Improving Operational Efficiency at an Aging RO Water Treatment Plant through Replacement & Rehabilitation

Jerry LeBeau and Mark D. Miller

Constructed in the early 1980s, Indian River County Utilities' Oslo Road Reverse Osmosis (RO) Water Treatment Plant in Vero Beach is more than 20 years old. At this age, improvements and replacement of some key components were not only necessary to maintain plant operations and meet changing regulations, but were also needed to improve the facility's operating efficiency. This article evaluates some of the key improvements to an aging membrane treatment plant rated at 8.57 million gallons per day (MGD). Improvements included:

- Replacing aging fiberglass pipe with HDPE and stainless steel pipe.
- Replacing cartridge filter the vessel type to improve pretreatment system.
- Replacing aging membranes and improving treatment efficiency and operating costs.
- Installing an improved post-treatment system.
- Upgrading high-service pumping system to improve operations and operating costs.
- SCADA system improvements.
- Upgrading electrical gear no longer available.

Upgrades to the plant, including replacement and rehabilitation of key equipment, have been ongoing for several years. This article highlights some of the real-life experiences of maintaining plant operations while implementing these improvements and the effects on treatment plant efficiency and operations.

Replacing Fiberglass Piping

Raw water piping for many of the older and larger RO plants was typically constructed of fiberglass (FRP) to minimize corrosion. Larger diameter piping for underground installations such as PVC typically was not available many years ago and could be constructed more economically using FRP, compared to coated ductile iron piping.

Depending on the chloride levels of the raw water, FRP was the preferred pipe material many years ago when larger capacity RO plants were being constructed, but the brittleness of FRP and the inexperience of contractors with installing FRP piping systems led to failures of the pipe, resulting in frequent shutdowns of treatment facilities. Many of these FRP piping systems were therefore unreliable and warranted replacement with different materials, such as high-density polyethylene (HDPE) and stainless steel.

All the larger diameter underground raw water and permeate water piping at the Oslo Road plant were originally constructed of

Jerry LeBeau is an operations specialist in the Maitland office of CDM, a consulting, engineering, construction, and operations firm. At the time this article was written, he was water production superintendent at Indian River County Utilities. Mark. D. Miller, P.E., is a vice president with Port St. Lucie office of the engineering consulting firm Kimley-Horn and Associates. This article was presented as a technical paper at the Florida Section AWWA Fall Conference in November 2007.

FRP. The trench piping within the process building was also constructed of FRP, including the feedwater, permeate, and concentrate piping. Frequent failures of both piping systems resulted in the decision by Indian River County Utilities to replace the FRP pipe with HDPE pipe. The difficulty in replacing this pipe came from the requirement that the plant stay fully operational with minimal shutdowns.

The facility operated at nearly 75 percent of its full capacity and is one of two regional treatment facilities providing potable water to the system. The plant also had limited storage capacity, which allowed no more than eight-

Figure 1. Removal of FRP Piping

Figure 2. Temporary Cartridge Filter Header

Figure 3. New Stainless Steel Feedwater Pump Header

Figure 4. Old Filter Vessels

hour shutdowns of treatment. The existing storage capacity of 4 million gallons with only 3 million gallons of useful storage, compared to the plant rated capacity of 8.57 MGD, barely met Florida Department of Environmental Protection requirements of 25 percent of the system's maximum-day water demand, so critical piping tie-ins not only had to be limited, but had to be carefully planned in advance.

Temporary piping headers were constructed to allow raw water to enter the feedwater pumps, while allowing removal of FRP pipe sections (see Figure 1 and Figure 2). An additional chemical injection assembly with stainless steel static mixer was constructed to allow removal of the existing FRP static mixer assembly. Full sections of pipe that had to be replaced in identical locations were phased in sections to minimize plant shutdown durations.

All of the underground FRP was replaced with HDPE pipe and the interior process piping with 316 stainless steel (see Figure 3). Grooved type couplings (Victaulic style) were used to help in expediting pipe installation, since they were much easier and quicker to install and allowed some flexibility in pipe alignment.

Cartridge Filtration Vessel Replacement

The original pretreatment filters were vertical-style cartridge filter vessels (see Figure 4). The cartridges were not only difficult to replace, since a ladder typically was required to allow easier cartridge removal, but historically allowed sand or filtered material to settle in the discharge pipe during cartridge element replacement.

The plant had a history of sand intrusion from a collapsed well to the membrane system. With the added disadvantage of vertical-style filter vessels allowing some of the settled sand within the vessels to migrate to the membrane system, sand intrusion to the membrane system was difficult to prevent.

