Reverse Osmosis Post-Treatment Stabilization Utilizing Liquid Lime

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The Dauphin Island Water & Sewer Authority (Authority), in Dauphin Island, Ala., owns and operates a reverse osmosis (RO) drinking water treatment facility that first came online in May 2010. The facility serves Dauphine Island's 1,200 permanent residents, and a seasonal tourist population of more than 20,000. The barrier island is located off the coast of the state, approximately 30 mi south of Mobile. The facility treats water from a sand aquifer that is about 700 ft below the ground's surface. The water is relatively good quality and only requires treatment for chlorides in the 1,700-parts-per-mil (ppm) range. The facility currently operates at a recovery rate of 75 to 80 percent (depending on the season) and can supply a production of up to 1.2 mil gal per day (mgd).

The RO treatment of brackish water purifies and significantly changes the mineral composition of the water. Pure water is considered a reactive chemical, and water containing little to no hardness is often found to be aggressive towards distribution system components. Consequently, poststabilization of RO-treated water is required prior to storage and distribution.

The Authority re-evaluated its post-treatment and stabilization treatment after failing a lead corrosion sample soon after the plant was commissioned. It looked at four primary options for improving its poststabilization treatment:

- Chemical addition: minerals other than lime or calcite
- Blending with a water containing high mineral content
- Carbon dioxide (CO_2) addition, followed by calcite or dolomite dissolution
- CO_2 addition, followed by lime (slurry) dosing

Each of these four methods was reviewed and a cost evaluation for implementing each option was prepared. The evaluation narrowed the prospective treatment alternatives to two possible secondary options of the primary CO_2/lime (slurry) dosing option. The Authority pilot-tested the two selected methods and then selected the most advantageous option for poststabilization at its water treatment facility.

The Authority commissioned a new RO treatment facility in May 2011. From start-up, the facility has experienced problems with corrosive water and meeting the Alabama Department of Environmental Management (ADEM) requirements for lead levels. The Authority initially implemented a corrosion control program, held over from a previous iron removal plant, by treating the plant effluent with a proprietary blended zinc-orthophosphate. In August 2011, the Authority failed the ADEM lead sample limits; in January 2012, it implemented a new corrosion control plan that included changing the corrosion inhibitor to a blended orthopolyphosphate and increasing the corrosion inhibitor dosage. The new plan also included extensive testing at the water plant and in the system. The sampling plan and performance monitoring program included corrosion test coupons located at various locations in the Authority's service area, frequent water sampling, and trending of historical data.

In September 2013, the Authority again failed the ADEM lead exceedance level. Since that time, Constantine Engineering has worked with the Authority's operators to develop, evaluate, and implement alternative water treatment processes that provide stable finish water chemistry and eliminate the permit violations.

Study Objectives

The RO process removes dissolved solids from feed water, including calcium and bicarbonate/carbonate ions. The resulting RO permeate will typically have low levels of calcium hardness and alkalinity and is "stabilized" to protect distribution pipelines, pump stations, and storage tanks. The Authority has attempted to provide stabilization with proprietary blended phosphates and pH adjustments using sodium hydroxide. This approach has provided adequate poststabilized water; however, the lead corrosion continues to bump the exceedance level and a new approach should be implemented.

The chemical stability of potable water is typically determined by three parameters:

- pH buffering capacity or alkalinity
- Tendency of the water to precipitate calcium carbonate or scaling potential
- Concentration of soluble calcium ions in the water

The pH is relevant in the finished water, but it is dependent on the values of the three parameters listed. Several calculated indices are used in the water industry for water stability control to determine the scaling tendency of calcium carbonate. The most commonly accepted indices are calcium carbonate scaling potential (CCSP), Ryznar Stability Index (RSI), and Langelier Saturation Index (LSI).

