Conversion from Membrane Softening to Brackish-Water Reverse Osmosis

A Case Study of the Fort Myers RO Water Treatment Plant

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Florida water management districts are growing more concerned over increased drinking water demand, dry weather, degraded source-water quality, and reduced levels in the shallow freshwater aquifers in many parts of the state. Water management districts have recommended use of brackish water from deeper wells as a preferred and plentiful alternative water source in areas of limited fresh groundwater supply.

In the spring of 2002, the city of Fort Myers was proactive in developing a new brackish-water supply to replace its existing limited shallow aquifer water source, which also was causing some membrane fouling issues at the existing facility. The city also converted its existing nanofiltration (NF) membrane softening facility to a brackish reverse-osmosis (RO) system and expanded the plant capacity.

The Fort Myers conversion in 2002 from NF to RO initially included developing seven new upper Floridan aquifer wells, replacing the used NF membrane elements with new low-pressure RO membrane elements, epoxy coating the existing membrane feed pumps, and relocating existing degasifiers to a lower elevation to minimize permeate backpressure.

Benefits of the conversion included a plentiful raw-water supply and the ability to blend more feed water with membrane permeate because of the lower source-water color.

Unfortunately, the conversion resulted in a loss of treatment capacity from 12 million gallons per day (mgd) to less than 9 mgd because of increased membrane feed-pressure requirements. Changes in the quality of raw water and membrane permeate caused process and mechanical issues, including reduced process control, process equipment corrosion, elevated finished-water turbidity, increased chemical demand, and corrosion of the distribution system piping.

In early 2004, CH2M Hill was contracted as the design builder to expand the Fort Myers RO Water Treatment Plant (WTP) capacity to meet future capacity and to solve the problems resulting from the previous conversion from NF to RO. Process modifications included new membrane feed pumps, new flow-control valves, new degasifiers, and changes to chemical feed systems. Expansion included the addition of new membrane trains, installation of higher-rejection membrane elements, and four new brackish-water production wells.

Process Flow and Facility Layout

Major unit processes for the Fort Myers RO WTP include:

- Raw-water production wells
- Pretreatment
- Membrane feed pumps
- 1st- and 2nd-stage membrane blocks
- Degasifiers and transfer pumping
- Finished-water chemical addition
- Finished-water storage
- Higher-service pumping
- Concentrate injection well

The groundwater supply wells are located near the WTP site. The pretreatment, membrane feed pumps, and membrane blocks are located in the RO building.

The membrane system is arranged in a block configuration with common headers between the membrane feed pumps, first-stage membrane blocks, and second-stage membrane blocks. Each block is a single-stage array of 32 pressure vessels that draw feed water from a common header on the discharge of the membrane feed pumps for the first stage and on the concentrate discharge of the first-stage blocks for the second stage. Three blocks (two first-stage and one second-stage) make up a process train.

The degasifiers, transfer pumping, and finished-water storage are located on the WTP site. High-service pumps are located in the main RO building, and the concentrate injection well is located on the site next to the RO building.

Nearly all the unit processes were impacted by the conversion from membrane softening to brackish-water desalting. Only

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TABLE 1

Feed-water quality before and after conversion to RO

Constituent	Surficial Wells*	Brackish-Water Wells**
pH (units)	7.4	7.2
Total Alkalinity (mg/L as $CaCO_3$)	197	140
Total Hardness (mg/L as $CaCO_3$)	220	790
Color (CU)	78	1
Iron (mg/L as Fe^{+3})	0.3	0.01
Chloride (mg/L as Cl^-)	78	1,350
Conductivity (mS/cm)	600	5,300
TDS (mg/L)	480	3,000
Sulfide (mg/L as S^{-2})	0.65	3.5

* Before RO – membrane softening used to treat surficial-aquifer water ** RO used to desalt brackish groundwater

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finished-water storage and high-service pumping were unaffected.

Changes in chemical feed dose were the only changes required to the pretreatment process. All other processes were significantly impacted. The following sections discuss key changes to each process.

