MEMBRANES

RECOVERY OF RO MEMBRANE PERFORMANCE THROUGH DIRECT OSMOSIS-HIGH SALINITY MEMBRANE CLEANING PROCESS

The water treatment plant at Ameren Energy Resources' Newton Energy Center was constructed and commissioned in 1997. The plant consists of membrane filtration (MF) followed by reverse osmosis (RO) treatment. The overall system is designed to provide the power plant with up to 300 gallons per minute (gpm) of high-purity water for use in the steam generator/turbine systems. The overall quality specification from the water treatment plant is for the purified water to have a minimum resistivity of >17 megohm-cm, with dissolved silica and sodium concentration <5 parts per billion (ppb) (micrograms per liter [µg/L]).

The water plant treats raw water from Newton Lake, a manmade cooling water lake. The lake water has low salinity, about 200 parts per million (ppm) (milligrams per liter [mg/L]) of total dissolved solids (TDS), total hardness of 90 ppm (mg/L), alkalinity of 80 ppm (mg/L), and dissolved silica below 2 ppm (mg/L). The raw water periodically contains around 4 ppm (mg/L) of dissolved total organic carbon (TOC), and 15 ppm (mg/L) of total suspended solids (TSS).

The pretreatment system consists of two ceramic microfiltration units, each unit with a filtrate capacity of 200 gpm (45 cubic meters per hour [m^3/h]). The RO system consists of two parallel trains, each rated at 150 gpm (34 m^3/h) permeate flow.

From the time of initial startup of the RO system, fouling of the membranes has been a continuous problem, and many attempts have been made to 1. characterize the fouling materials; 2. either prevent the fouling or clean the membranes. Primarily, the first-stage membrane elements have tended to foul with a colloidal organic material that most likely originated from biological activity in the membrane unit.

While some success has been achieved, the issue has never completely been resolved. During the spring and summer, chemical cleanings can be required on a weekly basis.

The Direct Osmosis-High Salinity (DO-HS) process has been implemented to control biofouling and reduce the frequency of membrane cleaning. The effectiveness of DO-HS process was initially tested on one RO train (Train B) for a period of 6 months. The operational results indicated significant effectiveness of the DO-HS process in suppressing feed-concentrate pressure drop increase and extending the operational interval between cleanings. Subsequently, the DO-HS process application has been extended to the second RO unit.

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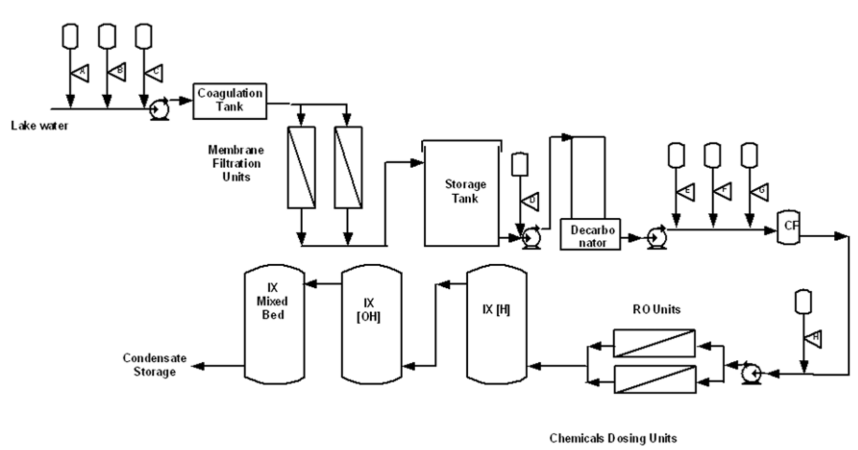
Water Treatment Process

The configuration of the water treatment system is shown schematically in Figure 1. The raw water, pumped from the Newton Lake, is filtered through a membrane filtration system employing of ceramic membranes. Prior to membrane filtration, sodium hypochlorite, an aluminum-based coagulant, and a cationic polymer are injected into the influent. The presence of a coagulant in the feedwater prior to membrane filtration increases the operational time between backwash steps. Membrane filtration operates at a feed pressure of 75 pounds per square inch gauge (psig) (5.2 bar) at a nominal filtrate capacity of 350 gpm (79 m^3/h). The filtrate effluent has a turbidity below 0.2 Nephelometric Turbidity Units (NTU). The filtrate flows from the membrane filtration units to the 400,000 gallons filtrate water storage tank. From the storage tank, the filtrate is pumped to a decarbonator to remove excess carbon dioxide (CO_2). From the decarbonator clearwell, water is pumped



Chemicals Dosing Units

Tag	Chemical	PPM	Tag	Chemical	PPM
A	Sodium Hypochlorite	2 residual	E	Sodium Hydroxide	pH = 8
B	Aluminum Chlorhydrate	80	F	Isotiazolin	8
C	Cationic Polymer	10	G	Scale Inhibitor	2
D	Sulfuric Acid	pH = 6	H	Sodium Bisulfite	

Figure 1. Flow diagram of the water treatment system.