The targeted post-treatment water quality objectives are as follows:

- $40 < \text{alkalinity} < 80$ mg/L as calcium carbonate (mg/L as $CaCO_3$)
- LSI>0
- $50 < \text{calcium (Ca)} < 120$ mg/L as $CaCO_3$
- $8.0 < pH < 8.5$

The goal for the Authority was to increase alkalinity from the current level of 10 mg/L to above 40 mg/l and increase the LSI from the current -3.5

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Table 1. Common Chemicals that Add Carbonate or Shift Carbonate Species

Chemicals that Add Carbonate	Chemicals that Shift the Carbonate Species
Sodium bicarbonate	Quicklime
Sodium carbonate (soda ash)	Hydrated lime
Carbon dioxide (CO_2)	Caustic soda
	Sodium carbonate (soda ash)
	Sodium hypochlorite (not practical)

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to a positive number between 0 and 1. This can be accomplished by post-treatment remineralization.

Generally, post-treatment remineralization can be achieved by four treatment processes:

- Chemical addition: minerals other than lime or calcite
- Blending with a water containing high mineral content
- Carbon dioxide (CO_2) addition, followed by calcite or dolomite dissolution
- CO_2 addition, followed by lime (slurry) dosing

Treatment Options

Chemical Additions

Chemicals, such as sodium bicarbonate, calcium sulfate, or calcium chloride, can be used, but there are challenges associated with chemical cost, storage, and dosing. The addition of chemicals also introduces additional minerals in the finish water. In the case of calcium chloride, the resulting permeate chloride levels would increase to 110 to 180 mg/L above the current levels, which would put chloride levels close to or above the U.S. Environmental Protection Agency (EPA) maximum contaminant level (MCL) of 250 mg/L . Due to these undesirable results and challenges, chemical additions were not considered for post-treatment and they were eliminated from further consideration.

Blending

At the Authority, blending with low saline feed water from existing shallow wells is a cost-effective option; however, undesirable constituents in the blend water, such as color-causing agents and dissolved organic matter, prevent this option, which was eliminated early in discussions with the Authority's operators due to associated undesirable effects and operation issues.

Calcite Contactor

Acidification of permeate by the addition of CO_2 that is followed by upflow calcite (limestone) contacting is recognized in Europe and the Caribbean to be a suitable method of post-treatment of RO permeate. Although the process is used at plants in south Florida and Texas, the design criteria used to develop these systems are not well established in other parts of the United States.

Dissolution of calcite is a dynamic process, which may be enhanced or inhibited, depending on the contactor design and influent water quality. Constantine consulted with Tonka Water Treatment (Tonka) for its expertise in designing and operating calcite filters for the U.S. military.

Calcite design factors include loading rate, calcite particle size and purity, contactor bed height, and bed porosity. Influent water quality parameters that affect calcite dissolution include influent calcite saturation level, pH, temperature, ionic strength, and feed water impurities. A calcite contactor was included in the cost comparison, but was eliminated from discussion due to site constraints and the capital cost of the system.

Lime Feed Systems

As discussed earlier, the alkalinity of water can be increased by a variety of chemicals that are common at water treatment plants. The challenge with alkalinity is to find a chemical that can shift the carbonate species, add more carbonate to the system, and remain cost effective. All of these goals cannot be accomplished with one chemical, so treatment requires the use of multiple chemicals that can add carbonate to the system, and the chemical that can shift the carbonate species toward carbonate ion.

Table 1 shows the most common water treatment plant chemicals that add carbonate or shift the carbonate species. The approach to the challenge of adding alkalinity is to use two of the chemicals (one from each column) with the lowest costs simultaneously.

An advanced lime feed system utilizes dissolved CO_2 dosing systems to provide the carbonate. These systems dissolve CO_2 into a carrier water solution to be added to the process stream. When carbon dioxide solution is added to water with moderate pH changes, the required reaction time is approximately two minutes. The Authority is fortunate to have source water that has ample amounts of naturally occurring CO_2 dissolved into the raw water, which eliminated the need for a CO_2 feed system, thereby saving approximately $75,000 to $150,000 in capital costs.

