Case History of a Water Treatment System in Puerto Rico

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IWC-09-11

KEYWORDS: Reverse Osmosis; Electrodeionization, Silica, Ion-Exchange, Membranes

ABSTRACT: This paper will review the lessons learned in designing, commissioning and operating a water treatment system consisting of depth filters, antiscalant feed, and cartridge filters as pretreatment, followed by a single pass reverse osmosis system and polished with a single pass electrodeionization system for a 300 MW, combined cycle co-generation power plant in Puerto Rico. This paper shall provide background on equipment selection, unit operation, water quality issues, system rework, operational problems, system profiling and validation protocol.

Special consideration will be placed on profiling the reverse osmosis system (ROS) and electrodeionization (EDM) system performance due to radical changes in feed water quality.

INTRODUCTION

Most gas turbine plants and combined cycle co-generation applications use either water injection or steam injection into the combustion zone to reduce the emission of nitrogen oxides (NO_x) in the exhaust.

For simple-cycle installations, water injection control is the most widely used means for controlling NO_x emission. For combined cycle co-generation, where waste heat from the exhaust of the gas turbine is used to produce steam either for process or combined-cycle electrical power generation, either steam injection or water injection is used to control NO_x. Some gas turbines can accept massive quantities of steam injection (relative to that required for NO_x, control) for both power augmentation and heat rate improvement.

Gas turbines require high purity water for injection into harsh environment of the combustion zone. Today, turbines manufactures have established guidelines for the water and steam purity used for injection into the gas turbine. Typical Gas Turbine Injection Water Requirement is illustrated below:

TABLE 1 – TYPICAL GT INJECTION

Parameters	Limits	ASTM
Total Solids	5 ppm	D5907
Dissolved Solids	3 ppm	
Sodium	0.10 ppm	D2751
Silica	0.10 ppm	D589
Particle Size	10 max	F312
Conductivity (micro/cm)	1.0 max	D5391
	1.5 max	

If these water and steam requirements are not meet, serious damage can occur in the gas turbine's hot section.

To meet these stringent requirements, it is necessary to provide process makeup to the gas turbine or boiler that meets the requirement of 3 part per million (ppm) of total dissolved solids (TDS). Lower boiler water silica concentrations are particularity important in steam-injection application applications for high-compression-ratio gas turbines (requires stream pressure above 600 pounds per square inch (psig), since silica will become volatile at high boiler pressures and will pass through moisture separators and deposit on turbine components.

BACKGROUND

The traditional approach to producing high quality water for co-generation plants historically uses two-bed ion-exchanger (TB-IXS) systems followed by a polishing mixed bed ion-exchange system (MB-IXS). This process requires using, handling and storing acid and caustic for ion-exchange resin regeneration. Plus the waste generated from these systems requires pH adjustment, typically to 6 to 9 before it can be discharged. The cost associated with providing a bulk chemical handling facility and a neutralization system has a tremendous impact on new Greenfield plants. This cost combined with the limitation on space, environmental and safety issues of dealing with chemicals, obtaining discharge permits, and waste handling; all has a major impact when selecting the water treatment system.

The remarkable advancement and market penetration of membrane technologies being used as both pre and post treatment water treatment systems have grown steadily. The original introductions of Reverse Osmosis Systems (ROS) were plagued with performance, reliability, and operational problems. Once these issues were properly addressed and resolved, the commercial re-introduction of the RO membranes lead to the rapid growth of existing systems being retrofitted with Reverse Osmosis Systems being used as pretreatment in lieu of the traditional two-bed (IX) system. With the introduction of thin-film composite (TFC) type membranes, current ROS operate successfully at 85% recovery at less than 150 psig, and the RO elements may last longer than 5 years with infrequent cleaning. The use of RO systems in place of the traditional two beds (IX) has had a major impact in the decline of chemical usage at many operating facilities.

The limited ability of existing technology to cost effectively meet the requirements of high purity water production in a chemical free environment offers a significant market opportunity for the introduction of electro-deionization (EDI). The current generation of the RO membranes works very well as a pretreatment roughing process for total dissolved solids (TDS), particulates, and total organic carbon (TOC) reduction. Many applications require further deionization, which was frequently done by mixed bed ion-exchangers (MB-IXS), although they required chemicals and produce large volumes of waste water that needs to be neutralized. The recent re-introduction of electro-deionization (EDI) technology that has the ability to produce high purity water without chemicals has again revolutionized the industry were EDI now replaces MBS-IXS for co-generation, power and semiconductor application requiring high purity water.

DESIGNED WATER QUALITY

Feed water for this co-generation system is surface water supplied from the local Municipal Water Treatment Plant on the island, which is pre-filtered and chlorinated. The feed water source is crucial to the operation of the water treatment system. The equipment and size are determined by the feed water analysis. Other considerations are the product flow rate and process water quality requirements.

