BRACKISH WATER RO AND NF OPERATIONS
ON HIGH TDS FEED WATERS

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Introduction

An increasing number of brackish water RO (Reverse Osmosis) and NF (Nanofiltration) systems are being designed and operated on high salinity brackish feed water sources which can range from 2,000 to 12,000 mg/l TDS (Total Dissolved Solids). Increased feed TDS can dramatically impact the design of the RO/NF in terms of hydraulic design, feed pressure requirements and in permeate quality. Issues discussed include hybrid RO/NF membrane system designs for improved hydraulic flux design, the use of ERDs (energy recovery devices), and the impact of higher salinities on the rejection of ions. Systems with improved hydraulic flux designs can reduce the rate of fouling and cleaning, be more energy efficient, and improve permeate quality. Systems with either feed-side or interstage energy recovery devices can be more energy efficient but the payback time period has to be reviewed. A discussion will be presented that the industry has not widely addressed and that is the observation of increased system salt passage with increased feed TDS and increased concentrate TDS at higher recoveries. The industry historically calculated salt passage based on temperature, membrane type, membrane age, and the composition of ionic species in the feed water. Improved calculations for salt passage address the three theoretical mechanisms of salt passage which are convection, diffusion and charge repulsion. In particular, the combined effects of feed ionic strength and membrane surface charge play an important role in the rate of salt passage. It is important that the RO system design projection programs account for the high TDS effect on membrane salt rejection. Two new case studies with high feed TDS feeds are presented which reviews how well design correlates with actual operations. The 1st case study is the 16-mgd 75% recovery North Miami Beach Norwood Oeffler water treatment plant which includes a 6-mgd hybrid RO system whose feed source is the 2900 mg/l Floridan Aquifer. The 2nd case study is El Paso Water Utilities, the world's largest inland desalination plant, has a rated plant output at 27.5-mgd with a 15-mgd 81% recovery RO system whose feed source is the 2000 ppm mg/l Hueco Bolson Aquifer.

Design Considerations for High TDS Brackish Feed Waters

For purposes of this paper, high TDS brackish feed waters have been identified to have feed TDS up to 12,000 ppm and can be treated by brackish water NF and RO membranes with feed pressures up to 450 to 600 psi (31 to 41.4 bar). As feed TDS increases over 12,000 ppm TDS, then higher pressure seawater RO membranes rated up to 1000 to1200 psi (69 to 82.7 bar) tend to be used to accommodate the higher feed pressures associated with over-coming the higher osmotic pressures that are generated.

The basic steps and design parameters to address in designing an RO/NF are:

- Define the target permeate quality. This is important in membrane selection.

- Define the quantity of feed water to be processed or permeate produced as this dictates the size of the system.
- Define the per cent recovery of feed water as permeate, as these impacts permeate quality, system hydraulics, concentrate TDS and osmotic pressure.
- Define the feed water source quality for determining pretreatment requirements and in selecting a suitable flux design that mitigates potential fouling.
- Define the feed water specific ions for determining osmotic pressure requirements and in determining specific ion rejections.
- Define the temperature range as the warmest temperature is the worst case permeate salt passage and the coldest temperature is the highest feed pump pressure requirement.
- Define the age of the system to project normal membrane degradation due to usage and cleaning, predict the rate of fouling using a fouling factor or annual % flux decline factor, and predict the annual % salt passage increase factor.
- Define the operating cost of energy and the pay-back time period to determine if the capital cost of an energy recovery device can be recovered.

The focus of this paper is to address the effect of high TDS feed waters in computer design projections and how this correlates to actual field operations.

Hybrid RO/NF Systems

High TDS feed water systems lend themselves to designing with hybrid RO systems, primarily due to the hydraulic flux imbalance created by the large osmotic pressure differential from the feed end to the concentrate end. A hybrid RO/NF system is one which uses a different set of RO/NF membranes from one stage to another stage or can use a different set of membrane types within a stage itself. Table 1 reflects the design opportunities available to the design engineer with the final membrane selection based upon the permeate quality required, the optimal feed pressure and energy requirement, and whether an interstage energy recovery device or booster pump is desired.