In order to prevent any potential of sand intrusion, a "belt and suspenders" approach was implemented by the utility. A sand separator was installed on the raw water main and the vertical cartridge filter vessels were replaced with horizontal vessels, allowing easier access for cartridge replacement and a more efficient means of cartridge removal.

Membrane Replacement & RO Train Operational Improvements

The existing membrane system was limited in capacity because of membrane damage from scaling, fouling, and sand intrusion. The rated treatment capacity was limited to 5 MGD, nearly 20 percent less than the design rated capacity of 6.0 MGD. Several other mechanical features limited the capacity, including leaking valves, lack of first-stage permeate control valves, control philosophy, and reduced feedwater pump capacity.

Most of the mechanical issues were a result of older technology and the age of the equipment. Some of the operational issues that needed to be changed were also philosophical, such as how control valves were operated.

Physical damage to the membranes, meant that replacing them was not only a critical element in restoring capacity, but important in improving the operating efficiency of the plant. Power consumption, chemicals, and finish water quality were all directly affected by poor membrane performance.

Membranes could not be replaced, however, without correcting the other mechanical and operational elements which allow them to maintain consistent performance. Several of these include:

1st-Stage Permeate Control Valve

With newer technology membranes, which typically have higher flux capacities, the membrane system first stage typically has throttling valves that control the amount of flux in the first stage to prevent scaling potential in the tailing elements. The membrane system at the Oslo Road facility did not have throttling valves.

Permeate header isolation valves had been used for this purpose, but they provided very little control, since they were butterfly valves and there was no means of measuring total flow from each stage. V-port ball valves were installed on the first-stage permeate header of each of the RO trains in order to control flux within the first-stage membrane array.

Interstage Cleaning System Valves

The cleaning system valves that were connected to the interstage piping were wafer-style butterfly valves, which are only as good as the flanges they are sandwiched between. When additional membrane system capacity was desperately needed, the system was operated at elevated pressures, which caused leakage to increase through the interstage valves.

The interstage piping is constructed of stainless steel, and the cleaning system pip-

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ing was constructed of PVC and Van Stone style PVC flanges. Although the PVC flanges are rated for 150 psi, it is difficult to prevent leaking between these valves and the flanges when the system operates up to 130+ psi. The PVC flanges typically become over-stressed and crack when flange bolts are tightened where stainless steel flanges are installed on opposite sides of the butterfly valves. These valves were replaced with lug-style butterfly valves, which allowed the flange bolts to be tightened to each of their respective pressure ratings.

Miscellaneous Improvements

Several operational and mechanical modifications improved the operating efficiency of the RO system. The feedwater pumps were upsized with larger impellers to maximize the use of the existing 150-horsepower motors. Some of the feedwater pump impellers were also worn and inefficient, so replacement not only improved capacity, but increased the design capacity of the entire feedwater pump system.

The concentrate control valve operation was originally designed with valve actuators that failed closed upon lack of signal and air supply and were forced closed during RO train shutdown. This contributed to a membrane scaling event in which feedwater valves were not fully closed and created a condition in which 100 percent recovery occurred. The actuators were changed to operate fail open and remain open when the RO train is not in operation.

Membrane Replacement

The membranes were not only scaled from a previous scaling event, but were fouled from sulfur fouling and had sand intrusion. These factors contributed to poor membrane performance with elevated feed pressures and lower rejection. Feed pressures were elevated by more than 40 psi in some cases and membrane rejection was non-existent in others.

Fouling occurred because of air entering the system through well pump intakes during low water levels and because of air release valves that allowed air to enter the well pump columns during pump shutdown. Sand entered the system through the old vertical-style cartridge filter vessels and at one time when a well had collapsed. Most of these operational issues have been addressed to prevent future membrane damage.

The approach to membrane replacement included:

- Select the worst performing RO train with the least capacity and poorest water quality and replace those membranes first.
- Install profile valves to determine if some of the existing membranes were salvageable.
- Order new membranes once the number was defined and schedule delivery with replacement.
- Remove existing membranes, keep salvageable ones, and perform corrective work on RO trains.
- Flush membranes for 24 hours, collect bact's, and place into operation.