Well water is high in mineral content, low in biological and organic content, and usually requires simple pretreatment. Surface water is usually low in mineral content, but is very high in organic and biological content, and usually requires extreme pretreatment. The organic content is subject to seasonal variation. The changing feed water means that unit operation of the treatment system must be monitored and operated efficiently to overcome the variation in organic loading.

The Designed Feed Water Analysis limits are based on a ten (10) year average. This water is characterized by very low levels of Alkalinity, plus no data on Silica, Sodium, Turbidity, and Organics were provided. In addition, the Total Cations do not match the Total Anions as $CaCO_3$. The missing data is a source of problems that could later cause problems with the operation of this water treatment system.

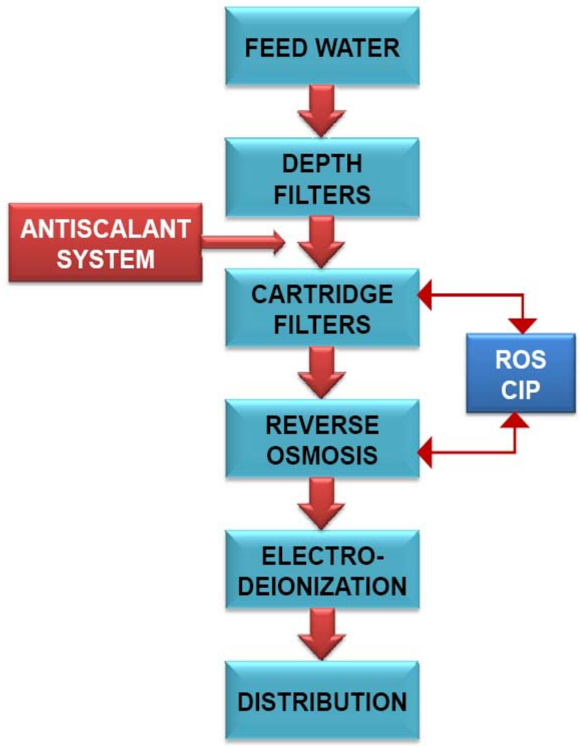
TABLE 2 – DESIGN WATER QUALITY

Cations	$CaCO_3$	Anions	$CaCO_3$
Ca	107	HCO_3	0.1
Mg	35.4	SO_4	1.0
Na	0	Cl	140*
K	0	NO_3	0.3
TC	142.2	TA	142.2
		SiO_2	0
pH		CO_2	8.7
* added to balance		TA(A)	150.7

SYSTEM DESIGN

Water Treatment System (WTS), consisting of a Reverse Osmosis (ROS) combined with an Electrodeionization (EDI) System. This system will be provided with a Depth Filter System (DFS), Antiscalant Feed System (AFS) and Duplex Cartridge Filters (CFS) as pretreatment. Other ancillary equipment was provided as required to make this system a complete and workable system.

FIQURE 1–WATER TREATMENT SYSTEM



The Depth Filtration System (DFS) is designed to reduce turbidity, suspended solids, chlorine, and total organic carbon from the water supply at the design flow rate. This pretreatment depth filter system consists of three different grades of media, which includes acid wash carbon, anthracite, and garnet. The activated carbon adsorption media is widely used to remove both chlorine and organic matter. Removal of chlorine reduces odor and prolongs the life of the ROS elements and EDM modules. Removal of organics reduces the toxic compounds, and the TOC. The anthracite is a highly metamorphosed variety of coal and is a more stable carbon with about 90 to 98 percent, with less than 8 percent of volatile matter making it the best media to effectively provide for depth filtration. Garnet is well known for its hardness and durability. It has a high specific gravity as well as its chemical and abrasive resistance makes garnet an ideal filter to provide surface filtration,

allowing filtration to 3 micron or less.
Advantages of Media Selection:

- Different specific gravity allows unique filter designs. In combination with other filter media both higher flow rates, higher loadings and better filtration can be achieved.
- Different media provides for depth filtration, chlorine removal, TOC reduction and surface filtration in a single vessel.

Without the means of scale inhibitors, reverse osmosis systems membranes would scale due to the precipitation of soluble salts. Some common examples of scale are calcium carbonate, calcium salts, barium sulfate, and strontium sulfate. The effect of scale on the permeation rate of the membranes follows an induction period. The length of the induction period varies with the type of scale and degree of supersaturating. Based on the feed water analysis provided, this system required an antiscalant treatment for calcium carbonate and sulfate scales. This product is used for surface waters that contain colloidal solids and silt.

Cartridge filters are provided, designed at 3 gpm per 10" equivalent. Five (5) nominal micron polypropylene elements with double O-rings to assure proper fit will be provided. This system is the ROS pretreatment filtration equipment designed to remove turbidity, particulates and reduce the feed water Silt Density Index (SDI). This type of element will allow for depth filtration, and along with the pretreatment filter will provide adequate filtration to the ROS system.