For comparison purposes, the feed TDS is 4,000 ppm, the recovery is held the same so that the concentrate TDS is basically the same at 20,000 ppm TDS, and the average of the feed and concentrate TDS is 12,000 ppm. The osmotic pressure of the feed is 46 psi and 210 psi when you get to the concentrate, all of which has to be overcome by the applied feed pump pressure before any water can be produced by the membranes. This wide differential in osmotic pressures of 164 psi makes it a challenge to create a design with good hydraulic flow and flux balances between stages. The design used all 8-inch diameter 400 sq.ft. elements in a two-stage 2x1-7M array with 3 pressure vessels and 7 elements per pressure vessel.

The flux for the system was 15 gfd and the flux for the 1st stage was 17.5 gfd and 10 gfd for the 2nd stage. Balancing the flux between stages has the advantages of spreading the rate of foulant deposition over the greatest membrane area and it also improves the final system permeate quality when the flux is increased in the later stages. To maintain the flux balance between stages, the design was operated with a 1st stage permeate throttling to generate sufficient permeate back-pressure as required to balance the flows. A typical rule of thumb for suitable flux balance between stages is not to exceed a 2 to 1 ratio. Another operating parameter used to establish flux balancing between stages is the desire not to exceed a minimum lead element flux rate based on the fouling potential of the anticipated feed water source and this can be found in the membrane manufacturer RO/NF design guidelines.

The design engineer can mechanically balance the fluxes by throttling the 1st stage permeate and as rule of thumb this is suitable up to 30 psi permeate back-pressure, after which serious consideration of operating cost savings can be realized by investing capital costs into an interstage ERD (energy recovery device) or pump & motor booster pump. It is important that if 1st stage permeate throttling is used, that the design does not allow the complete closure of the 1st stage permeate flow as this can result in irreversible membrane damage. The ERD typically in a brackish water system is a turbine-based ERD which boosts the 2nd stage feed pressure (or last stage depending on number of stages in the design) by recovering the energy from the high pressure final stage concentrate flow stream. Utilization of an ERD is typically based on a suitable return of capital investment and is not readily retrofitted once the system is installed as it requires capital cost, re-piping high pressure pipe, and down-sizing the RO feed pump to reduce feed pressure and improve pump efficiency. The use of an interstage booster pump would be used in the event that the ERD cannot produce sufficient boost pressure to create a desired final stage flux. There are design engineers who believe in balancing the stages with equal fluxes for the benefit of reducing the rate of fouling to a minimum.

It is noted that selecting the optimal membrane scheme for high feed TDS systems has a large number of parameters and design guidelines to address. There are design engineers who prefer to use only one type of membrane in their design for purposes of the operational flexibility of being able to move elements from one position to another in the field in the event of severe fouling situations or to minimize the spare element inventory required on site. A review of Table 1 highlights the advantages and disadvantages of membrane selection.

The 1st design of Table 1 uses a conventional design with all the same type of membrane and no ERD. In this case, it is a brackish LP-RO (low pressure reverse osmosis) which uses a low pressure membrane with high rejection and is rated at 9000 gpd at 99.6% NaCl rejection when tested at the factory under STC (standard test conditions) of 150 psi and 1500 ppm NaCl. Compared to the 2nd design which uses a hybrid SW-RO & LP-RO design, the permeate TDS is 44% higher and the energy requirement is the same at 3.44 Kw-Hr/1000 gallons of permeate produced. These low pressure/high flow elements require a significant 1st stage permeate back-pressure of 90 psi to achieve the proper flux balance. This could be the design of choice if the designer achieves his desired permeate quality, willing to add capital cost but save energy cost by using an interstage ERD, willing to add capital cost for an interstage booster pump to achieve a more equalized flux per stage, and wants only one type of membrane in all stages. This design has one advantage for systems that have high colloidal or biological fouling. Generally, this type of fouling occurs on lead elements. The loss of 1st stage product flow can be compensated by decreasing the permeate back pressure.

The 1st design of Table 2 adds an interstage turbine EDR device that would reduce the energy usage 24% from 3.44 to 2.8 Kw-hr/1000 gallons of permeate and make it the most energy efficient of the 1st 3 designs, but would still be the highest permeate TDS at 108 ppm and would still require 35 psi 1st stage permeate back-pressure to balance the fluxes to 17.5 and 10 gfd.