TABLE 2
Fort Myers RO WTP Degasifier Design Criteria

Criteria	Membrane Softening WTP	Brackish-Water RO WTP
Maximum Hydraulic Loading Rate (gpm/ft^2)	41.0	34.9
Minimum Air:Water Ratio	16.2	32.0
Packing Depth (ft)	5.25	14.0
Influent Sulfide (mg/L)	0.65	3.5
Minimum Required Sulfide Removal Efficiency (%)	62%	93%

Raw-Water Production Wells

Conversion to brackish-water desalting included abandoning the surficial-aquifer wells and replacing them with deep, upper-Floridan wells. The brackish raw water from the new wells was higher in salinity, hardness, and sulfide; however, it was lower in fouling organic content, color, and iron. Table 1 shows the approximate feed-water quality of the surficial wells used in the membrane softening facility and the new brackish-water wells.

The conversion to a more corrosive brackish raw-water supply required a change in wetted materials for the well pumps, wellhead piping, and components, as well as the raw-water transmission main. The new well pumps and all components that come into contact with the raw water at the wellhead used Type 316 stainless steel. Corrosion-resistant high-density polyethylene (HDPE) piping was used for the new raw-water transmission main instead of ductile iron pipe.

Pretreatment

Pretreatment for both NF and RO includes acid and scale-inhibitor addition, along with cartridge filtration. Conversion to brackish-water RO required changes to the optimum type and dose of scale inhibitor. The new scale inhibitor had similar physical and reactivity properties, so no changes were required to the feed-system materials of construction.

The change in feed dose was also well within the capacities of the existing tanks and feed pumps, so no new scale-inhibitor feed equipment was required. A small change in acid dose was required because of a change in the calcium carbonate scaling potential of the feed water; however, no changes in acid chemical metering pumps or storage tanks were necessary.

The existing stainless-steel cartridge filters were adequately sized for the new brackish water, which had a lower organic fouling potential than the surficial water. The stainless-steel materials of construction were also compatible with the new water supply.

Membrane Feed Pumps

The membrane feed pumps boost chemically treated, pre-filtered water to the pressure required by the membrane system. The existing 300-horsepower (HP) membrane feed pumps were designed to feed the NF system at pressures between 90 and 120 pounds per square inch (psi) at an average permeate flux rate of 15 gallons per square foot per day (gfd). The new RO system was designed for the same permeate flow rate (4 mgd per train – three blocks), but required feed pressures between 180 and 230 psi at an average permeate flux rate of 13 gfd.

The lower design recovery of the RO system from 87 to 80 percent, which was required because of the increased concentration of sparingly soluble salts, also increased the feed-flow requirements needed to produce the same finished-water flow rate (4.6 mgd per train increased to 5.0 mgd per train). At maximum output, the existing membrane feed pumps could drive the membrane system to produce a finished WTP flow of 10 mgd at feed pressures up to 180 psi, assuming 40 psi of available suction pressure. The 180-psi maximum pressure was not adequate to produce the necessary plant production flow as the RO membranes aged and were fouled.

The cast-iron construction of the existing membrane feed pumps was not compatible with the new 3,000-mg/L TDS brackish feed water. Initially, the wetted portions of the existing feed pumps were epoxy coated to protect them from the more corrosive brackish water; however, the epoxy coating was not well suited for the high-velocity flow and significant turbulence inside the pump housing.

New feed pumps with higher pressure and flow capacity were installed as part of the expansion in 2004. The new 500-HP membrane feed pumps have Type 316 stainless

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steel wetted materials of construction and are designed for discharge pressures above 230 psi at a flow rate of 5.0 mgd. One new membrane feed pump was installed for each of the new and existing membrane trains (four total).

Membrane Blocks

Converting to a brackish-water source from a surficial-water source required significant changes to the membrane system. Primarily, higher salt-rejection membranes were required. The staging of the membrane system also changed as flux rates and system recovery changed.

The NF membrane elements were gradually replaced with low-pressure RO membranes before the conversion was fully implemented to help spread out the cost of the new membranes. After the conversion to brackish-water wells, additional high-rejection RO elements were installed to replace the remainder of the NF membrane elements in order to improve finished-water quality.

During the expansion of the system in 2004, additional membrane blocks were added with higher salt-rejection membranes to increase the plant capacity. The different feed-pressure requirements of the low-pressure RO and the two types of high-rejection RO membranes made process control difficult when using the block configuration at the plant.