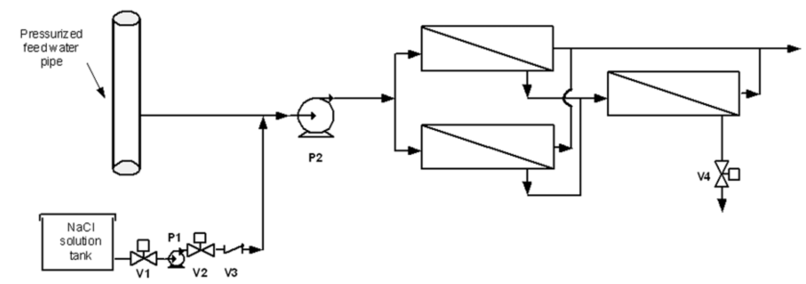


Figure 2. Configuration of an RO membrane system with a DO-HS unit.

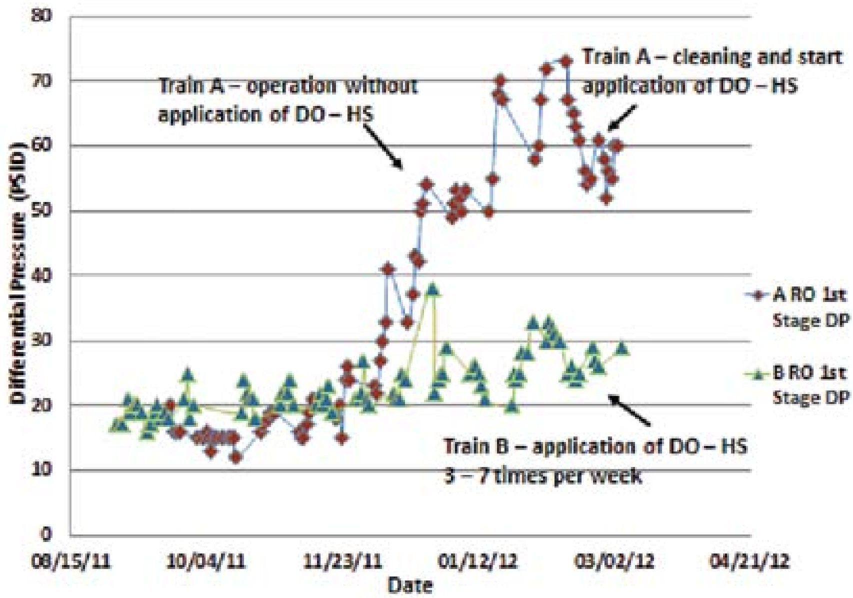


Figure 3. Pressure drop across Train A and Train B during verification of the DO-HS process.

through cartridge filters to the suction of the high-pressure RO feed pump. Figure 1 shows a flow diagram of the high-purity water treatment system.

A scale inhibitor, isothiazolin disinfectant, and sodium hydroxide are added to the RO feedwater before the cartridge filtration unit. Isothiazolin is added to suppress biological activity. The addition of sodium hydroxide results in an increase of the feedwater pH to 8. Increased feedwater pH improves the rejection of silica and alkalinity in the RO units.

At the suction of the feedwater high-pressure pump, sodium bisulfite is added to eliminate free chlorine. Two RO membrane units, identified as Train A and Train B process the pretreated feedwater. Each train is configured as a two-stage, 4:2 pressure vessels array with 6 membrane elements per pressure vessel.

The RO membrane units operate at a recovery rate of 75% to 80%, and a new/clean feed pressure of 175 to 200 psig (12.1 to 13.4 bar). The RO membrane units employ 400 square feet (ft^2) (37 square meters [m^2]) of spiral-wound membrane elements, resulting in an average permeate flux of 15 gallons of permeate per square foot of membrane per day (gfd), or 25.5 liters of permeate per square meter of membrane per hour (Lmh). Currently, low fouling membrane elements are being used in Train A and standard type membrane elements in Train B.