The 2nd design of Table 1 uses a hybrid approach with all SW-RO (Seawater RO) membrane in the 1st stage and all LP-RO elements in the 2nd stage and no ERD. The high rejecting SW-RO membrane is rated at 12,000 gpd at 99.8% NaCl rejection when tested at the factory under STCs of 800 psi and 32,000 ppm NaCl. The use of a high pressure seawater RO membrane in the 1st stage takes the energy required in 1st stage permeate throttling and converts it into the best permeate quality possible. The hybrid design of case 2 has the best permeate quality when compared to the 1st and 3rd designs by 44% and 33% respectively. The hybrid design has equivalent energy usage to the 1st design and 4% less energy usage than the 3rd design. The 1st stage permeate back-pressure is only 18 psi to balance the flux between stages and this design would be the lowest capital cost design and have the best permeate quality if no ERD is used.

Table 1: Conventional and Hybrid RO/NF Comparison
(with no interstage Energy Recovery Turbine Device)

	1	**2**	**3**	**4**
1st Stage Elements	**LP-RO**	**SW-RO**	**HP-RO**	**SW RO**
2nd Stage Elements	**LP-RO**	**LP-RO**	**HP-RO**	**3 HP-RO & 4 NF**
Permeate TDS ppm	108 ppm	**75 ppm**	100 ppm	**463 ppm**
% Salt Passage	0.9%	0.6%	0.8%	3.9%
Feed Pressure	293 psi	293 psi	305 psi	277 psi
Kw-Hr/1000 gal	**3.44**	**3.44**	3.58	**3.26**
1st Stage Permeate Back-Pressure	90 psi	18 psi	75 psi	0 psi
Feed TDS	4,000 ppm	Same	Same	Same
Recovery	80%	Same	Same	Same
Concentrate TDS	20,000 ppm	Same	Same	Same
Average Feed/Conc	12,000 ppm	Same	Same	Same
2-Stage Array	2x1-7M	Same	Same	Same
System Flux	15.0 gfd	Same	Same	Same
Stage 1 Flux	17.5 gfd	Same	Same	Same
Stage 2 Flux	10.0 gfd	Same	Same	Same

The 2nd design of Table 2 would readily accommodate an interstage ERD to reduce energy usage 15% from 3.44 to 3.0 Kw-hr/1000 gallons which would also create a 10% better flux balance of 16 gfd 1st stage and 13 gfd 2nd stage, and improve permeate quality 7% from 75 ppm to 70 ppm due to a better flux balance.

The 3rd design of Table 1 uses a conventional design with all brackish HP-RO (high pressure reverse osmosis) membrane and no ERD. The HP-RO element is rated for 11,000 gpd at 99.7% NaCl rejection when tested at STCs of 225 psi and 1,500 ppm NaCl. This design produces only 8% better permeate TDS than the all LP-RO and requires 6% more energy to do it. Compared to the 2nd hybrid design, the permeate TDS is 33% higher and the energy is 4% higher. The 75 psi 1st stage permeate back-pressure makes it a candidate for an interstage ERD or booster pump.

The 3rd design of Table 2 adds an interstage turbine EDR device that would reduce the energy usage 23% from 3.58 to 2.91 Kw-hr/1000 gallons of permeate. Its energy efficiency with the ERD is in the middle between the 1st and 3rd designs and its permeate TDS is also in the middle. It still requires 18 psi 1st stage permeate back-pressure to balance the fluxes to 17.5 and 10 gfd. The designer would either select the 1st low pressure RO design for the best energy efficiency and feed pressure requirement or he would select the 2nd hybrid design for the best permeate TDS if permeate quality is the deciding factor.

