Evaluation of New Generation Brackish Water Reverse Osmosis Membranes

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Since the development of brackish water reverse osmosis (RO) membranes their use has seen rapid development. All major RO membrane manufacturers have developed one or more brackish water RO membranes. In the last ten years these membranes have seen a large decrease in price and an increase in productivity making brackish groundwater desalination an attractive option in water scarce regions. The latest generation of brackish water RO membranes has shown marked improvements in terms of operating pressure and this could translate into lower costs for brackish water treatment. This paper will present the results of pilot testing conducted on these new generation low pressure brackish water RO membranes for groundwater desalination. Two new membranes were tested - ESPA 4 manufactured by Hydranautics, Inc, Oceanside, CA and 4040 BL manufactured by Saehan Industries, South Korea. Hydranautics, Inc. is a well established membrane manufacturer in the US while Saehan Industries does not currently have a presence in the US market. An older generation membrane (ESPA 2 from Hydranautics) was also operated in parallel with the new generation membranes to provide baseline data for comparison. This project was conducted as a part of a research program initiated by Desalination Research and Innovation Partnership, which consists of water purveyors in the Southern California region.

Materials and Methods

Site Description
The pilot study was conducted at the Richard A. Reynolds Groundwater Demineralization Facility located in National City, CA. This full-scale facility is owned and operated by the Sweetwater Authority, and treats water from four nearby brackish groundwater wells using reverse osmosis. The plant configuration is two-stage which currently provides a plant capacity of 4 MGD.

Pilot Equipment Description
Two RO pilot systems was operated during the study to treat brackish groundwater. One pilot skid was configured initially to provide two membrane trains each operating at a feed water recovery (FWR) of 50%. This configuration allowed testing of the new generation membranes from the two different manufactures. The other pilot skid was configured to provide one membrane train to provide baseline testing of an older

generation membrane. Each RO train consisted of two pressure vessels in series each containing three 4-inch by 40-inch membrane elements. Later on in the testing the larger pilot will be reconfigured to test the selected membrane at higher recoveries by utilizing a 2-2-1-1 array using six pressure vessels.

The RO skids used include the following equipment: high-pressure pump, cartridge filter setup and a chemical-feed system. Furthermore, the pilot skid is equipped with online meters for conductivity, pH, feed temperature, and a run hour clock. A schematic diagram of the pilot testing setup with the sampling locations is provided in Figure 1.

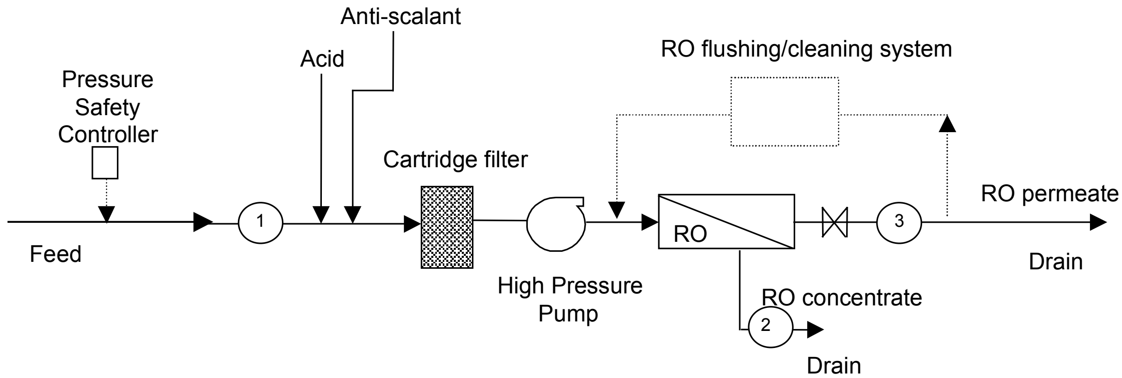


Figure 1 Pilot Testing Schematic with sampling locations (1. Feed, 2. Concentrate, and 3.Permeate)

Two manufacturers: Hydranautics and Saehan Industries supplied the RO test membranes. Each manufacturer provided their most recently developed brackish water RO membrane, designed specifically for desalting brackish groundwater. Hydranautics also supplied an older generation membrane for baseline testing. The above mentioned manufactures were chosen due to their success and innovation in the RO membrane industry. A brief description of each manufacturer is provided below:

- *Hydranautics* – Located in nearby Oceanside, CA, Hydranautics is a leading RO membrane manufacturer and currently provides products for major municipalities throughout the world. Hydranautics offers RO membranes for a variety of applications including the latest technology for desalination of groundwater, surface water and seawater. In addition, Hydranautics offers membrane products for light industrial applications as well as point of use applications.

- Saehan Industries - With headquarters in Seoul, Korea, Saehan Industries has been commercially producing RO membranes since 1994 for household and industrial water treatment applications outside the United States. In addition, Saehan has established a worldwide network of offices including Frankfurt, Ho Chi Minh, Hong Kong, New York, Shanghai and Tokyo.

EXPERIMENTAL PLAN

Pilot Scale Experiments

The criteria used for selection of the membranes for this study was that the new generation membranes to be tested would be the latest membranes available in the market or recently developed by the manufacturer. The testing site selection criteria was to select a site that had groundwater available with a TDS level high enough to be called "brackish". The membranes selected (ESPA 4 from Hydranautics and 4040 BL from Saehan Industries) are the latest from the two participating manufacturers and the site selected had access to brackish groundwater from the San Diego Formation. The older generation membrane used was ESPA2 from Hydranautics, Inc.