There are three options for feeding lime at the Dauphin Island Water Treatment Plant (WTP):

- Quicklime slaking
- Hydrated lime solution
- Bulk-delivered hydrated lime solution

The main differences between hydrated lime and quicklime are their reactivity, feed/dosing procedures, and chemical composition. Hydrated lime and quicklime are both calcium compounds. In its hydrated state, calcium is called calcium hydroxide, and in its pure state, it is called calcium oxide, or quicklime. Calcium oxide, the "natural" state of calcium that comes out directly from the mine, has a heavy density (65lb/ft^3) and is more reactive than hydrated lime.

Hydrated lime is the result of adding water to powdered quicklime, putting it in a kiln or oven, and then hydrating/pulverizing it with water. The resulting lime has a density of 35lb/ft^3, and is called calcium hydroxide because it has been hydrated.

It is necessary for quicklime to be slaked in a controlled environment because it can create heat that reaches up to 120°F. Calcium hydroxide, or hydrated lime, is already neutralized, so it will not undergo oxidation and can be used with water, for pH control, lime slurry addition, and lime slurry mixes.

Quicklime's hydrophobic reaction with water requires a lime slaker to be used in the process. The quicklime is generally received in pebbles of about one-quarter to one-eighth of an in., or in powder form (<300μ). The slaking of the pebble lime and powdered quicklime has to be engineered in respect to their exothermic reactions.

The lime slaker mixes quicklime with water to create calcium hydroxide in a solution, which is called lime slurry. Slakers are good for high-volume consumption or high demand of calcium. However, at the Authority's WTP, where a smaller or medium lime solution is needed, hydrated lime is more efficient because the equipment required to use the hydrated lime is simpler and does not need to be designed to handle an exothermic reaction. In this case, the powder can be fed with screw conveyors, or manually dumped directly into the slurry tank equipped with a slurry mixer; water is then added to create the required lime slurry concentration. The lime slurry is dosed to the permeate using peristaltic hose pumps.

Bulk liquid lime is simply hydrated lime that has been mixed into a slurry off-site at a chemical plant where the process is closely monitored and precisely controlled to provide a stable, consistent product delivered to the water plant.

Table 2. Reverse Osmosis Permeate Post-Lime Dosage

Parameter	28-Oct	29-Oct	30-Oct	31-Oct
pH	8.04	8.43	8.2	8.2
Hardness (mg/L as $CaCO_3$)	51	51	68	51
Alkalinity (mg/L as $CaCO_3$)	60	60	60	60
Temp (C)	24	24	25	25
Turbidity (ntu)	na	na	na	na
TDS (mg/L)	na	391	516	378
LSI	-0.37	0.13	-0.02	-0.11

Table 3. Finished Water

	28-Oct	29-Oct	30-Oct	31-Oct	1-Nov
pH	7.99	8.14	7.9	8.2	8.1
Hardness (mg/L as $CaCO_3$)	51	51	51	51	51
Alkalinity (mg/L as $CaCO_3$)	60	60	40	40	40
Temp (C)	24	24	25	25	24
Turbidity (ntu)	0.184	0.176	0.172	0.164	0.169
TDS (mg/L)	na	444	419	417	414
LSI	-0.03	-0.15	-0.57	-0.26	-0.38

Pilot Testing

Bulk-Delivered Liquid Lime

Cal-Flo bulk-delivered liquid lime supplied by Burnett Lime Company Inc., which was pilot-tested in October 2013. Burnett Lime supplied a complete liquid lime feed system that included a bulk storage tank, feed pumps, mixers, and a programmable logic control (PLC) control system. The Cal-Flo system consists of the following major items:

- 16,000-gal lime slurry tank
- Feed pump building
- Feed pumps
- Control panel and instrumentation
- Tank mixer

The Cal-Flo system capital cost for equipment and installation is estimated to be $330,000, and the yearly operating cost is estimated to be $12,000.

Cal-Flo presented an option to purchase a used system that was approximately $100,000 less than the cost of a new system, stating that it would provide a warranty and support the used system as if it were sold as new.