Table 2: Conventional and Hybrid RO/NF Comparison
(With interstage Energy Recovery Turbine Device)

	1	**2**	**3**	**4**
1st Stage Elements	**LP-RO**	**SW-RO**	**HP-RO**	**SW-RO**
2nd Stage Elements	**LP-RO**	**LP-RO**	**HP-RO**	**3 HP-RO & 4 NF**
Permeate TDS ppm	108 ppm	**70 ppm**	100 ppm	**430 ppm**
% Salt Passage	0.9%	0.6%	0.8%	3.9%
Feed Pressure	236psi	254 psi	248 psi	220 psi
Kw-Hr/1000 gal	**2.77**	2.98	2.91	**2.59**
1st Stage Permeate Back-Pressure	35 psi	0 psi	18 psi	0 psi
Interstage Turbine ERD energy saving	24%	16%	23%	26%
Feed TDS	4,000 ppm	Same	Same	Same
Recovery	80%	Same	Same	Same
Concentrate TDS	20,000 ppm	Same	Same	Same
Average Feed/Conc	12,000 ppm	Same	Same	Same
2-Stage Array	2x1-7M	Same	Same	Same
System Flux	15 gfd	15 gfd	15 gfd	15 gfd
Stage 1 Flux	17.5 gfd	**16 gfd**	17.5 gfd	**15 gfd**
Stage 2 Flux	10.0 gfd	**13 gfd**	10.0 gfd	**15 gfd**

The fourth design of Table 1 uses a hybrid design with a higher permeate TDS requirement as is found often with potable drinking water systems with a target permeate TDS of < 500 mg/l. The 1st stage uses all high rejecting SW-RO membrane in the 1st stage and a combination of HP-RO and NF membranes in the 2nd stage and no ERD. The use of a high pressure seawater RO membrane in the 1st stage takes the energy required in 1st stage permeate throttling and converts it into the best permeate quality possible but it also aids in the flux balance between stages and eliminates the need to apply 1st stage permeate back-pressure. The 2nd stage uses three HP-RO elements in series for the lead elements in the pressure vessel, followed by four NF elements in series as the lag elements in the pressure vessel. The 8-inch 400 sq. ft. NF element in this case is a high flow and low rejecting membrane rated for 8,200 gpd at 91% NaCl rejection when tested at STCs of only 75 psi and 1,500 ppm NaCl. The use of the HP-

RO and NF elements allows the designer the flexibility to dial in the desired permeate TDS while minimizing the feed pressure requirement of the system. This design has the lowest energy requirement of all four systems by 5% to 10% but also has the highest permeate TDS.

The 4th design of Table 2 would readily accommodate an interstage ERD to reduce energy usage 20% from 3.26 to 2.70 Kw-hr/1000 gallons of permeate. This design would also create a 10% better flux balance of 15 gfd 1st stage and 15 gfd 2nd stage, and improve permeate quality 8% from 463 ppm to 430 ppm due to a better flux balance.

The Effect of High TDS on Salt Passage Through Brackish Water Membranes

Since 1998 the effect of high TDS feed on salt passage has been studied and suitable correction factors have been developed for computer design projection programs to account for the effects of feed water on the projected permeate quality for brackish water polyamide-based RO and NF membrane elements. The salt passage rate through membranes is based on the following parameters:

