POST TREATMENT OPTIMIZATION FOR DESALINATION AND GROUNDWATER RECHARGE

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Executive Summary

Post-treatment of membrane processes is an essential step for ensuring compatibility of reverse osmosis permeate with the intended use of the water. This paper examines three case studies of membrane treatment, with a focus on more than a dozen lessons learned from the following three desalination and groundwater recharge facilities:

- Clearwater, FL Groundwater Replenishment (GWR) Project,
- San Antonio Water System (SAWS) Brackish Groundwater Desalination (BGD) Program
- Tarpon Springs, FL variable salinity brackish groundwater RO WTP

The Clearwater, FL facility is a Groundwater Replenishment Project designed to take tertiary reclaimed water, purify it with advanced treatment, and inject it into an aquifer that also serves as a water supply to the City, thus providing a form of indirect potable reuse (IPR). Purified water post-treatment for groundwater recharge consists of both remineralization and oxidant removal. Remineralization is practiced in groundwater replenishment in order to stabilize the purified water with respect to calcium carbonate, minimizing dissolution of the limestone aquifer. Oxidant removal is helpful in groundwater replenishment to keep the purified water pure by mitigating the release of naturally occurring trace metals (e.g. arsenic) from the aquifer into the purified water. This project has completed its pilot phase testing and is now proceeding to final design. Discussion on the Clearwater project highlights the operational results and optimization from 12 months of pilot testing chemical feed of lime slurry.

The Tarpon Springs and SAWS facilities are brackish groundwater desalination treatment plants producing water for potable consumption. Each of the two desalination facilities utilizes a different approach for post-treatment, emphasizing remineralization for corrosion control. The San Antonio Water System BGD is under construction and will use limestone contactor beds with CO₂ addition to a permeate sidestream, to achieve remineralization. Because the SAWS BGD treatment plant is still under construction, discussion of the SAWS facility is limited, focusing on the design features of the calcite contactor post treatment system. The Tarpon Springs, FL desalination facility, recently completed and now operational, utilizes a liquid lime slurry feed system with carbon dioxide addition, before sending the potable water to the distribution system. By examining the results of post treatment from operations at three different desalination and groundwater recharge facilities, beneficial lessons learned can be obtained over a range of membrane applications.
Clearwater: Groundwater Replenishment (GWR)

Introduction

Challenged by the demand for affordable, safe drinking water and the need to reduce the impact of a high urban density on the coastal environment, the City of Clearwater investigated potable reuse through a pilot testing program for groundwater replenishment. Goals of this project include improving groundwater levels within the City of Clearwater through the recharge of the aquifer with purified water and minimizing the impact of potential increases in groundwater withdrawal from the City’s existing wellfields. The Southwest Florida Water Management District (SWFWMD) is providing support and funding for the Clearwater Groundwater Replenishment Project (GWR) as an alternate water supply that beneficially uses reclaimed water to help meet the Tampa Bay Region’s water supply needs. To demonstrate the performance and reliability of the water purification process, the City conducted a one-year pilot of the water purification treatment system.

The water treatment processes included in the purification process (Figure 1) were ultrafiltration (UF), reverse osmosis (RO), and an advanced oxidation process (AOP) with hydrogen peroxide and UV. Reclaimed water was received from the City’s Northeast Water Reclamation Facility. Piloting included an extensive water quality sampling and analysis program. The treatment train was operated to provide full treatment and disinfection, meet potable drinking water standards, remove microorganisms, reduce mutagenicity, reduce microconstituents, and produce a finished water compatible with the native groundwater and minerals in the aquifer.

![Figure 1: Groundwater Replenishment Pilot Process Flow Diagram and Sampling Points](image)

Post Treatment for Groundwater Replenishment

The purposes of post treatment for groundwater replenishment at Clearwater are best understood by examining a mineral sample taken from Lower Zone A of the Floridan Aquifer (the target...
injection zone). Figure X presents elemental analysis images from a scanning electron micrograph of the mineral sample. The sample is predominately calcium (limestone and dolomite) with iron sulfide (pyrite). Arsenic is adsorbed to both minerals, but it is especially concentrated on the iron sulfide. Therefore in order to mitigate release of arsenic into the purified water, calcium carbonate stabilization of purified water is necessary to prevent dissolution of limestone and oxidant removal/quenching is necessary to prevent oxidation of iron sulfide (a reduced form of iron, sensitive to oxidation). Experience with aquifer storage recovery (ASR) in Florida has shown that oxygenated water can mobilize mineral-bound arsenic from the rock formation into groundwater. Remineralization of the purified water is also desirable in order to reduce the likelihood of large-scale dissolution of limestone by the RO permeate quality water.

Post treatment steps for the Clearwater GWRP pilot included, membrane contactors to remove dissolved oxygen), carbon dioxide injection (to adjust pH and add carbonate alkalinity), liquid lime slurry injection (to add calcium (remineralization) and adjust pH), and sodium bisulfide injection (to neutralize monochloramine and peroxide).