NF and RO membrane systems required different membrane element arrays to have balanced feed-concentrate flows and permeate-flux rates between stages. The original NF membrane system used a three-stage membrane array with a 56:28:12 pressure-vessel configuration containing seven membrane elements per vessel to achieve 87-percent recovery. The converted RO trains operate at 80-percent recovery, which requires a two-stage system with seven elements per vessel. The membrane trains were converted to a 64:32 pressure-vessel configuration by moving the unused "original" third-stage pressure vessels to the modified first- and second-stage blocks.

Concentrate Injection Well

The salinity of the concentrate waste stream increased significantly after conversion to a brackish-water supply. The concentrate flow rate also increased because the recovery of the brackish-water RO system was lower than the previous membrane softening system. The concentrate, with higher salinity and increased flow rates, had to be disposed of properly after the conversion, so the facility changed from surface-water discharge to a concentrate injection (disposal) well.

The well discharges concentrate into a deep groundwater aquifer with similar high-salinity water quality. Construction and permitting of the injection well was an involved process that took several years of monitoring and testing. Also, modification to the existing FDEP industrial wastewater permit was required.

Membrane Bypass/Blending

A portion of the raw water is bypassed around the membrane system and blended with the permeate stream prior to post-treatment degasification. This is advantageous because for a given finished-water capacity, less groundwater is needed, pretreatment and post-treatment chemical addition is reduced, the membrane system does not need to be sized for the full plant capacity, there is less concentrate to be disposed of, and the treated-water costs are reduced.

After converting to the brackish source water, the bypass flow percentage of the finished water was increased from approximately 5 percent to 10 percent. A new cartridge filter was added to treat the bypass stream as part of the plant improvements.

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Degasifiers and Transfer Pumping

Degasifiers remove hydrogen sulfide from the membrane permeate as the first step in the post-treatment process. Chlorine oxidizes any remaining sulfide in the finished water, creating unwanted turbidity. The sulfide exiting the degasifiers should be below approximately 0.25 mg/L to prevent excessive finished-water turbidity and chlorine demand.

The increase in feed-water hydrogen sulfide from 0.65 mg/L in the surficial wells to 3.5 mg/L in the brackish wells required improvement of the sulfide removal efficiency by the degasifiers.

Hydrogen sulfide removal efficiency is a function of the hydraulic loading of the degasifiers, the air-water ratio, the packing type, and the packing depth. The new degasifiers have the design criteria shown in Table 2 on page 52.

New degasifiers with deeper packing and larger blowers were needed to achieve the required 95+ percent hydrogen sulfide removal efficiency on the higher-sulfide RO permeate.

The existing product transfer pumps did not require any changes after the conversion to RO.

Finished-Water Chemical Addition

Sodium hypochlorite, sodium hydroxide, and a phosphate-based corrosion inhibitor were added to the membrane-softened finished water before the conversion to RO. These same chemicals stabilize and disinfect the finished RO water; however, some changes were required because of the lower hardness and alkalinity of the RO product.

In addition to the original post-treatment chemicals, carbon dioxide is now added to the finished water to increase its alkalinity when combined with a higher sodium hydroxide dose. The target finished-water pH has been increased from 7.8 to 8.7 to reduce the corrosivity of the finished water and eliminate the red-water complaints that occurred before the post-treatment improvements. Changing the corrosion inhibitor from zinc orthophosphate to phosphoric acid ensures that zinc will not precipitate at the new higher finished-water pH value.

Finished-Water Storage & High-Service Pumping

The existing 15 million gallons of finished-water storage and 17 mgd of high-service pumping were adequate after conversion to RO and the plant capacity expansion. No changes were made to these systems.

Summary

Converting the Fort Myers membrane softening WTP to a brackish-water RO WTP was a complex process that required changes to several of the WTP unit processes. Here is a summary of key process changes that were needed:

- The addition of new brackish-water wells.
- The installation of membrane feed pumps that are sized for the higher flow and pressure requirements of an RO system .
- The use of corrosion-resistant materials that can withstand the higher salinity of the brackish feed and concentrate waters.
- The replacement of NF membranes with high salt-rejection RO membrane elements.
- Changes in recovery, staging, and flux rates in the membrane system.
- The replacement of mechanical components that were not rated for the higher pressures associated with RO membranes.
- Modified degasifiers designed to remove higher levels of sulfide found in deep brackish wells.
- Adjustments to post-treatment chemical feed strategies, including use of different corrosion inhibitors, higher finished-water pH, and carbon dioxide to help stabilize the finished water.
- The change from surface-water discharge to an injection well for concentrate disposal.