There could be some potential cost savings by designing and implementing a system other than that presented in the Cal-Flo proposal. The Authority can purchase an exterior tank and mixer and utilize a transfer pump-to-pump liquid lime to the existing chemical feed room; a new day tank and mixer would be required, along with an additional chemical feed pump. It's estimated that the cost for this used liquid bulk lime alternate system would be $115,000, which would be a savings of $100,000 over a new system. A major disadvantage is that the Cal-Flo feed system is patented, and dosing its product with alternate equipment would eliminate the operation guarantee from Burnett Lime for the performance of the system.

The Cal-Flo system pilot-tested very well and the operators found it to be easy to operate and maintain. When the system was running, the water quality was easy to maintain, pH was stable, and alkalinity was easily adjusted by changing the lime dosing rate (Tables 2 and 3). The following shows the pros and cons of the system, both subjective and quantitative:

Pros	Cons
Precise application	Higher operation cost
Low maintenance	Requires large bulk tank
No dust	Single supplier
Nonhazardous	
Predictable results	
Dissolves on contact	

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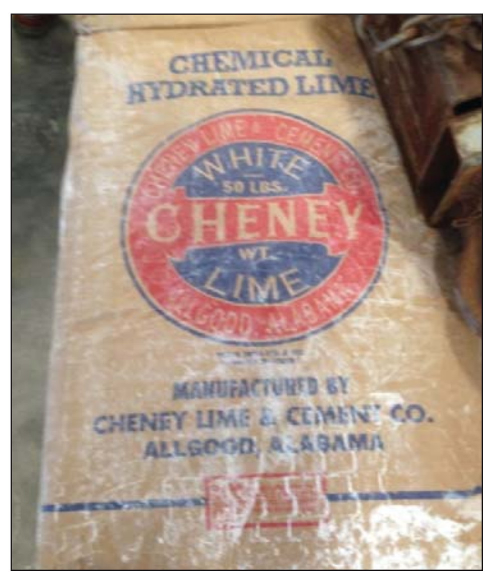

Hydrated Lime Bag Delivery

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On-Site Liquid Lime Mixing

Liquid lime can be produced on-site at the water treatment facility by mixing hydrated lime and water to the required concentration percentage. For the Authority, dry hydrated lime would be delivered to the WTP on pallets with 50-lb bags; the product is delivered in 45 bags per 48-in. x 40-in. pallets. The operator would mix the product by manually dumping the bags of lime into a mixing tank and adding the appropriate amount of water to create a 30 percent solution. The lime solution would be fed to the RO permeate with a hose pump.

This system would be best operated in a separate building from the existing WTP due to the heavy amount of dust that is created from filling the mixing tank. The new building would need an area for lime pallet storage, an area for the mixing tank, and a protected area for the control panel. Some of the recommended building amenities, and their pros and cons, would include:

- 16-ft x 24-ft brick-and-siding building to match the WTP building
- Space for lime pallet storage
- Loading dock for pallet offloading
- Separate PLC panel room to protect the control system from dust
- Roll-up doors for easy ingress/egress of equipment and pallets
- Mixing tank with ergonomic height for dry lime filling by operators

Pros	Cons
Lower operating cost	Dusty
No bulk tank	Increased operator attention
Nonhazardous	Clumping and clogging
Dissolves on contact	Varying consistency
Multiple suppliers	Turbidity

Plant operators have pilot-tested the on-site lime mixing method and the results are extremely good. The biggest drawbacks mentioned by operators are the dusty environment created by emptying the bags of lime and stabilizing the pH. The pH may have been difficult to stabilize due to inconsistent mixing with the pilot mixer and tank; this can be improved with a full-scale system. It should be noted that operators did not experience any turbidity spikes or clogging during the pilot study.

The abundant amount of CO_2 in the raw water reacts to dissolve the lime almost instantaneously after injection. Another drawback that should be noted is the higher feed rate that was required to achieve the same water quality improvements. This problem could be from the same issues that caused the inconsistent pH stabilization. This disparity in the solution feed rate between liquid bulk and on-site mixed lime brings the operating cost closer than it would be if the dosage were equal. From the pilot study data, the estimated operating cost for the on-site mixed liquid lime is approximately $9,000, which is about 25 percent less than liquid bulk lime.