![Elemental Analysis from Scanning Electron Micrograph](image)

**Figure 2** Elemental Analysis Imaging of Mineral Removed from Lower Zone A of the Floridan Aquifer, Indicating the Need for Remineralization and Oxidant Removal

**Remineralization**

This section discusses the typical water quality during remineralization, clogging in the injection system, and scale formation in the purified water line. Recommendations are also provided for a full-scale system.
Pilot Operating Setpoints

Sampling results indicated that the post treatment process improves the calcium carbonate stability of the water; however, dosing control was important to limit the precipitation of calcium carbonate scales in the purified water pipe. Before post treatment, the process water was characteristic of RO permeate, with pH 5.5, calcium 5 mg/L as CaCO₃, alkalinity 10 mg/L as CaCO₃, and calcium carbonate precipitation potential (CCPP) of negative 110 mg/L as CaCO₃. The negative CCPP indicates that this water would tend to dissolve calcium carbonate. While passing through the membrane contactor, much of the dissolved carbon dioxide was removed from the water, increasing the pH to 6.5, while maintaining the same levels of calcium and alkalinity, and increasing the CCPP to negative 15 mg/L as CaCO₃. After the membrane contactor, approximately 70 mg/L of carbon dioxide was injected into the solution under pressure, followed by 75 mg/L as CaCO₃ of lime, increasing the total calcium to 80 mg/L as CaCO₃, the pH to 7.25, the alkalinity to 100 mg/L as CaCO₃, and CCPP negative 10 mg/L as CaCO₃.

Looking at scaling in the purified water pipe, earlier in the pilot study, the pH was adjusted to 7.75, and closer to zero CCPP, by adding less CO₂. However, at these targets, the pH was more difficult to control, and the purified water line would frequently grow a film of calcium carbonate scale (Figure 3) and result in high turbidity above 10 NTUs (nephelometric turbidity units). This increase in calcium carbonate scale over time was monitorable through pressure readings on the purified water line. It seems that many of the scaling problems occurred since the lime slurry did not have adequate time and driving force to completely dissolve into solution. Presumably, the instability in pH near 7.75 was due to some combination of instability in carbon dioxide addition at low gas flow rates, and the lower pH buffering capacity of water near pH 8.

More Dilute Liquid Lime Slurries Had Fewer Problems

The liquid lime feed pumps should be carefully specified to avoid problems seen during the pilot. The original liquid lime feed system utilized a 30-percent slurry and a peristaltic feed pump. The feed line clogged frequently and the peristaltic pump was replaced with a diaphragm pump. The lime slurry was also diluted to 15-percent. The lime feed pump lines required manual cleaning for clogging about once every one to two weeks. Towards the end of the pilot the slurry was diluted again to about 7 1/2-percent to reduce pulsing. According to the operators, this resulted in better control of finished water stability.

The diaphragm feed pump was operated at the lowest end of the speed and stroke settings for the diaphragm pump to provide a low enough feed of concentrated lime slurry to meet the target calcium concentration. The diaphragm pump fed lime at a speed of one-stroke every one to two seconds. This low feed was a factor in several problems that should be avoided at full-scale, which are listed below.

Inject a Steady Stream of Liquid Lime to Minimize Fluctuations that Lead to Scale Buildup

The lime injector clogged with calcium buildup frequently during the pilot, and had to be removed for manual cleaning. The lime injector should inject the lime into the line at high velocity to avoid stagnancy within the injector. Lime should be fed by either a diaphragm pump at moderate speed (with multiple strokes per second), or a peristaltic pump and tube system that has a large enough tube diameter and a high enough velocity to avoid clogging. When liquid lime is fed in an unsteady and pulsing manner, as was done during the pilot, it creates localized slugs of water with elevated calcium concentrations and elevated pH. Localized areas of water with high pH (>8.3) and high calcium could cause problems by converting dissolved carbon dioxide to carbonate and triggering
the formation of calcium carbonate particles. These particles could act as seed crystals for scale formation on the finished water line. Calcium scaling was seen on the finished water piping, static mixer, and pH and ORP probes, all downstream of lime addition.

**Maintain a Slightly Negative CCPP**

Swings in pH could have led to the onset of calcium carbonate precipitation. When the carbon dioxide dose was increased, and pH dropped to 7.25, pH stability improved, calcium carbonate scale formation diminished, and turbidity dropped below 10 NTU. From this, it was concluded that the CCPP should be maintained slightly negative in order to avoid clogging the purified water line and potentially scaling the aquifer, increasing well pressures. Nevertheless, the CCPP should be increased beyond the negative starting point of negative 110 mg/L CaCO₃ to reduce the potential for limestone dissolution in the aquifer.