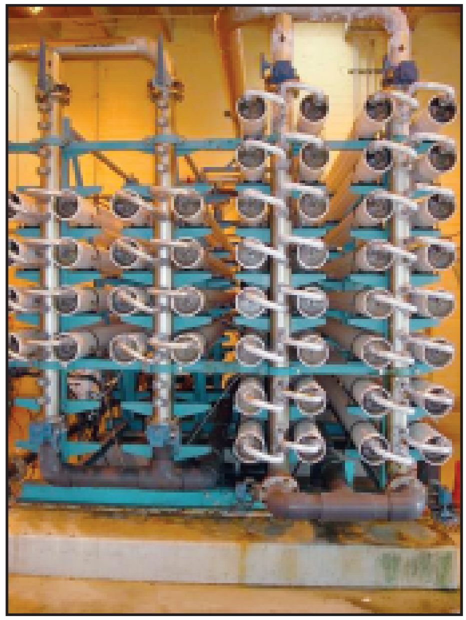

Figure 5. Typical RO Train Array

The original membrane softening elements were replaced with DOW Filmtec NF90-400. Membrane projections were performed for the proposed NF90-400 elements and predicted initial feed pressures below 90 psi and permeate water quality of 130 mg/l total dissolved solids.

Once the membranes were replaced for the first RO train, the remaining trains were replaced one at a time to minimize impact to the plant's capacity. Table 1 illustrates the results of the membrane replacement.

The feed pressure, delta p, permeate, and concentrate flows were restored to optimal levels consistent with the membrane projections. For instance, the average feed pressure for Train 4 dropped significantly after membrane replacement from 115 psi to 80 psi, respectively. Besides the feed pressure significantly decreasing after replacement, the Stage 1 pressure drop had a similar trend, experiencing a reduction from 40 psi to 14 psi.

Train Capacity Increase to 1.8 mgd (1.5 mgd Design)

The existing RO train arrays were somewhat oversized and on average operated at a conservative flux rate of 13 gallons per square foot per day (GFD). Higher average flux rates up to 15 GFD could be achieved safely with consistent raw water quality and careful control of the first-stage element flux. Operating at higher flux rate could also be achieved when one of the RO trains was down without jeopardizing overall treatment plant capacity. It is also another means of providing standby capacity and improving redundancy of the treatment system. In order to confirm the ability of the membrane system to operate at a higher flux rate, RO train 4 was operated at an elevated capacity of 1.8 MGD.

Three membrane projections were performed that included having each train produce 1.6, 1.7, and 1.8 MGD. The average system flux was 15.64 GFD, resulting in a lead element flux rate of 22.4 GFD, which is acceptable and within flux rates that have been pilot tested before. Typical elevated flux rates have been tested up to 27 GFD for membranes of this type.

One important operational condition of operating at higher flux rates is to insure that the first-stage elements don't over flux. Installation of the first-stage permeate control valve allowed control of first-stage permeate flow to prevent over fluxing the lead membranes.

Alarms

The original alarms were also outdated and did not adequately protect the membrane system. None of the alarms triggered a train shutdown. Prior to membrane replacement, the RO train operating logic was streamlined and shutdown alarms were added for key operating parameters, which included high feed pressure, high first-stage permeate flow, and low concentrate flow. These parameters have appropriate setpoints that will trigger alarm or shutdown, with a given time delay, depending on the parameter type.

Normalized Trends & Historical Data

A custom normalizing spreadsheet was prepared and installed on the SCADA system, which automatically collects raw data from each of the RO train field devices during each operator shift (eight hours) and stores the data within the spreadsheet to provide historical and real-time trending of each RO train.

With all of these improvements to the RO trains, the reduction in operating pressure saved Indian River County approximately $5,000 per month in electrical costs. Not only did operating costs decrease, but water quality improved significantly, allowing the plant to blend more raw water with the permeate stream.

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Figure 6. Existing Degasifier

Figure 7. New Post-treatment System

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Improvements to the Post-treatment System

The post-treatment system consisted of two forced-draft degasifiers which removed dissolved hydrogen sulfide and carbon dioxide gas from the permeate stream. The degasifiers and blowers were elevated above the ground storage tanks, allowing the treated water to flow by gravity into the center of the tanks. Although the only advantage of this installation was to eliminate repumping the treated product water, several disadvantages included:

- Maintenance of the system was more difficult and routine inspection of the equipment was less frequent.
- The water quality of the effluent, such as pH and chlorine residual, was difficult to monitor because these parameters could be measured only at the POE, giving little time to react and make changes to the treatment process.
- No odor control system existed, which caused heavy corrosion of the equipment surrounding the degasifiers and odor complaints from neighboring properties.