On-Site Lime Mixing and Dosing System

Because the CO_2 is naturally occurring, it should be noted that the operators have no control over the CO_2 concentration. While the concentration remains at its current level, there is plenty of CO_2 to react with the lime; however, if the CO_2 concentration should drop in the future, a supplemental CO_2 system would be required. The CO_2 levels have been high since start-up of the well in 2011, so the likelihood of a change should be small.

Table 4. Equipment Capital Cost Comparison

Liquid bulk lime feed system (Cal-Flo)	$400,000
Liquid bulk lime used alternate (Cal-Flo)	$265,000
Liquid bulk lime alternate (Cal-Flo)	$115,000
Lime feed system	$300,000
Calcite filter system	$520,000

Table 5. Operation and Maintenance Cost Comparison

	Liquid Bulk Lime Feed System (Cal-Flo)	Onsite Lime Feed System
Lime solution feed rate (mg/L)	35	45
Solution strength (%)	30%	30%
Dry product per day (lb)	131.4	168.9
Dry product cost ($/lb)	$0.24	$0.14
Daily flow (mgd)	0.45	0.45
Daily cost	$31.53	$23.64
Yearly Cost	**$11,506**	**$8,630**

Pilot Study Conclusions

The pilot study tested two liquid lime feed options as stabilization treatment for finished water at the water plant. The study results show that both options were able to sufficiently raise alkalinity and pH, and thereby stabilizing the RO permeate to achieve the water quality targets. The RO permeate treated with liquid lime, both mixed and bulk, delivered yielded alkalinity and hardness at levels above the target 40 mg/L as $CaCO_3$ and an LSI above -0.3. No visible turbidity was observed during the tests of either product and no increase in chlorine gas was required for proper chlorine (Cl_2) residual. Operators had no problems meeting the pH, hardness, and alkalinity target levels; adjustments could be made to match any pH level desired. The mixed liquid lime did fluctuate more than the bulk product and some factors that could cause this include inadequate mixing, inaccurate measuring the dry product, or water and/or changing consistency (i.e., changing percent solids in the mix tank). The quality of dry lime delivered to the site can fluctuate where bulk delivered liquid lime is produced in a factory, with precise formulation and quality control.

Operators have continued to work with Carus Chemicals to select the appropriate corrosion inhibitor and dosage. Carus recommended targeting a pH of 8.0-8.2 and a hardness of 25-35 mg/L, and continuing to provide a 1 ppm phosphate residual in the system.

The pilot study shows that both the bulk purchase liquid and the dry mix on-site product will work to stabilize finish water at the Authority's WTP. Tables 4 and 5 provide a cost comparison for installing and operating each system.

Capital and Operation and Maintenance Cost Comparison

The conceptual capital cost in Table 4 is based on equipment budget quotes and estimated installation cost by a contractor providing a sealed bid. There may be some cost savings for separating portions of the construction and/or self-performing portions of the project.

The operation and maintenance (O&M) cost comparison in Table 5 is based on the pilot-study lime consumption and only takes into account lime usage; it was assumed for this comparison that power cost and equipment maintenance cost differences should be negligible. Prior to the new system, the WTP used approximately $3,000 per year of sodium hydroxide solution that will no longer be required; this amount can be deducted from the cost shown on the table to achieve a net O&M value.

The 20-year present-worth analysis in Table 6 is based upon the capital and O&M costs presented in Tables 4 and 5.