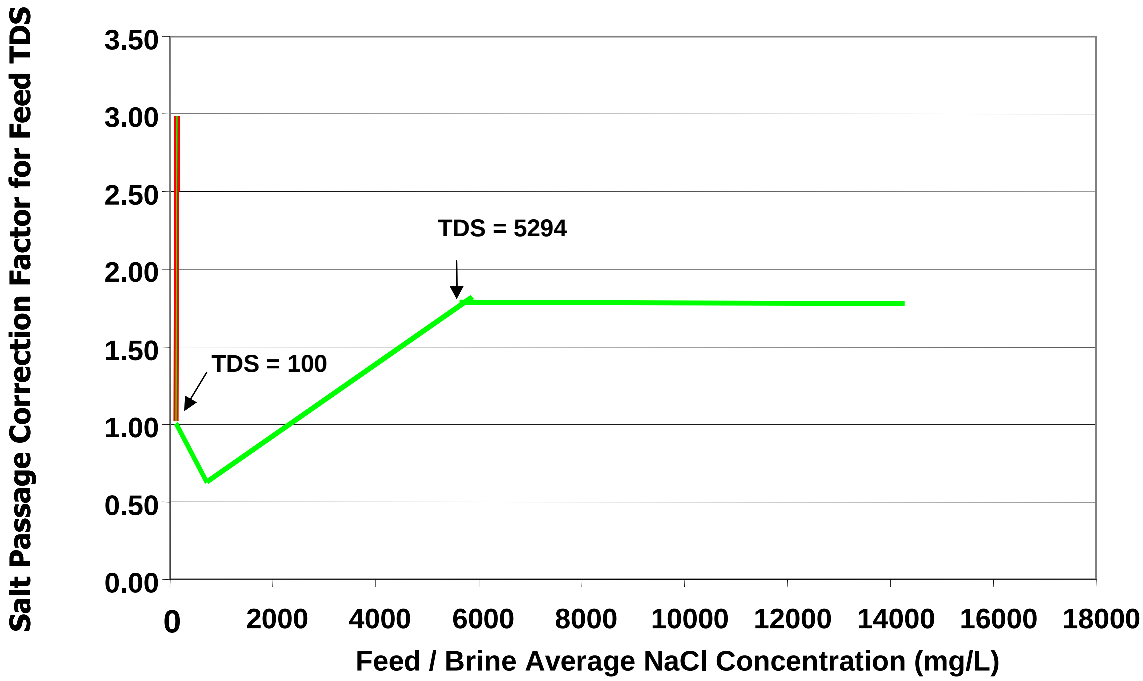
- Temperature: The higher the temperature, the higher the passage.
- Membrane type: Brackish membranes have higher passage rates than seawater membranes.
- Ionic species: The passage of inorganic ions is ion dependent based on size and charge (e.g. monovalent ions pass more readily than divalent ions).
- Feed pH: Variations in feed pH impacts the passage of ions (e.g. lowly ionized boron and silica are better rejected at pH greater than 9).
- Feed TDS: Salt passage is higher at very low feed TDS and at high feed TDS.
- System recovery
- Membrane water flux
- Age

Graph 1 shows the permeate Salt Passage Correction Factor to be applied for a given feed TDS. Interpretation of the curve shows that the feed TDS in the range of 100 to 2,000 mg/L results in no significant correction of salt passage for feed TDS. Feed less than 100 mg/L TDS results in an increased salt passage. Feed in the range of 2,000 to 5,300 mg/L TDS also results in an increased salt passage. The increase in the Salt Passage Correction Factor for feed salinity stabilizes at feed TDS above 5,300 mg/L.

The increase in the feed TDS salt passage correction factor for feed salinities less than 100 mg/L TDS are attributed to the impact of interaction between the membrane surface charge and the low ionic strength of the feed solution. NF and RO elements are factory tested and challenged with a relatively high salinity test solution (500 to 1,500 mg/L).

This feed TDS salt passage correction factor is not applied to projections using seawater elements. The seawater elements are factory tested at high salinity (32,000 ppm NaCl) and thus already has taken this high salinity affect into account.

Graph 1: Salt Passage Correction Factor for Feed Salinity



The feed TDS salt passage correction factor is applied to all brackish RO and NF membranes in a liner fashion from 1.0 to1.8 in the TDS range of 2,500 to 5,300. The correction factor is applied equally to all cations and anions calculated in computer projection programs. This safety factor automatically corrects the permeation rate of specific ions as the feed flows over the membrane and is concentrated.

The increase in the feed TDS salt passage correction factor for feed salinities above 2,500 mg/L TDS is attributed to a previously unaccounted effect of high salinity waters with brackish water composite polyamide membranes. This effect is theorized to be due to charge shielding at the membrane surface. Improved calculations for salt passage address the three theoretical mechanisms of salt passage which are convection, diffusion and charge repulsion. In particular, the combined effects of feed ionic strength and membrane surface charge play an important role in the rate of salt passage. A theoretical discussion of the increase of salt passage is described in detail in other papers. A short explanation of this theory entails the generation of an electrical potential known as the Donnan potential. The Donnan potential occurs at the membrane surface and is created by the repulsion of negatively charged anions away from a negatively charged membrane surface, while there is an attraction and alignment of positively charged cations at the membrane surface. Salt passage through a membrane depends on the passage of negatively charged anions through the negatively charged membrane. The positively charged cations are attracted to the negatively charged membrane and shield the membrane and inhibit the passage of anions when the Donnan salt rejection potential is high. An increase in feed TDS leads to an increase in cations which starts to reduce the Donnan rejection potential and results in an increase of salt passage. As the curve indicates, eventually the Donnan rejection potential finally stabilizes and the increase in salt passage levels off. Studies have indicated that the Donnan rejection potential is higher and salt passage is less for membranes with higher negative charges and for feed waters with a higher percentage of divalent cations. [1]