**Consider Substituting Calcium Chloride for Liquid Lime**

One possible alternative that could avoid the turbidity issues and, potentially, the rapid scale formation, would be to substitute calcium chloride and caustic soda for lime. The advantage of this approach is that it would be more operator-friendly since all calcium in calcium chloride is dissolved. This alternative approach could be cost prohibitive. Preliminary desktop calculations indicate that a calcium chloride/caustic soda substitution could be up to six times more expensive than the current calcium carbonate addition approach using liquid lime.

**Allow for Purified Water Line Cleaning with CO₂**

The purified water line going to the injection wells should be designed to allow operators to clear the line of calcium carbonate scale buildup. During the pilot shutting off the lime feed and increasing CO₂ to lower the pH to 4-5 was effective in completely removing the scale. The low pH water would soak in the line until the scale is removed. The low pH water would then need to be discharged through a pipe to some location other than the injection wells. Non-metallic piping should be considered for the purified water line due to the potential corrosivity of CO₂ during cleaning.

**Provide Separate Static Mixers for Lime Injection and Sodium Bisulfide**

During the pilot study lime injection was followed by sodium bisulfide injection and then by a static mixer. Two separate static mixers should be provided to mitigate potential calcium scaling. A dedicated static mixer should be provided immediately after the liquid lime injection point to help dissolve the lime slurry and avoid any pH-related interactions between poorly-mixed liquid lime and sodium bisulfide. Another static mixer should be provided immediately after the bisulfide injection point to avoid creating regions of extreme pH. Sodium bisulfide is a base that can raise the pH to about pH 9.

**Provide Adequate Carbon Dioxide Injection Turndown**

The carbon dioxide injection system should provide adequate turndown for fine control of pH after the membrane contactors. The membrane contactors not only remove dissolved oxygen but also acted as degasifiers, removing carbon dioxide from the purified water, resulting in a water with very little buffering capacity. The carbon dioxide system on the pilot was operated manually at the lower end of the rotameter and control throttling dosing whatever valve, making it difficult to adjust the pH precisely. This factor contributed to early inconsistent pH levels that were resolved at a lower pH target with a higher, more repeatable CO₂ feed rate.
Setup an Appropriate Automated Chemical Feed Loop for Liquid Lime and CO$_2$

During the pilot study, manually controlled post-treatment chemical feed systems were used for carbon dioxide, liquid lime, and sodium bisulfide. This constant speed chemical addition caused repeated scaling in the finish water lines. When just enough scale built up on the finished water pipe wall, back pressure to the membrane contactor increased and purified water flow decreased. As line pressure increased, lime and bisulfide chemical feed rates remained constant and CO$_2$ feed decreased. Naturally, this created a positive feedback effect, increasing the lime and bisulfide doses (by reducing water flow rate at steady chemical feed rate), while decreasing or halting CO$_2$ addition (backpressure exceeded CO$_2$ injection pressure). This led to further increases in pH and an acceleration of scaling. This effect was rapid enough to severely constrict the finished water line in as little as one to two days.

Chemical feed systems at full-scale would be automatically flow-paced through feed forward control. The lime feed system should shut off automatically if flow decreases below a low flow alarm set point. Lime feed could also be automated through feedback control using either an online calcium ion selective electrode or conductivity probe. As noted below in the Tarpon Springs discussion, liquid lime should only be used to raise the water to a specific conductivity target. This should enable fairly steady and stable feed.

Carbon dioxide feed could also be automated through feedback control by pH, turbidity, and/or line pressure alarms. CO$_2$ should be added only with consideration to a target pH. Enough carbon dioxide should be added to maintain the pH near 7.5. Elevated turbidity and/or finished water line back pressure would be early warning indicators to trigger an increase in CO$_2$ feed (and a decrease in target pH) to arrest an impending scale buildup in the line. An online turbidity meter could be set after the static mixers to watch for signs of incomplete dissolution. This would signal an increase in CO$_2$ added.

Scaling could be identified using a pressure transducer and a field-tested system curve for flow and pressure. The line would be considered to have scaling if, the pressures were above the normal for a given flow.

Figure 3 Calcium Carbonate Scale Build-Up Observed in the Purified Water Line After Liquid Lime Injection at the Clearwater GWR Pilot

Oxidant Removal

The membrane contactors and sodium bisulfide chemical feed work together to reduce the oxidation reduction potential of the water, by removing (dissolved oxygen) or converting oxidizing
species (chlorine, peroxide) from the water, which could potentially cause undesirable mobilization of arsenic or other metals in the aquifer.

**Pilot Operating Setpoints**

Dissolved oxygen (DO) entered the membrane contactors at near 100% saturation (6-9 mg/L), and was removed down to 100 ppb or less of DO, with the capability of operating near 1 ppb of DO. Figure 4 shows the trace DO levels in ppb over time. Proper air calibration and zeroing of trace DO meters was essential to measurement of DO at ppb levels. While operating the membrane contactor, in order to maximize performance, it was important to maintain adequate sweep gas flow rate and adequate vacuum on the sweep gas line (less than approximately -27 inHg). The membrane contactors routinely removed most of the dissolved oxygen from the purified water.