Various types of computer modeling software are utilized to create and verify ROS designs, including process modeling. For this application, high quality TFC membranes were selected. The ROS system design is an 8 x 5 x 2 array at 85% recovery. The feed water design flow is 366 gpm, producing 311 gpm permeate and resulting in 55 gpm reject at the design temperature of 85^{0}F.

From experience, we know that manufacturer's computer modeling programs are slightly conservative with regards to actual operating experience; therefore, we take the output from the model at "face-value" and use them in our designs. The complete output from the RO simulation program is illustrated.

FIQURE 2–ROS OVERVIEW

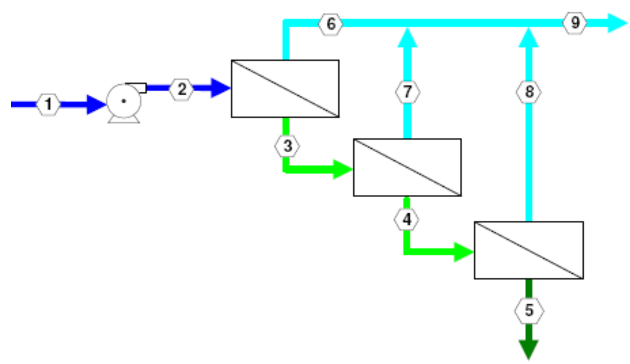


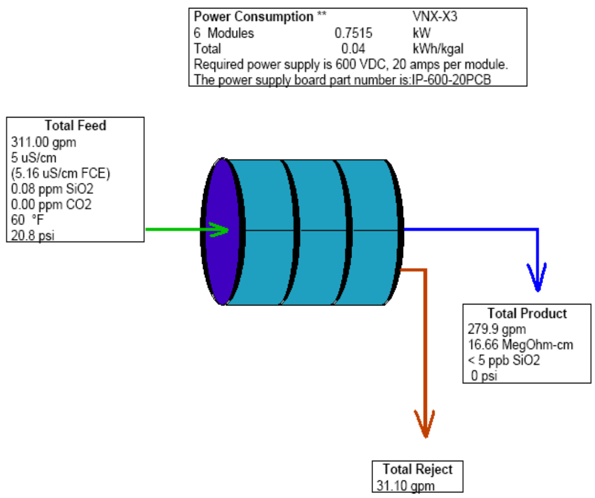
TABLE 3 – ROS PROJECTION

		1	2	5	9
Flow	gpm	366	366	55	311
Press	psig	30	160	101	60
TDS	ppm	309	309	2043	2

In addition, the EDI module was utilized as the polishing unit to enhance water quality to the standards required for this application. At the heart of this system is advancement on conventional ion exchange technology in which the ion exchange resins are continuously regenerated through the use of an imposed electric current making the process chemical-free. *Previous versions of EDI technology required the concentrate flow to recirculation through the EDI module and sometimes inject a salt brine solution to increase concentrate conductivity. The latest EDI technology provided no longer requires concentrate recirculation or brine injection.*

The complete output from the EDI simulation program is provided. A review of this model verifies that the EDI system design has the proper design flow rates, which leads to a reduction in chemical cleaning and longer membrane life.

FIQURE 3 - EDI SYSTEM PROJECT



The EDI system will produce a permeate flow of 280 gpm. The system requires a feed rate of 311 gpm combined with a 10% reject flow of 31 gpm. The EDI permeate will pass down stream to the client supplied storage tank at 60 psig.

FACTORY ACCEPTANCE TEST

The system was run and provided with a complete Factory Acceptance Test (FAT) at the manufacturing shop prior to shipment. A 5,000 gallon storage tank was filled with demineralized, city water at a feed rate of 366 gpm to produce an EDI permeate of 280 gpm. Permeate and reject waters were recirculated to allow continuous running of the system. Only the silica and sodium analyzers were run but not calibrated, all other instruments were calibrated at the factory. Several of the EDI power supplies were found to overheat and required replacement before shipment. Minor problems found during the FAT were identified and corrected at the factory before shipment.

SITE ACCEPTANCE TEST

At the site, the system was provided with a full Site Acceptance Test (SAT) and the following items illustrated in Table 4 were determined as problems.

TABLE 4 – SITE ACCEPTANCE TEST (SAT) ISSUES

High Permeate conductivity from last two RO membrane housings
• Replaced RO Membranes
ROS permeate conductivity cell leaking
• Repair leaking connection on RO permeate conductivity cell
Sodium & Silica analyzers' – No 4-20 ma signal
• Install Conditioner
EDI not meeting water quality requirements due to RO problems, feed water quality changes and operating problems with the EDI membrane. EDI transformer was overheating.
• Continue running with increased pH – may need a full day to fully regenerate. The system needed to be run 1-3 days for silica to reach it's optimum value. • Need to increase pH to 8.6 – 8.8 • Inlet silica is too high as a result of RO problem with permeates port o-rings in last 2 housings. • Replace all 20 amp fuses with 30 amp fuses. • Installation of fans were required in the EDI panel were required to keep the transformer from overheating.