Case Study: North Miami Beach Florida

A hybrid low-pressure RO (LP-RO) system was commissioned in April 2008 at the Norwood Oeffler Water Treatment Plant in North Miami Beach, Florida. There are 3 trains that can produce 2 mgd (7,570 m3/day) of permeate each at 75% recovery. The groundwater supply for the LP-RO is extracted from the Floridan Aquifer at a depth of about 1400 feet (425 m). The feed TDS can range from 2900 ppm to 3800 ppm, but this water source has the advantage of being low in TOC (total organic carbon), color < 1, and iron < 0.1 ppm. Interestingly, in this plant there are 3 trains of NF which operate at significantly lower feed pressures and process feed water from shallow Biscayne Aquifer wells. The NF feed water is a completely different feed water with low TDS averaging 400 ppm, but is high in TOC, color and iron. Ultimately, the 6.0 mgd permeate from the hybrid LP-RO system, the 9.0 mgd from the NF system, 15 mgd from the existing lime clarification system and 2 mgd of filtered raw water will be blended and produce 32 mgd of finished potable water from the plant.

The low pressure RO system was designed to use two types of membranes. The 1st stage uses a better rejecting but lower flow RO membrane, ESPA2, rated at 9,000 gpd and 99.6% NaCl rejection to aid in balancing flux between stages without the use of 1st stage permeate throttling. The 2nd stage uses a lower rejecting but higher flow RO membrane, ESPA1, rated at 12,000 gpd and 99.3% NaCl rejection to aid in flux balancing and improved energy efficiency. The factory standard test conditions for both are 150 psi and 1500 ppm NaCl. An interstage turbine-style ERD device is used to improve energy efficiency and aid in flux balancing between stages. The pretreatment consists of cartridge filtration, sulfuric acid for pH adjustment and antiscalant. The system is a 2-stage array 36x18-7M and runs at 75% recovery.

All 3 trains were successfully started and Table 3 illustrates the results of the system operation after one year of operation in February 2009 in terms of projected design versus actual operations. The actual salt passage of 1.4% was 20% better than the projected 1.8%. The computer projected salt passage would have added a 20% increase in permeate TDS when the feed TDS is 2,900 ppm and an 80% increase at the concentrate end of the system when TDS is 11,300 ppm. In this case it would appear that the applied high feed TDS salt passage correction factor was on the conservative side. A review of the specific ion rejection showed good correlation, with actual salt passage of hardness and bicarbonate was less than expected.

Table 3: North Miami Beach Train 1 Hybrid RO Actual vs Projected Data at Year 1

	Projected	**Actual**
% Salt Passage	1.8%	1.4%
Permeate TDS	119 ppm	101 ppm
Permeate Hardness as CaCO3	5 ppm	2 ppm
Permeate Sodium	40 ppm	40 ppm
Permeate Chloride	51 ppm	51 ppm
Permeate Sulfate	6 ppm	6 ppm
Permeate Bicarbonate	20 ppm	7 ppm
Feed TDS	2,900 ppm	Same
Concentrate TDS	11,300 ppm	Same
Average Feed/Conc TDS	7,100 ppm	Same
Energy Consumption of HPP	2.53 kWhr/kgal	2.59 kWhr/kgal
Feed pressure	196 psi (13.5 bar)	201 psi (13.9 bar)
Permeate pressure-both stages	19 psi	Same
System Flux	13.2 gfd (22.4 lmh)	Same
1st Stage Flux	14.7 gfd (25.0 lmh)	Same
2nd Stage Flux	10.4 gfd (17.7 lmh)	Same
% Recovery	75%	Same
One year fouling factor	0.95	0.88
One year flux decline	7%	12%
One year salt passage increase	0% (typically 10%)	0%

Case Study: El Paso Texas

A conventional low-pressure RO (LP-RO) system was started in July 2007 at the Kay Bailey Hutchison Desalination Plant for El Paso Water Utilities. There are 5 trains that can produce 3.0 mgd (11,355 m3/day) of permeate each at 75% recovery. The groundwater supply for the LP-RO is extracted from an aquifer called the Hueco Bolson. The feed TDS can range from 2000 ppm to 3200 ppm and has a high sodium chloride content. Ultimately, the 15.0 mgd of permeate from the LP-RO will be blended with raw water to produce 27.5 mgd (105,000 m3/day) of finished potable water from the plant.