Prior to implementing the DO-HS process, cleaning was applied at an average frequency of every 4 to 6 weeks. Timing for membrane cleaning was based on an increase of pressure drop and loss of membrane permeability. Many attempts at in-place cleaning have been made, using numerous different cleaning protocols, with minimal success.

High pH cleaning formulations were more effective in recovering part of the lost permeability. Some success was experienced with removing the membrane elements, shipping them offsite for cleaning, and then returning them to service. Generally, each time this was done, 10% of the membrane elements sent off would fail post-cleaning tests and would need to be discarded. Typically, a set of membrane elements would need replacement every 12 to 18 months.

The DO-HS Process

The DO-HS treatment, US Patent 7,658,852 (1, 2), uses injection of a high-salinity solution, usually sodium chloride (NaCl), into the feedwater stream to an RO or nanofiltration (NF) membrane unit. The mechanism of the process and its merits has been discussed in a number of publications (3-8).

The typical configuration of an RO system that uses the DO-HS process is shown in Figure 2. In this configuration, the high salinity solution is pumped from the NaCl storage tank by pump (P1) and injected into the suction of the high-pressure feed pump (P2).

The injection of the NaCl solution is conducted while the RO unit is in operation. The injection lasts 10 to 15 seconds and is commonly applied at a frequency of 3 to 7 times a week.

During normal RO unit operation, the applied pressure (gauge), produced by the feed pump, is higher than the osmotic backpressure of feed-concentrate stream. In the RO membrane unit at the Ameren Energy Resources' Newton Energy Center, the difference between the inlet gauge pressure, 265 psig (18.3 bar), and the osmotic backpressure of 5 psig (0.3 bar), provides a net driving pressure (NDP) of 260 psig (17.9 bar). This NDP drives part of the feed stream through the membrane as permeate.

During application of the DO-HS treatment step, a pulse of say 5% NaCl solution flows through the membrane unit having an osmotic backpressure of around 550 psig (37.9 bar) and resulting in a localized excess of osmotic pressure, above the feed pressure, of: 550 to 265 psig = 285 psig (19.6 bar). The excess of osmotic pressure drives permeate through the membrane in the reverse direction, lifting fouling deposits from the membrane surfaces.

It's important to note that osmotic pressure is not gauge pressure. In reality, there is always more gauge pressure on the feed side of the membrane compared to the permeate side of the membrane during the DO-HS membrane cleaning procedure. Therefore, there is no delamination of the membrane or other negative effects that will occur if the permeate-side gauge pressure exceeds the feed-side gauge pressure.

As the high-salinity pulse moves along the membrane surface, it sweeps the lifted material and flushes it out of the membrane unit into the concentrate stream. At the same time, the high salinity pulse dehydrates bacteria that are used to living in lower osmotic pressure water. This effect of high salt concentration on bacterial population in the membrane unit is the same as the well-known "salting" process applied for food protection for thousands of years.

Following an initial feasibility and technical evaluation of the Newton Energy Center's (NEC) RO units by the David H. Paul, Inc., author Mark Wilf, Ph.D., provided the process design to NEC's Mr. Harold Stansfield. In the end, it was determined that the best installation would be to use the existing RO cleaning tank and pump and to add appropriate piping and valves to inject the brine solution into the RO feed pump suction line.

DO-HS Testing Schedule

The testing plan was to treat one of the RO units with the DO-HS process whenever it was in service, and to hold the other RO unit as a control to indicate what fouling might develop during the testing period. After a period of time, if successful, then the DO-HS process would be performed on both RO units.

Both RO units had relatively new membrane elements in place. Train A uses low-fouling membrane elements. Train B used standard brackish water membrane elements. Membrane elements in both units have 400 ft^2 (37 m^2) of membrane area. As a side note, it is worthwhile to mention that the low-fouling membrane element used in Train A was selected after testing demonstrated longer operational intervals between cleaning with these membrane elements as compared to standard membrane elements.

At the time testing began, the decision was to use the Train A as the untreated control and to DO-HS treat Train B when it was running. The typical operating cycle at the Newton Energy Center is to operate an RO unit for 7 days, remove it from service and place the other RO unit in service. This cycling of RO units is generally performed on Saturday evenings. The RO unit that is offline receives regular offline flushes with DI water to protect the membrane elements from biological activity.

Starting on Oct. 15, 2011, the DO-HS treatment was applied to Train B 3 times per week. Starting from middle of November, the frequency of DO-HS application was increased to 7 times per week, while the RO system was in service. Train A was left untreated as the control. By mid-December, there was a rise in differential pressure and a loss of normalized flow in Train A, and the decision was made to start treating Train A as well starting on Dec. 19, 2011.