SYSTEM COMMISSIONING PROBLEMS

The Water Treatment System (WTS) plant has experienced at least two adverse conditions related to water quality since startup. First, the raw water has higher than expected concentrations of impurities, and second, the administrative limits for demineralized product water, have been exceeded.

TABLE 5–FEED WATER QUALITY CHANGES

Parameter	Proposed	Actual	Increased
Alkalinity	0.1 ppm	142 ppm	130K %
Hardness	107 ppm	154 ppm	44 %
Silica	10 ppm	19 ppm	88 %
pH	7.4	7.7	--------

Secondary contributors to this issue include lower than expected silica rejection by the RO membrane elements, and mechanical failure in one of the six EDI units. This document explores issues related to these conditions and offers potential solutions

After several weeks of operation in the normal and recycle mode (over 2 Mgal through put) the WTS plant continued to exceed product water quality limitations. Investigation into this issue identified higher than expected concentrations of impurities in the raw water as the primary reason for poor product quality.

The RO feed water quality and permeate impurity concentrations are proportional to one another *(membranes are not 100% efficient; therefore, a small portion of the impurities pass through the membranes)*; therefore, increased concentrations of impurities in the feed means that there is going to be increased concentrations of impurities in the permeate. Raw water analysis indicates higher calcium carbonate, alkalinity and silica concentrations than design.

Further, alkalinity converts to carbon dioxide (CO_2) at the RO operating pH's, thus causing it to pass through the membranes and impact the performance of the downstream EDI.

This is causing excessive carbon dioxide, which may be keeping the EDI resistivity low and silica high.

Sodium hydroxide addition was added to remove carbon dioxide and improve EDI performance**.**

REVERSE OSMOSIS SYSTEM REVIEW

The modeling software from the RO membrane manufacturer predicted 2% passage of the silica from the feed to the permeate. In actual operation, approximately 2.7% to 3.5 % of the silica is passing through the membrane. The increased silica feed concentration and silica passage leads to silica concentrations in the RO permeate that are too high for the downstream EDI system.

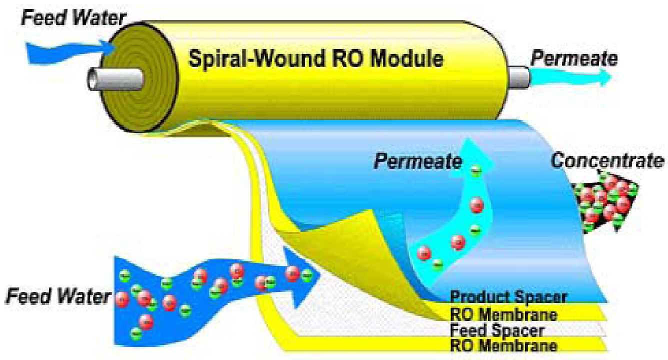
The WTS plant is designed to produce approximately 280 gpm of demineralized product water. The final water treatment component is the EDI and it is comprised of 6 separate EDI units that operate in parallel at approximately 46.7 gpm each. One of the six EDI modules was damaged.

During startup, the WTS plant was never operated at more than 250 gpm in an effort stay within the operating range of the 5 EDI units. Operating the RO at this lower flow lead to increases in impurities in the permeate. The 6^{th} EDI module has since been replaced and flows are back to their design values; therefore, this is no longer an issue.

The damaged EDI reduced flows throughout the WTS plant by approximately 46.7 gpm.

On the surface, one would think that reduced flows would be good for product water quality, but that is not the case for reverse osmosis. The following paragraphs describe the importance of flow for optimizing performance.

FIQURE 4 - ROS MEMBRANES



ROS membranes are hydraulically designed for cross-flow versus a cartridge filter, which would be straight-through or dead-end filtration. The pressurized feed stream enters the RO membrane and flows parallel to the membrane surface as shown in the following illustration.

A portion of this stream passes through the membrane *(creating the permeate)*, leaving behind the rejected particles in the concentrated remainder of the stream. Since there is a continuous flow across the membrane surface, the rejected particles do not accumulate but instead are swept away by the concentrate stream, which becomes the RO reject.