Table 6. 20-Year Present-Worth Analysis

	Liquid Bulk Lime Alt. (Cal-Flo)	On-site Lime Feed System	Used Liquid Bulk Lime (Cal-Flo)	Liquid Bulk Lime Feed System (Cal-Flo)
Capital Cost	$115,000	$300,000	$265,000	$400,000
O&M Cost	$11,507	$8,630	$11,507	$11,507
Cost Increase/ Year	2%	2%	2%	2%
O&M 20-Yr PW	$279,582	$209,687	$279,582	$279,582
Total 20-Yr PW	**$394,582**	**$509,687**	**$544,582**	**$679,582**

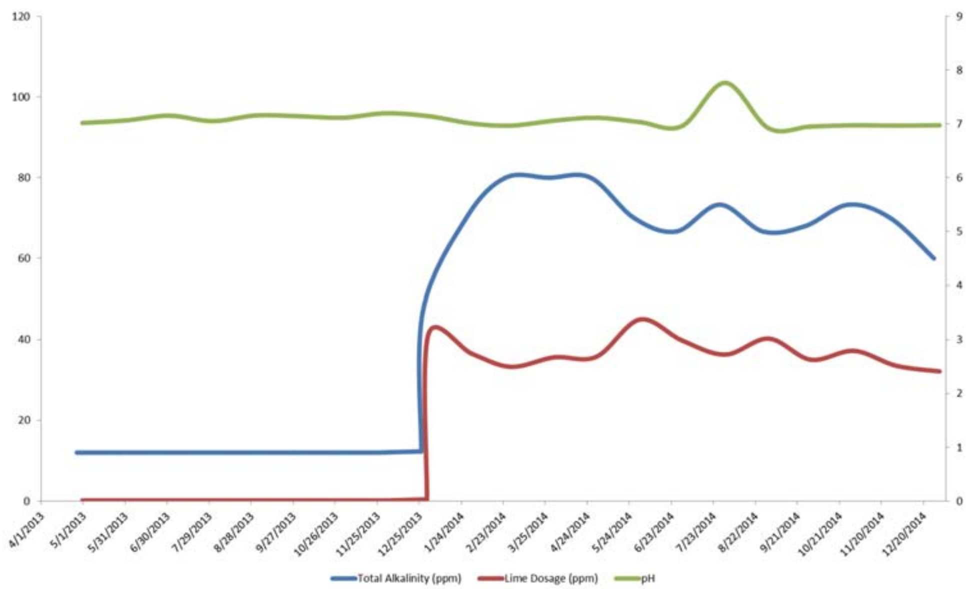

Figure 1. Lime Dosage Impact on pH and Alkalinity

Improvement Summary

The pilot study confirmed that liquid lime is the best solution for properly stabilizing the RO permeate water and eliminating the lead permit limit excursions.

In January 2014, Burnett Lime proposed a refurbished lime feed system. A site visit was conducted to assess the condition of the proposed equipment and to allow Authority personnel to inquire about O&M procedures. From the site-visit findings and the results of the pilot study, the Authority's board selected Burnett Lime to provide the refurbished Cal-Flo lime feed equipment. This equipment was commissioned in June 2014.

The Authority continues the sampling and monitoring program put into place in 2012. The continuation of this program includes the following:

1. Achieving a 1 mg/L of total phosphate residual in the distribution system.
2. Coupon testing in the service area and at the WTP. Coupon samples should be pulled for testing quarterly. Quarterly samples should indicate corrosion rates not greater than 10 mils/yr, with a target of 5 mils/yr or less. Coupons should include mild steel, copper, and lead.
3. The sampling and performance monitoring program. This program provides historical data that can be used to adjust chemical rates, change chemical types, and alert department personnel to changes in water quality within the distribution system; samples were taken weekly for the first quarter and monthly thereafter. Samples are taken from the same locations each time (at coupon testing sites). The following tests are recorded:
   - Alkalinity (mg/L as $CaCO_3$)
   - pH
   - Hardness (mg/L as $CaCO_3$)
   - Temperature
   - TDS
   - Iron
   - Polyphosphates and orthophosphates
   - Lead and copper

The sampling and performance monitoring has shown that the original goals are being met, and the plant operators have flexibility to adjust water quality to suit their specific treatment goals. Figure 1 shows the pH and alkalinity prior to and after the lime system was placed on-line.

The targeted post-treatment water quality objectives are as follows:

- 40<alkalinity<80 mg/L as calcium carbonate (mg/L as $CaCO_3$)
- LSI>0
- 50<calcium (Ca)<120mg/L as $CaCO_3$
- 8.0<pH<8.5