DO-HS Testing Results

The verification of the efficacy of the DO-HS process for controlling membrane fouling at the Newton Energy Center RO system was conducted during the period of October 2011 through March 2012. The pressure drops across Train A and Train B during that period are shown in Figure 3.

Both membrane units were operated on the same feedwater stream and at similar process parameters of permeate flux and recovery rate. As shown in Figure 3, pressure drop in Train B shows a slight upward trend over a period of 6 months of testing, in the range of 10 psig (0.7 bar). The pressure drop across Train A shows a huge increase in pressure drop during the same period, about 50 psig (3.4 bar). At the end of the verification period, membrane elements in Train A were cleaned and the DO-HS process was implemented for Train A as well.

Injecting a high salinity NaCl solution into the feed stream results in an increase in permeate salinity for around one minute. Higher permeate salinity could affect the operation of downstream ion-exchange units. To date, the plant indicates that the impact is minimal due to the brief period of increased permeate salinity.

During the DO-HS process verification period, the injection of NaCl solution has been conducted manually; however, the process can be fully automated. Overall, the DO-HS process has been found to be simple to integrate into the configuration of the existing RO systems and easy to apply.

DO-HS Procedure Benefits

It is very common for RO units operating on pretreated surface water (either directly or from municipal drinking water) to experience significant biofouling. Depending upon many factors, including feedwater temperature, TOC concentration, chlorination-dechlorination, and design/operational factors, it is common for organic/biofouling to be significant enough to require chemical cleanings every 1 to 6 weeks.

It is also common that with significant organic/biofouling chemical cleanings become progressively less effective. High fouling rates result in the following:

- Higher chemical cleaning costs
- Higher waste neutralization and/or waste discharge costs
- Higher labor costs (overtime)
- Higher electrical cost due to higher feed pressure requirements
- Higher permeate conductivities with higher downstream effects/cost
- More downtime
- Higher membrane element costs (more frequent replacement)

The DO-HS procedure has been shown at the Ameren Energy Resources' Newton Energy Center as well as at other facilities to control fouling in a cost effective manner. The benefits of DO-HS are the opposites of the last list.

- Lower chemical cleaning costs
- Lower waste neutralization and/or waste discharge costs
- Lower labor costs (overtime)
- Lower electrical cost
- Lower permeate conductivities

- Lower downtime
- Lower membrane element costs

Benefits for the Energy Center

The annual cost savings as the result of using the DO-HS membrane cleaning procedure at the Newton Energy Center are currently projected to be around $30,000 or more per year. This is based upon the following:

1. Decreased use of proprietary cleaning products (50%): $6,000 per year

2. Decreased use of RO biocide (50%): $6,000 per year

3. Extend life of RO membranes (2 to 4 years): $20,000 per year

Actual savings will be documented and published after a year of using the DO-HS membrane cleaning procedure. From results at other facilities, it is likely that the savings will be significantly higher because of these reasons:

- Reduced energy costs due to lower feed pressures (were not included above)
- Greater reduction in chemical cleaning frequency is likely
- Elimination of biocide injection is likely

One other significant reason why cost reductions will likely be greater is because the system has not been fully optimized. Due to pumping limitations, the maximum concentration of NaCl measured during the 6 months of testing was 4.5%. The ideal is to achieve a 7% concentration for 2 seconds. Parts have been ordered and will be installed in June. With such excellent results at 4.5% NaCl concentration, the benefits will be even greater when the optimum concentration is achieved.

Conclusion

The DO-HS membrane cleaning procedure has been patented in the United States. This article presented the findings of one of the first plants in the United States to be licensed to use the DO-HS membrane cleaning procedure.

The plant had the unique opportunity to evaluate the DO-HS procedure by comparing the performance of two identical RO units operating on the same feedwater; one with DO-HS injections, and one without. The RO unit with DO-HS injections performed much better than the other RO unit. This is especially interesting as the RO unit without DO-HS injections was loaded with "low-fouling" membrane elements.

Also of interest was that the DO-HS procedure was highly successful at a 4.5% NaCl solution, which is significantly less than the optimal 7% concentration. Optimization should occur in June 2012, and a future paper will document the results.❑

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Coauthor Mark Wilf, Ph. D., has been involved in process development, system design, project execution, plant operation, and maintenance of large, commercial desalination plants in the United States, Europe, and the Middle East since 1977. He is a regular contributor to professional journals, and has written chapters on membrane technology processes and applications for a number of technical books. Dr. Wilf regularly presents and teaches desalination and membrane technology subjects to engineers and water professionals.

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