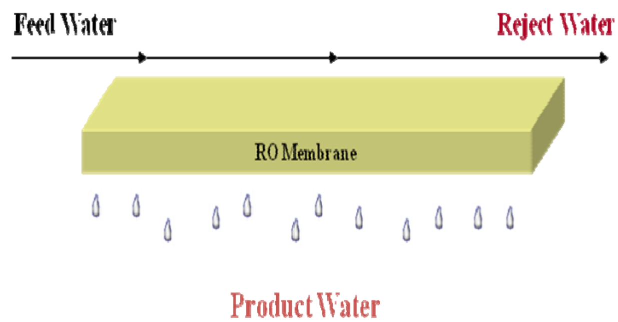
It is important to maximize the cross-flow velocity in the membranes. Conservative designs maximize the cross-flow velocity of the feed and concentrate streams. A higher cross-flow velocity reduces the concentration of salts and foulants at the membrane surface by increasing their diffusion back into bulk feed stream above the membrane surface.

If cross-flow velocities are too low, then a thick layer of impurities forms at the membranes surface *(boundary layer)*, which leads to reduced product water quality and a higher probability of scaling.

The increased recycle recovery combined with a cross-flow that is too low to create the flow turbulence necessary to *sweep-away* impurities leads to reduced permeate quality.

Flux is the membrane throughput, expressed in volume of permeate per unit time per unit area. The units are typically Gallons per square Foot per Day (GFD). The design flux of the RO is 12.4 GFD. This means that on average, 12.4 gallons of permeate are produced by 1 square foot of membrane over a 24 hour continuous operating period. Pictorially, if you assumed the following RO Flow Projection was 1 ft^2 of membrane, and then it would produce 12.4 gallons of water in one day.

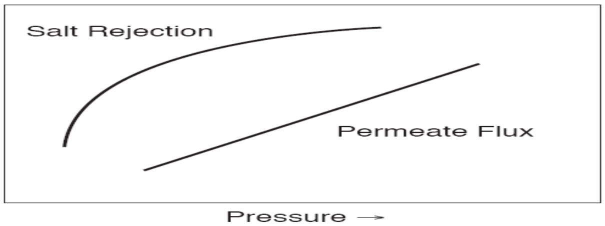
FIQURE 5 - ROS FLUX PROJECTION



The principle of RO is based on the solution - diffusion model, which states that water transport is a function of the net driving pressure and membrane water permeability, salt transport is function of the concentration differential and the membrane salt permeability. Salt flux divided by water flux equates to the permeate concentration. Relatively speaking, this means that salt transport is not pressure or flux dependent, but water transport is highly pressure/flux dependent.

This principle is illustrated in the following graph from the membrane manufacturers' technical manual.

FIQURE 6 – EFFECT OF FEED WATER PRESSURE ON SALT REJECYION & FLUX



Operation of a membrane system at higher fluxes results in lower permeates salt concentrations and a better permeate quality. At the lower recycle permeate flow of 243 gpm, the average membrane flux is 9.7 gfd, which is approximately 22% lower than the design flux of 12.4 gfd. This lower flux allows the ratio of salts to water in the permeate to increase, thus lowering the RO permeate quality.

ALKALINITY REVIEW

Alkalinity is a combination of carbon dioxide, bicarbonate, carbonate and hydroxide, and the percentage of each one of these constituents is pH based. The following paragraphs discuss the impacts of alkalinity on RO performance.

Operating a reverse osmosis system at a lower pH negatively impacts the throughput of downstream ion exchange components due to increased amounts of carbon dioxide (CO_2) in the RO permeate. CO_2 is a gas and RO's don't reject gases; therefore, at lower pH's a good portion of the CO_2 ends up in the permeate or product water. Once the CO_2 encounters the high pH's surrounding the downstream anion resin membrane in the EDI, it is converted back to the ionic bicarbonate (HCO_3) and removed by ion exchange.

There are three reactions that govern the chemistry of CO_2 in water, increasing pH drives the reaction:

1. $CO_2 + H_2O \leftrightarrow H_2CO_3$ (carbonic acid)
2. $H_2CO_3 \leftrightarrow H^+ + HCO_3^-$ (bicarbonate ion); pKa = 6.38
3. $HCO_3^- \leftrightarrow H^+ + CO_3^{2-}$ (carbonate ion); pKa= 10.37

When gaseous CO_2 is dissolved in water, a portion is hydrated to form carbonic acid (First Equation). This carbonic acid dissociates into bicarbonate and hydrogen ions. At a pH of 4.3, very little of the carbonic acid is dissociated. At a pH of 6.38. the molar concentration of carbonic acid equals that of the bicarbonate and hydrogen ions. At a pH of 8.3, there is no longer any appreciable amount of CO_2 or H_2CO_3 present in the water. Above a pH of 8.3 pH, the bicarbonate ion is converted to carbonate and H+ as shown in the last equation. The H^+ is quickly consumed by the excess hydroxide (OH^-) at elevated pH's.

Impacts of CO_2 on ion exchange was expected to have the equivalent of 3 to 4 mg/L (ppm) of sodium chloride (NaCl) in the RO permeate based on the original feed water quality data, which showed very little alkalinity. Based on recent runs, we are encountering tens of ppm's of CO_2 due to the presence of over 100 ppm of alkalinity. This has placed and elevated ionic load on the EDI with has significantly reduced its product water quality.