Dissolved oxygen readings were lower and more repeatable when they were taken before post treatment chemical addition. Before January, the trace DO sensor was drawing off of the purified water line, after lime addition and bisulfide addition. After January, the dissolved oxygen sensor membrane was replaced and set to run only on water received immediately after the membrane contactor and before chemical addition. When the old sensor membrane was removed, it appeared to have a yellow hue, and some precipitate, indicating that some of the post treatment chemicals may have interfered with the sensor. Therefore, two trace DO sensors should be installed on a full-scale system: one before post treatment chemical addition (and potential chemical interference), and one after chemical addition.

Sodium bisulfide was added in order to target a 0.5 mg/L S residual after quenching. After sodium bisulfide addition, the chlorine residual was consumed within seconds to below the detection limit of field instrumentation. Approximately 1.2 mg/L of chloramines carry through the membrane contactors until the point of sodium bisulfide addition. Hydrogen peroxide reacted slowly with sodium bisulfide, typically requiring about 30 minutes to reach completion. If insufficient sodium bisulfide was added, the sodium bisulfide was used up and residual peroxide remained. Underfeeding of sodium bisulfide and incomplete quenching of peroxide appeared to impact early mutagenicity tests. Hydrogen peroxide was added upstream at a residual of about 2 mg/L, as a part of the UVAOP. During the advanced oxidation process, only about half of the added peroxide was consumed, and the remaining 1 mg/L of peroxide, passed downstream through the membrane contactors, until sodium bisulfide was added.
Sodium bisulfide addition is important for quenching remaining oxidants in the water, and reducing the overall oxidation reduction potential (ORP) before injection into the aquifer. The feed rate of bisulfide needed to be monitored throughout the usage of each barrel of chemical. As the barrel of chemical aged, it turned from a yellow color to a red color, and a higher chemical feed rate was needed to neutralize peroxide completely. After initial mutagenicity tests indicated that more sulfide feed was required to quench peroxide, the sulfide dose was increased such that after 30 minutes, peroxide would be quenched, and a 0.5 mg/L sulfide residual would remain.

**Rock Core Testing and Aquifer Recharge Testing**

Rock core and aquifer recharge testing were being studied concurrently with the pilot purification process. Rock core testing consisted of running purified water through native rock core samples with varying amounts of post treatment. Arsenic release data indicated a direct correlation between dissolved oxygen removal and arsenic mobilization, supporting dissolved oxygen removal as a control strategy for arsenic mitigation. Water quality samples collected from lower zone A of the Floridan aquifer, during the recharge test indicated that native arsenic levels decreased with decreasing dissolved oxygen concentration, and increasing sulfide content, supporting the selected treatment approach of dissolved oxygen removal and sulfide addition.

**Sodium Bisulfide Feeds Require Adjustment Since Bisulfide Loses Strength Over Time with Exposure to Atmosphere**

Sodium bisulfide hold times in chemical storage should be limited to avoid oxidation of the sodium bisulfide by the atmosphere. Within several weeks after delivery the NaHS solution, bright yellow upon delivery, turned red and a higher pump feed rate was required to maintain the same effective sulfide dose. If the pump feed rate was not increased, this degradation could cause a facility to underfeed bisulfide, resulting in incomplete quenching of peroxide (Mercer et al. 2015).

**Peroxide Quenching is Necessary in Groundwater Replenishment**

The reaction between sodium bisulfide and peroxide was relatively slow, going to completion only after several minutes. Closed loop testing at the pilot site demonstrated that at 6 mg/L of bisulfide, 10 minutes was adequate to quench 1.2 mg/L of peroxide for pH 6 to pH 8. Higher bisulfide doses consumed peroxide more rapidly.

There are a few approaches that can be taken for quenching of peroxide. If no peroxide is allowed to contact the aquifer, then a sealed peroxide quenching tank, closed to the atmosphere, would be needed in order to provide adequate hold time for complete quenching of residual peroxide with bisulfide before aquifer injection. Alternatively, if no quenching tank is provided, then the peroxide-laden water could be injected underground with excess sulfide residual. The peroxide reaction would go to completion within a short distance of the injection wall.

Another potential approach to quenching of peroxide would be to use closed-vessel granular activated carbon (GAC) beds, which could eliminate the need for bisulfide addition by quenching both monochloramine and peroxide. One potential drawback of a GAC bed, is the potential for it to be overcome by biological growth; however, this potential should be limited in an anaerobic environment.
**Setup an Appropriate Automatic Chemical Feed Loop for Bisulfide Addition to Reduce pH Impacts on Calcium**

During the pilot study, a manually controlled post-treatment chemical feed system was used for sodium bisulfide. Chemical feed systems at full-scale would be automatically flow-paced through feed forward control. Sodium bisulfide feed should also be automated through feedback control using online hydrogen peroxide analyzers before the first wellhead. ORP sensors could also be used as a secondary indicator of peroxide removal.