Since the degasifiers had reached the end of their useful life, a new post-treatment system was installed to replace them. The system included a clearwell, transfer pumps, forced-draft degasifiers, two-stage off-gas scrubber system, chemical injection, and monitoring. Key advantages to the new system are the ability to maintain consistent treatment of the product water, the ability to improve mixing and blending of raw water, and the ability to improve monitoring of the treated water prior to transferring it to the ground storage tanks.

High-Service Pump Upgrades

The high-service pumps were originally designed for a 7.5-MGD plant rated capacity. With the addition of elevated storage within the system and an uprating of the treatment capacity to 8.57 MGD, no increase in high-service pumping capacity was implemented at that time. It was assumed that the elevated storage would meet peak flows and the north water plant would provide the necessary peak pumping requirements. With the new August 2003 amendments to Chapter 62-555 permitting requirements for public water systems and an increase in water system demands, upgrades to the high-service pumps were necessary.

With the upgrades, three new 3,200-gallons-per-minute pumps were designed, which provide 9.2 MGD of pumping capacity, slightly more than the plant rated capacity with the largest pump out of service. The higher-capacity pumps were also more efficient at the design operating point. Larger impellers were selected for the same model pump, which also provided flexibility in providing a shelf spare pump.

Due to normal plant operation at nearly 75 percent of capacity, replacement of the high-service pumps had to be phased one at a time in order to maintain adequate pumping capacity during replacement.

SCADA & Electrical System Improvements

The programmable logic controller (PLC) and supervisory computer and data acquisition (SCADA) system were antiquated and in need of optimization. Several deficiencies included: poor documentation within the ladder logic programming software, outdated drivers for the PLC hardware, alarms that were disabled because instruments were uncalibrated, loops that were disabled or inoperable, and outdated HMI software.

In general, the plant was operated in manual mode more often than automatic mode because of these insufficiencies. When instrumentation was consistently out of calibration or was inoperable, it was much easier to operate in manual mode or force values within the control logic to maintain operation of the plant.

A significant portion of the SCADA system optimization could be implemented only once an instrumentation technician was secured and calibration of the majority of equipment was complete. Also, calibration of some of the instruments uncovered more issues than were initially observed. Given the age of some of the equipment and the poor condition of some of the valve actuators, instruments, equipment, etc., the resulting failures prevented staff from being more proactive in fixing problems, since much of their time was used in reacting to failures and problems. This perpetuated operating the facility in manual mode, rather than the preferred automatic mode.

Several of the key benefits of optimizing the control system recently include:

- Improved automation of the system allows more time to focus on compliance issues and enables staff to be proactive in maintaining equipment.
- Optimizing alarms has renewed staff's confidence in significant alarms and awareness of critical alarms.

IMPROVEMENT	BENEFIT
• Replacement of FRP Piping	Improved reliability, prevents intrusion of sand from pipe failures
• Cartridge Filter Vessel Replacement	Easier access for element replacement and prevents sand intrusion
• Membrane Replacement	Lower operating costs and improved water quality
• Improved Post-treatment System	Easier maintenance, improved water quality, reduced corrosion and odor complaints
• Upgrade High Service Pumps	Increase capacity and improve operating costs
• SCADA and Electrical System Improvements	Improve automation, reduce staff effort, less wasted water, and reduced chemical demands

- Implemented contract services for a part-time SCADA system integrator and instrument technician has helped maintain confidence in operating the system in automatic mode.
- Normalized data from the RO system indicates current performance is consistent and stable.
- There is less wasted water during shutdowns and startups.
- There are reduced chemical demands with optimized chemical feed loops.

Some of the electrical gear and motor control centers were also in need of replacement, since they were more than 25 years old. There were no replacement components available for this equipment, and corrosion of some of the bus bars was severe enough to warrant replacement due to the potential for sudden failure. All of the high-service pumps were fed off these components, so this was a critical item that needed immediate attention.

The approach was to develop a phasing plan that allowed for the demolition and replacement of the motor control centers to occur within a single 48-hour (maximum) shutdown. The plan also included transitioning the high-service pumps from the existing starters to the proposed variable frequency drives with no loss of pumping capacity.

Summary

Given the age of the Oslo Road plant, taking advantage of a replacement and rehabilitation program is an effective vehicle to improve operations and the efficiency of the treatment process. With improvements in technology, stricter regulations, and operating efficiency becoming more important and drawing more attention, implementating several key plant improvements can result in multiple benefits.