The following calculations show the ionic load of the permeate stream. The original design was for an ionic loading in the range of 0.07 milliequivalents per liter (meq/L) as shown in the following calculation.

4	mg NaCl	**X**		meq	**=**	**0.07**	**meq**
	L		58.5	mg NaCl			**L**

After the start of onsite operations, it was identified that there was over 100 ppm of alkalinity in the feed water. In a reverse osmosis system, the alkalinity tends to convert to CO_2 *(due to pH changes caused by the membrane)*, which passes into the permeate. We have encountered over 10 ppm of CO_2 in the permeate which translates into a measureable ionic load for the EDI as shown in the following calculation:

10	mg CO_2	**X**		meq	=	**0.23**	**meq**
	L		44	mg CO_2			**L**

As can be seen from the following calculation, the ionic load from carbon dioxide alone is over 3 times that expected in the RO permeate:

0.23	=	**3.32**
0.07		

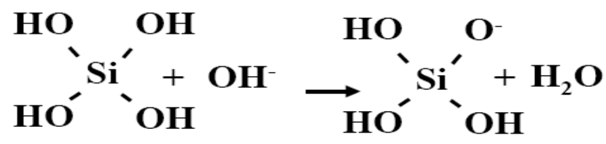
This loading has overwhelmed the EDI and reduced the quality of the product water. To correct the problem, sodium hydroxide can be added to increase the RO permeate pH to keep the alkalinity in the form of carbonate (CO_3) or bicarbonate (HCO_3) as shown in equations #2 and #3 above. Alkalinity is this form is ionic, versus a gas, and it can be rejected by the RO membrane.

Even though the sodium hydroxide aids by improving alkalinity rejection, it still places a higher ionic load than originally expected on the RO and EDI. Optimization will have to be performed onsite to identify ideal flows (RO/EDI recovery) and EDI amperage to efficiently produce the highest quality of water practical.

SILICA REJECTION

Silica can be present as a non-ionic or ionized compound. The non-ionized form is less efficiently rejected than the ionized (Silicate) form. The exact reason that the silica passage is slightly higher that the manufacturers' model is not known, but is not a typical for the salt passage to vary due to the varying forms of silica present in water.

FIQURE 7 – SILICA REACTIONS



Ortho-Silicic acid plus alkalinity yields Silicate ions

ACID INJECTION

The RO system is currently being operated at an elevated pH in order to remove carbon dioxide prior to the EDI system. Operating at an elevated RO feed water pH of approximately 8.4 in the presence of 150+ ppm hardness which will lead to membrane carbonate scaling and frequent chemical cleaning. The RO modeling software indicates that operating at a lower RO feed water pH of approximately 6.7 will eliminate the scaling potential. Therefore, it was recommend injection of sulfuric acid in front of the RO to lower pH to approximately 6.7. Components for injecting the sulfuric acid already exist; therefore, no further modifications to the equipment are necessary. Lowering the pH to 6.7 will require between 0.75 and 1.0 gallons per hour of 93% sulfuric acid. This option was not accepted by the client.

HIGH REJECTION MEMBRANES

An almost unlimited number of reverse osmosis membranes are available to optimize a wide variety of processing goals. The selected membranes were the TFC membrane rated at 11,000 gpd for this project based on the specified raw water characteristics. Based on the actual impurity concentrations encountered for this site, it was recommended to replacing the current TFC membranes with a TFC membrane rated at 10,000 gpd. The 10,000 gpd membranes is higher rejection membranes that will reduce the RO permeate silica concentration by over 50%.

The only disadvantage, is that it will require the RO feed pressure to increase approximately 40 psig in order to force the water through this tighter membrane; therefore, the RO feed pressure will increase from approximately 160 to 200 psig.

Fortunately, the raw feed water pressure is higher than the design anticipated and the RO booster pump has excess capacity; therefore, no further modifications to the equipment are necessary to accommodate these new membranes.

RECOMMENDATIONS

There are a multitude of options for improving the performance of the Water Treatment System at this plant. Rather than listing each one of these, we have streamlined the list to those actions we deem as most appropriate.

Accurate characterization of the raw water is imperative for proper membrane system design. It is recommended that a complete analysis be performed on the raw water on bi-monthly bases until the variability in the influent water is known.

Once an accurate feed water characterization has been provided, profile both the RO and EDI system to project leakage expected and take grab samples to evaluate the system actual performance versus projected performance. Profile of the RO and EDI is based on using new water quality data.