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**San Antonio Water System (SAWS): Brackish Groundwater Desalination**

**Introduction**

San Antonio, along with many parts of Texas is experiencing double digit growth rates every 10 years. San Antonio Water System (SAWS) must be able to provide adequate water supplies in order to meet this growth. SAWS, currently, gets the majority of its drinking water from the Edwards Aquifer, but water levels are decreasing, resulting in limitations on water withdrawals imposed by regulatory agencies. This reality has resulted in SAWS looking for ways to diversify their water sources, including brackish groundwater located in an aquifer beneath the Edwards. To meet their water supply needs, SAWS has is developing a proposed Brackish Groundwater Desalination (BGD) Program consisting of a reverse osmosis (RO) treatment facility that is scheduled to be in service by October 2016.

At its proposed buildout capacity of 30 MGD the SAWS BGD project will be the largest municipal RO treatment facility in the State of Texas and will be one of the largest in-land potable desalination facilities in the United States. A key component of the treatment facility design is the goal to maximize the available raw water supply resources and minimize concentrate disposal flow (due to in-land deep injection well limitations) through the implementation of an enhanced recovery RO process. This presentation will provide insight of the project including facility planning and programming considerations, as well as a review of the proposed treatment process design. The presentation will include information on the source water quality and proposed pretreatment and the unique approach that is proposed for the 3-stage RO treatment process.

For several years leading up to the decision by SAWS to begin implementation of a brackish groundwater desalination program, a series of studies and preliminary testing were conducted by the Texas Water Development Board and various engineering and hydrogeological consultants for the SAWS. These studies included pilot testing of membrane treatment utilizing RO membranes, and pilot tests of remineralization using calcite (calcium carbonate) contactors. Pilot testing was conducted using water available from the Wilcox aquifer from test wells that were constructed during initial exploratory hydrogeological work. The water quality of the test wells indicated slightly brackish water on the order of 1,600 mg/L TDS, with some variability between wells. In general, the test well water quality was high in sulfate, sodium, and calcium hardness but relatively low in chloride when compared to what is typically seen with relation to sodium levels. Color and organics in this supply source were also observed to be low.
The RO Treatment Plant for the SAWS BGD Program will be designed to initially produce 10.0 MGD of RO permeate. There will be additional raw water that will bypass the RO treatment and be combined with the permeate to assist with post-treatment stabilization. This bypass is currently estimated as 10-20 percent of the permeate flow or 1-2 MGD for the initial phase of this project. Expansion of the treatment facilities is projected to occur in two future phases to provide a total RO permeate capacity of 20.0 and 25.0 MGD, respectively. Brackish groundwater for the initial capacity will be supplied by 13 production wells that will be located near the treatment facility site in southern Bexar County. The proposed RO Treatment Plant will be located at SAWS’ existing ASR site.

Post-treatment following the RO process will be required to stabilize the product water and to meet SAWS product water goals, including the following: TDS<400 mg/L; calcium 40-110 mg/L as Ca; total hardness 100-300 mg/L as CaCO₃; alkalinity>100 mg/L as CaCO₃; sulfate 10-75 mg/L; chloride <100 mg/L; sodium (minimize); pH 7.0-8.5; LSI 0.1-0.4; RSI <8; Larson ratio <1.

Innovative Approach to Post Treatment Using Sidestream Calcite Contactor System

A portion of the permeate flow will receive pH adjustment utilizing CO₂ addition, and then be fed through parallel calcite contactor units to meet the minimum water quality goals for calcium hardness and total hardness in the finished water. The calcite contactor effluent water will recombine with the remaining RO permeate flow and blend with raw water that bypasses the RO treatment before passing through degasifiers to remove a majority of excess CO₂, radon, and any other potential dissolved gasses of concern prior to the chlorine contact basin. The addition of free chlorine for disinfection and sodium hydroxide for final pH adjustment will occur downstream of the degasifiers at the head of the chlorine contact basin. Transfer pumps will convey the RO Treatment Plant water to the clearwell storage at the ASR facility. RO concentrate will be conveyed through a pipeline using residual RO system pressure to injection wells where booster pumps will provide an increase of the line pressure to levels required for disposal.

An innovative feature of the post-treatment design is the use of a sidestream calcite contactor system where only a portion of the flow is passed through upflow calcite contactors, and the contactors are made to operate at a higher mass transfer by injecting a high amount of CO₂ into this side stream of water. The intent is to maximize transfer of calcium in a limited footprint to reduce overall costs. To enhance dissolution of CO₂, the CO₂ injection system uses a pressurized solution feed sidestream to create a carbonic acid solution that is then injected into the water at high pressure. This increases the efficiency and stability of CO₂ utilization.

