, a majority of the fundamental knowledge and control aspects of the process have been forgotten; however, there are many operational modifications that these utilities can employ to optimize their lime softening treatment process (Figure 9).

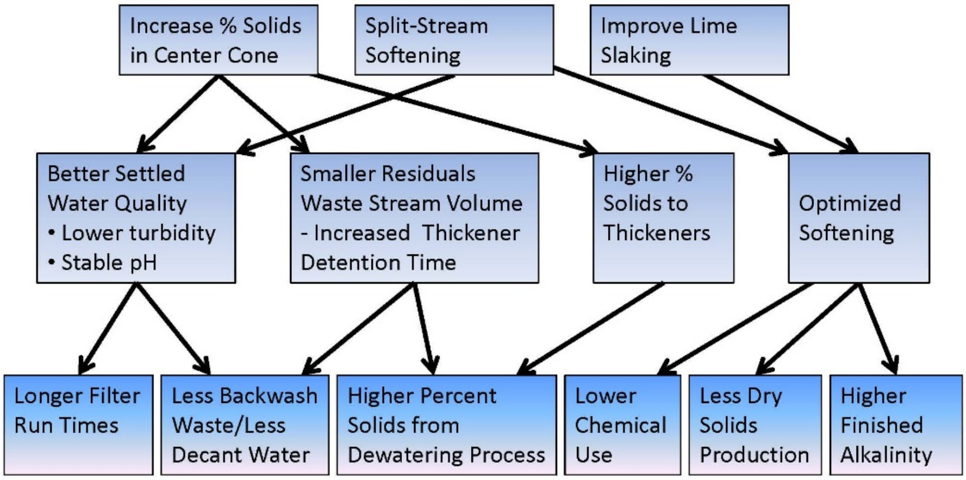

Figure 9. Summary of Lime Softening Optimization Strategies

Softening via the solids contact process is like a light switch—it's either on or off, and control of the hardness from the process is limited, unless bypassing is an option. Utilities should consider the addition of color removal technology, which would decouple the lime softening process from color removal (that requires softening of 100 percent of the flow) and allow for the targeting of finished water hardness goals. In these cases, there would be an opportunity to bypass a portion of the flow around the softening process to help control finished water hardness and alkalinity, and reduce operating costs. An optimizing dose considering raw water alkalinity, finished water hardness, and alkalinity goals could help avoid overdosing of lime. Finished water corrosion indices like CCPP and LSI should be confirmed prior to any bypass or lime dose changes.

There is an opportunity to review currently installed SCCs in Florida to see if increases in upflow rates could be achieved that could provide an overall increase in process capacity. Additionally, utilities should consider adjusting the recirculation ratio (via mixing speed) to encourage a high volume and quality of solids within the center cone to improved settled water quality. Optimizing the mixing speed in the SCC could also provide for reduced operating torque, resulting in extended life of SCC equipment.

Actively managing solids blowdown provides the opportunity to improve the solids inventory within the SCC, and a target of 6 to 12 percent solids (by volume) within the center cone is ideal. If solids are out of this range, then modifying operations, including blowdown frequency and mixing speed, could help achieve inventory, and ultimately, finished water goals. If the SCC cannot achieve these goals due to mixer or rake limtations, then the utility should consider replacing the equipment.

Finally, confirming the proper lime activation and slaking can help reduce overall lime usage. Utilities can modify the water-to-lime ratio (or utilize equipment with this inherent design feature) to control slaking temperature to the ideal range.

By re-examining the goals of the lime softening process to leverage existing SCCs, lime slaking, slurry systems, solids handling, and instrumentation, and implementing them in a cost-effective manner, allows for opportunities to re-align the process to achieve current-day goals and address legacy challenges. Utilizing these various techniques allows utilities to revive the lime softening process and also allows them to serve their needs, while reducing operating costs and improving finished water quality.