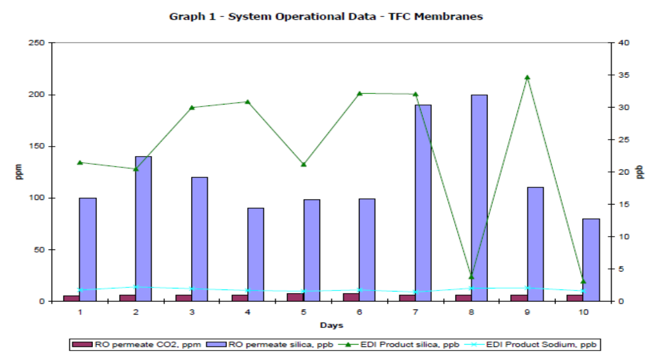
TABLE 6A – ROS PERFORMANCE TFC

Parameters	Feed Water	ROS – Calculated	ROS-Actual
Calcium	54.4ppm	400ppb	160ppb
Sodium	32.9ppm	1000ppb	----
Alkalinity	126ppm	280ppb	----
Silica	18ppm	200ppb	666ppb
pH	8.2	6.6	6.7

TABLE 6B – EDI PERFORMANCE

Parameters	Feed Water	EDI – Calculated	EDI-Actual
Calcium	54.4ppm	0	---
Sodium	32.9ppm	20ppb	86ppb
Alkalinity	126ppm	0	----
Silica	18ppm	20ppb	109ppb
pH	8.2	6-9	6-9

GRAPH 1, SYSTEM DATA TFC



The CO_2 & SiO_2 on the RO permeate in ppm, SiO_2 and Na on the EDI permeate are display in ppb.

RO MEMBRANES AUTOPSY

The "F-Test" was used to confirm that a polyamide (PA) thin-film membrane has been exposed to an oxidizing halogen, such as chlorine, bromine or iodine. The test analyzes qualitatively whether halogens have become part of the PA polymer structure through oxidative attack.

The presence of halogens in the membranes polymer structure is indicated by the formation of a pink color in the pyridine layer. The "F-Test" run on several test samples from both membranes was positive, indicating that the elements have been exposed to a halogen (probably chlorine).

The RO elements showed evidence of pouching delimination along the glue line edges. This type of damage is consistent with permeate back pressure damage.

High pressure and salt package is caused by halogenations of the rejecting membranes surface and the back pressure damage is further contributing to the poor performance

FIQURE 8 – RO MEMBRANE DELIMINATION

The "P-Test" is a polyamide membrane rejection enhancer. The formulation restorer's rejection to the RO membranes that have been oxidized. The application of "P-Solution" reduces salt passage by half. The typical treatment mode is to inject "P-Test" into the RO feed stream while the system is in operation, the best results are obtained under normal operating pressures. The beneficial effects of this treatment are immediate and last until the next RO clean.

Summary of the RO elements performance before and after treatment. Performance data were normalized to the manufacturer's published test conditions.

TABLE 7 – The "P-SOLUTION" RESULTS

Element	Treatment	Flow gpm	Rejection %	DP psi
Test #1	Pre	9.11	89.1	4
	Post	7.73	98.6	4
Test #2	Pre	12.8	91.6	4
	Post	8.8	98.8	4
Spec.		7.6	99.5	

EDI MEMBRANES AUTOPSY

The EDI system was not able to meet the projected performance due to a combination of factors and possibilities. The feed water is considerable higher in contaminants than originally designed. The CO_2 in the feed water is significantly higher due to lower pH and much higher alkalinity. During this stage of the evaluation, caustic injection was added to maintain a 1.5 ppm of CO_2. The conductivity increase was nearly double. Trouble shooting the RO resulted in two membranes being replaced. The EDI was not regenerating 15 plus meg-cm, less than 20 ppb silica for a number of possible reasons.

- EDI contains a limited amount of resin and resin sites for ion exchange. If the resin is saturated, it may take 24-48 hours of operation before it will be fully regenerated.
- The RO permeate is higher in ionic impurities than projected.
- The EDI resin could have lost some of its removal capacity.
    - Inadequate power supply
    - Resin is oxidized by chlorine
    - Resin is organically fouled
- The EDI concentrate outlet pressure must be maintained 3-5 psi less than the dilute outlet pressure.
- Water hammer could have damaged the membranes.
- Polarity of one or more modules is reversed.

One element was producing a much lower resistivity than the others and it was sent to the manufacturers for an autopsy.

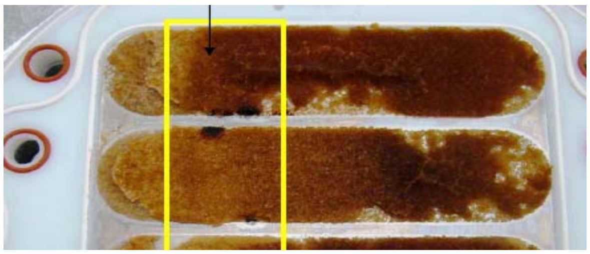
Their examination reported the EDI membrane had fail due to overheating.