Desktop Simulations of Post Treatment

A series of desktop water quality simulations were carried out to identify how the WTP could operate to meet its finished water quality goals, utilizing the calcite contactors. The following items were key findings of the water quality simulation conducted using the Tetra Tech (RTW) model for water chemistry, process, and corrosion control.

- Calcite contactors must always be operational to meet Ca goals. Groundwater blend alone cannot provide enough hardness.
- When blending raw water, passing all of the permeate through the calcite contactors would cause the TDS to exceed the 400 mg/L finished water TDS goal. This is not anticipated to be a problem if no raw water blending is occurring. This can also be controlled by only passing a portion of the permeate through the calcite contactor.

- Sulfate may limit raw water blending to only 10-15% depending on membrane performance.

The SAWS BGD program represents a significant investment by the City of San Antonio in securing future water supplies for their growing community. Like any new alternative water supply program, the proposed project brings several unique challenges given the proposed facility capacity and in-land location. Through the application of innovative concepts including the use of a Concentrator RO skid configuration within the RO treatment process, the proposed program endeavors to raise the bars of sustainability and technological achievement for in-land RO treatment facilities both within Texas, and abroad.

**Tarpon Springs: Variable Salinity Brackish Groundwater RO WTP**

*Introduction*

Tarpon Springs, FL recently constructed a new RO WTP treating brackish groundwater as an alternative water supply to meet increasing water demands. A unique aspect of this project is that it included a design for a nearly eight-fold increase in TDS over the design life of the WTP. This increase is anticipated as a shallow, slightly brackish aquifer, begins to be predominated by an adjacent, deeper more saline brackish aquifer.

The WTP was required to have a total finished water capacity of 6.4 MGD which includes permeate plus raw water blend. The design criteria for this facility call for a final finished water that meets the primary and secondary drinking water standards and provides the following additional limits for stability and corrosion control:

- Calcium Concentration: $> 40$ mg/L as CaCO$_3$
- Alkalinity Concentration: $> 40$ mg/L as CaCO$_3$
- pH: $\leq 9.0$
- LSI: 0.1 to 0.5
- CCPP: 4.0 to 10.0 mg/L as CaCO$_3$, if possible

The design raw water quality varied from an initial condition of 1950 mg/L TDS, 99 mg/L calcium, 197 mg/L alkalinity as CaCO$_3$ and 953 mg/L chlorides to a future degraded condition of 16,554 mg/L TDS, 227 mg/L calcium, 197 mg/L alkalinity as CaCO$_3$ and 9,067 mg/L chlorides. The design criteria intended that the finished water meet the limits as the water quality varied over time without significant changes to the treatment system or membranes. The design criteria specified that the system was to be designed with a raw water blend capacity of 1.0 MGD. The post treatment processes included in the design criteria were degasifiers and two stage wet
chemical odor control scrubbers, sodium hypochlorite, carbon dioxide, lime slurry, phosphate inhibitor, fluoride and post-blend sulfuric acid storage and feed systems.

The facility was designed using three RO skids with a maximum capacity of $6.4/3 = 2.133$ MGD each. The vessels were loaded with a hybrid design of DOW Filmtec seawater membranes with 440 and 400 square feet to provide the higher rejection needed for the future degraded water quality. The use of the seawater membranes produced a permeate that was very low in calcium and low in alkalinity since the majority of the bicarbonate ions in the feed were rejected.

The facility has a scale inhibitor feed and a sulfuric acid feed to condition the raw water prior to feeding it to the membranes. The sulfuric acid system was used to lower the feed water pH to a range of 6.8 to 7.0 pH units. The acid feed was kept to a minimum since the pH of the permeate was normally less than 6.0 and the alkalinity was very low even without acid addition. This required a significant addition of alkalinity in the post treatment processes to meet the finished water goals with or without raw water blend.

The raw water blend system was designed per the design criteria to provide a flow of up to 1.0 MGD of raw water to blend with the permeate. Calculations performed using the composite water quality from samples obtained from each of the wells indicated that the initial TDS and chlorides were somewhat higher than the initial water quality in the specifications and a maximum blend of 0.72 MGD was considered to be optimum to achieve the finished water quality goals, minimize chemical addition and provide a small factor of safety to raw water quality variations.

The design team was advised that during initial startup of the system that the interconnect with a neighboring utility which supplied the majority of the City’s customers would remain open until the new plant was fully operational. The utility uses a combined chlorine residual in the distribution system. Therefore, a proposal was made to add an ammonium sulfate storage and feed system to temporarily be able to produce a combined chlorine residual from the new facility. This proposal was accepted and the ammonium sulfate feed system was designed.

The raw water blend was mixed with the permeate prior to degasification and a post blending sulfuric acid feed system and the hydrofluosilicic acid injection point were placed prior to feeding the blended permeate to the degasifiers. The system was designed to provide a pH of 5.8 to the degasifiers to optimize hydrogen sulfide removal.