The low pressure RO system was designed to use only one type of membrane, ESPA1, rated at 12,000 gpd and 99.3% NaCl rejection at a factory standard test condition of 150 psi and 1500 ppm NaCl. Permeate throttling of the 1st stage is used to balance the fluxes between stages and an interstage turbine-style ERD device is not used in this case. The pretreatment consists of cartridge filtration, pH adjustment and antiscalant. The system is a 2-stage array 48x24-7M and runs at 83 % recovery.

All 5 trains were successfully started and Table 4 illustrates the results of the system operation after two and a half years of operation in January 2010 in terms of projected design versus actual operations. The actual salt passage of 4.1 % was 5 % higher than the projected 3.9%. The computer projected salt passage would have added a 5 % increase in permeate TDS when the feed TDS is 2,500 ppm and an 80% increase at the concentrate end of the system when TDS is 11,300 ppm. In this case it would appear that the applied high feed TDS salt passage correction factor was close to being accurate. It is possible that salt passage was higher than projected because higher permeable ESPA1 membranes were used in both stages. It is quite likely that these higher permeable membranes are more sensitive to the higher salinity feed waters.

A review of the specific ion rejection showed reasonable correlation with actual salt passage of hardness and bicarbonate was less than expected. The imbalance in the flux between stages in this case indicates there is probably a moderate fouling of the 2nd stage, but a cleaning of the 2nd stage is not required since the system normalized permeate flows, % salt passage and delta P (feed-to-concentrate) are all in acceptable ranges. This is more common for plants with very good feedwater, where turbidity and TOC are low.

Table 4: El Paso Train 1 Low Pressure RO Actual vs Projected Data at Year 2.5

	Projected	**Actual**
% Salt Passage	3.9%	4.1%
Permeate TDS	302 ppm	316 ppm
Permeate Hardness as CaCO3	16 ppm	5 ppm
Permeate Sodium	102 ppm	121 ppm
Permeate Chloride	140 ppm	183 ppm
Permeate Sulfate	10 ppm	1 ppm
Permeate Bicarbonate	41 ppm	8 ppm
Feed TDS	2,464 ppm	Same
Concentrate TDS	13,000 ppm	Same
Average Feed/Conc TDS	7,732 ppm	Same
Energy Consumption of HPP	2.04 kWhr/kgal	1.96 kWhr/kgal
Feed pressure	180 psi (12.4 bar)	173 psi (12.0 bar)
Permeate pressure-1st stage	39 psi (2.7 bar)	Same
Permeate pressure- 2nd stage	5 psi (0.3 bar)	Same
System Flux	15.3 gfd (26.0 lmh)	Same
1st Stage Flux	19.5 gfd (33.2 lmh)	18.0 gfd (30.6 lmh)
2nd Stage Flux	6.9 gfd (11.7 lmh)	10.0 gfd (17.0 lmh)
% Recovery	83%	Same
Fouling factor at 2.5 years	1.0	Same
Annual Flux Decline	0%	Same
Annual Salt Passage Increase	10%	13%

Conclusion

Increased feed TDS can have a dramatic impact on the design of brackish water RO and NF systems. Hybrid RO and NF systems which can use a number of different membrane types can be used to produce the most energy efficient systems, can produce the best permeate quality, and can improve system flux distribution that may reduce the rate of fouling. The use of turbine-type energy recovery devices in a design can improve the energy efficiency, improve permeate quality, and improve flux distribution and reduce the rate of fouling. Evidence was presented that high-lights the critical need for implementing feed TDS correction factors in design programs to increase the projected permeate salt passage for high salinity feed waters. Two case studies for North Miami Beach and El Paso reflect the value of applying feed TDS correction factors for salt passage.

References

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