Autopsy Observations:

- Inside PVC interconnector had whitish color - typical of heat damage.
- Minor burning in the resin
- Minor burning of membranes

Scaling of cathode & anion membrane

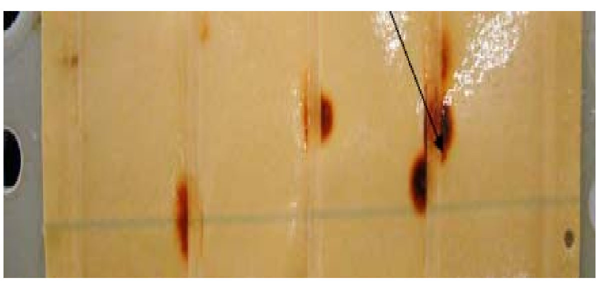
FIQURE 9 – RESIN BURNED EVIDENCE



Autopsy Observation:

- Membranes appears to have run for a short time with reduced or no water and with the DC power on

FIQURE 10 – MEMBRANES BURNED EVIDENCE



SYSTEM SOLUTIONS

The review of the system design when through many review, trails and tribulations. The client did not want to add additional equipment.

The WTS was land locked and it could not be altered, changed or moved without occurring major expense. The only real option was to find a solution that would work without adding equipment and process.

Once again, we looked at reverse osmosis membranes to determine which membranes were available to optimize a wide variety of processing goals.

Based on the actual impurity concentrations encountered for this site, it was that the TFC membranes were not providing adequate reduction in silica, despite manufacturer projection and should not be used.

The selected membranes were the seawater (SW) type membrane for this project based on the specified raw water characteristics. The SW membranes are higher rejection membranes that will reduce the RO permeate silica concentration by over 65% and do not require caustic feed for CO_2 control.

The only disadvantage of the SW membranes is that it will require the RO feed pressure to increase approximately 90 psig in order to force the water through this tighter membrane; therefore, the RO feed pressure will increase from approximately 160 to 250 psig.

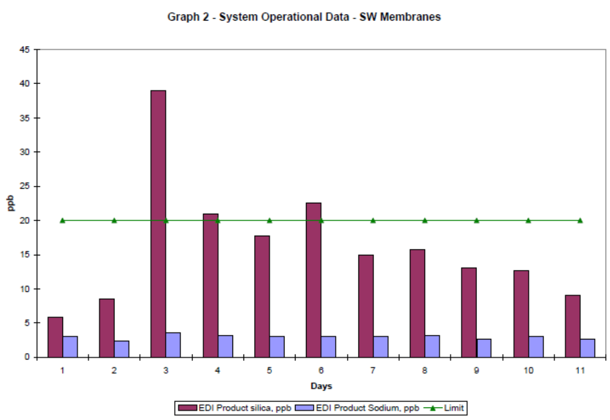
Fortunately, the raw feed water pressure is higher than the design anticipated and the RO booster pump has excess capacity; therefore, no further modifications to the equipment are necessary to accommodate these new membranes.

TABLE 9A – ROS PERFORMANCE SW

Parameters	Feed Water	ROS – Calculated	ROS-Actual
Calcium	54.4ppm	200ppb	160ppb
Sodium	32.9ppm	400ppb	257ppb
Alkalinity	126ppm	600ppb	----
Silica	18ppm	110ppb	80ppb
pH	8.2	5.8	5.9

TABLE 9B – EDI PERFORMANCE			
Parameters	Feed Water	EDI – Calculated	EDI-Actual
Calcium	54.4ppm	0	---
Sodium	32.9ppm	20ppb	3.3ppb
Alkalinity	126ppm	0	----
Silica	18ppm	20ppb	8.5ppb
pH	8.2	6-9	6-9

GRAPH 2, SYSTEM DATA – SW



The CO_2 & SiO_2 on the RO permeate in ppm, SiO_2 and Na on the EDI permeate are display in ppb.

CONCLUSIONS

In selecting the best overall system for a facility, one must consider specific site conditions and requirements. They should include the designed condition and cost associated with permits, engineering, equipment design, building, installation, operation, operating cost, environmental, and site personnel preference. No two facilities are identical enough to draw a straight recommendation without evaluating all the above factors.

For this site the lessons learned are as follows:

- Obtaining a good water analysis that covers all the key parameters to properly design, fabricate and operate the water treatment system is essential.
- Allow for flexibility in the design to account for seasonal feed water and operation changes.
- Always use a double pass RO system when employing EDI as the final polisher.
- Always think outside the box, many times the solutions are there it just requires someone to recognize them.
- Simply follow the data
- Stand firm with clients as to their discussion not to implement the best possible solutions.

REFERENCES

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2. Ion Pure, Electrodeionization Projections & Data Sheets
3. Avista Technologies, RO Membrane Autopsy Report
4. Ion Pure, Electrodeionization Membrane Autopsy Report
5. Energy Services, Inc. designed standards for Gas Turbine Water Injections