After the blended permeate was passed thru the degasifiers, sodium hypochlorite was fed as the primary disinfectant. A chlorine contact chamber with two parallel channels was provided to provide for 4 log virus removal using a 50 to 1 length to width ratio to provide a baffling factor of 0.7.

*Carbon Dioxide Addition*

Carbon dioxide addition and liquid lime were used to meet the above-mentioned post-treatment targets. Following chlorination the water passes into a chamber and flows thru an opening in the wall where CO$_2$ solution is added to lower the pH and allow for lime addition to increase the alkalinity. After CO$_2$ addition the flow passes over a weir wall across the width of the channel where phosphate inhibitor and ammonium sulfate are fed from the chemical feed pipes which terminate approximately 1 foot above the water level. The flow then passes through a longer rectangular section in which a pH probe measures the pH to control the CO$_2$ feed rate.
**Liquid Lime Addition**

At the end of the channel there is an opening in the wall that the flow passes thru where lime slurry is added to meet the finished water alkalinity, pH and calcium targets. The flow passes thru a final rectangular channel with an overflow measuring weir at the end. This flow is used to control the post chemical feed systems. After the flow passes over the weir into the transfer pump wet well a sampling pump continuously pumps out flow which is passed thru analyzers to measure pH, chlorine residual, temperature and turbidity.

Flow is pumped from the transfer wet well by three horizontal split case pumps into the 5.0 MG ground storage tank. Flow is pumped out of the ground storage tank to the distribution system by one of six high service pumps with a combined design capacity of 14.1 MGD.

**Operational Issues**

Several operational issues have been observed relative to post treatment at the WTP since startup. These are summarized below

**Slow Reaction Times Limited the Usefulness of pH Control of CO₂ Dosing**

The CO₂ system was generally effective in reducing the pH toward the set point, but in general the control loop in automatic was very sluggish and the operation was normally performed by entering a CO₂ dose rather than using the pH set point. The exact nature of this issue was not diagnosed, but probably was a combination of the control loop and the slower reaction of the CO₂ solution to reach a pH equilibrium. The other issue with the CO₂ feed was the location of the CO₂ diffuser in front of the under flow opening in the wall from the compartment in which the flow from the two sides of the chlorine contact chamber were combined. The manufacturer required that the holes in the diffuser point toward the opening, most likely to provide better mixing. However, with a single skid in operation the CO₂ solution was obviously passing thru the wall into the prior chamber at the end of the chlorine contact chamber. This was evidenced by the lower than expected pH values measured there which are used for determining disinfection effectiveness. This operational issue has been addressed by specifying fixed CO₂ feed rates.

A better approach to prevent this problem would be to combine flows from the two parallel chlorine contact channels to allow sampling for compliance monitoring purposes and separate this compartment from the CO₂ feed to prevent pH effects on the chlorine residual monitoring results or move the CO₂ diffuser away from the underflow opening.

**Supplier’s Modification to Lime Solution Feed Caused pH Interference to CO₂ Dosing**

The lime solution feed was problematic from several stand points during initial operation and troubleshooting. First the lime solution supplier advised that the end of the feed tube should be terminated above the water surface and allowed to drop down into the bulk flow, whereas the original design called for the end of the tubing to be set at the depth of the underflow wall opening. The recommendation of the supplier was probably based upon a fear of clogging of the feed tube. When the lime was fed in this manner due to the circulation of the flow in the chamber a back mixing effect was created and the pH meter used to control the CO₂ feed would read 1.5 to 2.0 pH units higher than without the lime feed. The diffuser was moved to the downstream side of the underflow opening and the impact upon the pH probe for the CO₂ system was minimized.
Incomplete Dissolution of Liquid Lime Can Increase Finished Water Turbidity

Another issue that arose was that in the final channel the lime solution was not completely mixing and the fine calcium carbonate particles were not completely dissolving. This led to measured turbidities in the transfer wet well of 3 to 10 NTU and turbidities of up to 3 NTU in the finished water storage tank. To provide better mixing and dispersion of the lime solution it was decided to use the bypass flow from the sample pump withdrawing from the first chamber after chlorine contact as carrier water. A diffuser was designed for use on the end of the pipe that was constructed from PVC with holes in it to create an exit velocity of the solution around 10 fps to feed the lime slurry and carrier water. This change reduced the turbidities down to 1.5 to 3.0 NTU. Finally, it was decided to deviate from the design chemical calculations and operate at a lower finished water pH. The target finished water pH was lowered to around 8.5. This change brought the finished water closer to a neutral LSI and the turbidities were reduced to 1.0 to 1.5 NTU in the transfer wet well. In general finished water pH should be kept below 8.5 to avoid issues with calcium carbonate turbidity.

Flushing the Lime Chemical Feed Lines Can Prevent Scaling, But Delay Startup Times

An additional issue with the lime feed system was the post flush feature programmed into the system by the supplier. Whenever one of the two lime feed pumps is taken out of service the feed line from that pump is flushed with water to remove all of the chemical from the line to prevent the line from scaling up over time. The down side to this feature is whenever a new pump is placed into service there is a period of several minutes in which only water is being fed into the finished water. Therefore, there is a volume of water that passes thru without chemical addition and the automatic controls cannot adjust to maintain the pH set point. This was partially compensated for by starting the chemical feed system at maximum flow to get chemical to the injection point as soon as possible.

Low Levels of Hydrogen Sulfide Permitted a Suspension of Degasification, Reducing CO₂ Removal and Dosing Requirements.

After several months of operation it was apparent that levels of hydrogen sulfide in the raw water and therefore, the permeate concentrations were so low that degasification was not required to remove them. The City advanced the idea of not using the degasifiers to save on the electrical cost of running the blowers. The design provides for a bypass line to bypass the degasifiers in the event that hydrogen sulfide levels are low. Some chemical calculations were performed and it was determined that it was better from a post treatment chemical feed situation to continue using both degasifiers, but to only use one blower to lower the amount of CO₂ removed that would have to be reintroduced by the chemical feed system.

For Many Reasons, Post Treatment is Challenging to Control Automatically while Expecting to Attain Precise Control at Set Points

The pH control loops for the CO₂ and lime feed systems did not prove to be as robust as required for automatic operation of these systems based upon use of pH set points for dose control. Controlling these two chemicals to simultaneously meet the calcium, alkalinity, pH and alkalinity goals is chemically complex when the blend ratio is changed to respond to the varying quality of the raw water from the 15 supply wells. The fall back is to operate these systems by entering a dose rate for each chemical. To do this most effectively the TDS, pH, calcium and alkalinity must
be measured in the effluent from the degasifiers and put into a chemical addition spreadsheet to
determine the CO₂ and lime doses. Such a spreadsheet was provided to the operators. However,
due to the imprecise nature of the exact concentration of the lime solution and the level of
inaccuracy of the CO₂ feed rate, the operators must monitor the TDS, pH, alkalinity and calcium
in the finished water transfer wet well to back check that the proper amounts of chemical are
actually being added as shown on the control system. In reality this is more complex than
reasonable to expect from many water treatment facility operators and therefore, very tight control
of the finished water quality parameters is probably not realistic.

A better approach, when the alkalinity target requires more lime addition than the calcium target
is to use calcium hydroxide solution only for adjusting the calcium concentration up to the finished
water target. This allows the lime slurry to be combined with the process water at a lower pH
which will reduce the quantity of undissolved lime particles in suspension. The pH can be adjusted
to the final target level using a separate sodium hydroxide feed at the end of the post treatment
chemical addition.

*Post Treatment Control: Theory versus Practice*

Post treatment chemical addition, monitoring and control requires rapid and thorough mixing of
chemicals, good separation of chemical feeds that might affect monitoring results, robust control
loops, increased access to chemical feed and monitoring locations and may require higher cost to
optimize control and performance.

In theory using pH set points to control the CO₂ and lime feed systems is the correct method of
control to automate the process. However, in practice it is difficult to mix these chemicals
completely and obtain accurate pH feedback in a timely manner to adjust chemical feeds quickly
to the set points. This is especially true when a single skid is in operation and the detention times
are longest and mixing energy is the lowest. At this facility the CCPP goal was not readily
achievable and was not enforced in the acceptance testing. This is reasonable considering that a
blended phosphate corrosion inhibitor was being fed with the higher concentration component
being polyphosphate which would have sequestered calcium and prevented it from precipitating.

Setting all post treatment quality goals to the ideal levels is good in theory, but may not work out
in actual practice. Significant additional chemical doses may be required to meet the targets. For
example to maximize the alkalinity and maintain an acceptable finished water pH requires
significant quantities of CO₂ addition to maintain pH while lime is added to increase the alkalinity.

**Summary**

Post-treatment is an important part of membrane treatment processes. As the number of membrane
treatment applications and facilities increase, the role of post-treatment will continue to increase.
Three recent projects were reviewed including two new brackish groundwater WTPs and a planned
indirect potable reuse (groundwater replenishment) water purification process. All three projects
required some form of remineralization for purposes of either corrosion control (brackish
desalination WTPs) or stabilization to mitigate arsenic release in the aquifer (groundwater
replenishment). Two projects use liquid lime addition and one uses calcite contactors.
Groundwater replenishment also requires utilities to consider oxidant removal processes.
Common issues between all projects include the following: control of turbidity, maintaining setpoints, and automatic controls. Specific recommendations for improvement were developed based on initial operations of two of the processes. By continuing to understand and apply lessons-learned in post-treatment, it is expected that utilities can meet finished water quality targets with less operational trouble.