The RO pilots were operated over a 9 month period under a variety of conditions. Table 1 provides a matrix of operating conditions to be implemented during each month of pilot testing. It should be noted that each month of testing represents a separate experimental run and therefore initially it was decided that the membranes will be cleaned at the end of each testing period. Testing results that there was no significant fouling at the end of each period so cleaning was discontinued to evaluate the effect on fouling. There were some shutdown period so some of the testing periods were longer than a month. As shown, both the new membranes being evaluated in this study will be operated at flux (gfd) rates of 12, 14, 18 and 20 during months 1, 2, 3 and 4 respectively. During the first month only the new generation membranes (ESPA 4 and 4040 BL) will be tested. The older generation membrane (ESPA 2 supplied by Hydranautics) has been tested under the same operating conditions (12 gfd and 50% recovery) in a recent study at the same testing site and the data is available to the team. During the first four months of testing the feed water recovery was held constant at 50%. The performance of the new generation membranes was assessed after the first four months of testing and compared to the performance of the ESPA 2 membrane. The new membrane 4040 BL from Saehan Industries was selected for further testing, as the operating pressure for this membrane was lower compared to the ESPA 4 even though the fouling was insignificant for both membranes. Finally, as shown in Table 2-1, the system feed water recovery (%) values during testing period 5 onwards, was be 75 percent to 90 percent. The recovery values was achieved by configuring the pilot system in a 2-2-1-1 array. Such a configuration allows concentrate from stage 1 to be fed to stage 2. It should be noted the manufacturer of each membrane was consulted to assure proper crossflow velocity I was maintained at various recovery rates.

Table 1: Matrix of Pilot Operating Conditions

Membrane	Testing Period (weeks)	Flux (gfd)	Recovery (%)
ESPA 4	1 (4 weeks)	12	50
4040 BL	1 (4 weeks)	12	50
ESPA 4	2 (4 weeks)	14	50
4040 BL	2 (4 weeks)	14	50
ESPA 2	2 (4 weeks)	14	50
ESPA 4	3 (4 weeks)	18	50
4040 BL	3 (4 weeks)	18	50
ESPA 2	3 (4 weeks)	18	50
ESPA 4	4 (4 weeks)	20	50
4040 BL	4 (4 weeks)	20	50
ESPA 2	4 (4 weeks)	20	50
4040 BL	5 (4 weeks)	20	75
4040 BL	6 (2 weeks)	21	85
4040 BL	7(4 weeks)	21	90

Data Collection and Analysis

Operational data from the pilot system was recorded at a minimum of once per day by the on site engineer. Parameters recorded include pressure (feed, concentrate and permeate), flow (permeate and concentrate), feed water temperature and pH and conductivity (feed and permeate). This data was then analyzed by making several plots including net driving pressure vs. time, transmembrane (TMP) pressure vs. time, specific flux vs. time.

Water Quality
Limited water quality analyses were performed. These analyses include : UV 254, TOC, Total Iron, Total Manganese and Silica.

Results and Discussion

Phase I testing (testing periods 1 through 4)

During this phase of testing a comparative evaluation of the older generation membrane was performed against the new generation membrane. This testing period was four months long and included operation of ESPA 4 and the 4040 BL membrane at 50% FWR and fluxes of 12,14, 18 and 20 gfd. ESPA 2 membrane was operated at a FWR of 50% and fluxes of 14, 18 and 20 gfd. Table 2 summarizes the results from this phase of testing

Table 2 : Phase I Testing Results

Testing Period	Target Flux	FWR	Membrane	Avg TMP (psi)	Avg Specific Flux (25deg) (gfd/psi)	Salt Rejection (%)
1	12 gfd	50%	ESPA 2	89	0.21	98.2
			ESPA 4	69	0.28	96.6
			4040 BL	64	0.32	97.0
2	14 gfd	50%	ESPA 2	97	0.21	98.3
			ESPA 4	77	0.28	96.8
			4040 BL	71	0.32	97.1
3	18 gfd	50%	ESPA 2	118	0.21	98.5
			ESPA 4	97	0.26	97.7
			4040 BL	88	0.30	97.8
4	20 gfd	50%	ESPA 2	131	0.20	98.6
			ESPA 4	109	0.25	98.0
			4040 BL	104	0.27	97.5

From the above Table it can be seen that the TMP values for the ESPA 2 are the highest for all the operating conditions followed by ESPA 4 and then 4040 BL. Correspondingly the specific flux for the ESPA 2 membrane the specific flux is the lowest, followed by ESPA 4 and then 4040BL. Also it has to be noted that for all the conditions the ESPA 2 has the highest salt rejection followed by 4040 BL and then ESPA 4. The rejection in the 4 th testing period for ESPA 4 is higher than 4040 BL.

Since this study is geared towards finding a more economical membrane to what is currently available the above data should be considered in the following light. TMP is the main driver in the operational costs of the membrane. Also for brackish water desalination plants a TDS of around 100 mg/L is acceptable and no economic benefit can be derived from very high rejection membranes as is the case with seawater desalination membranes. So the new trend in brackish water production is to increase the production of the membrane even if some rejection capabilities are reduced. This is clearly evident from the data on the three membranes tested here. The older generation membrane have higher rejection capacities but have high operating pressure leading to higher operating costs while the newer generation membranes have lower rejection values but the operating pressures are substantially lower (between 17 to 27 % over the operating conditions tested).

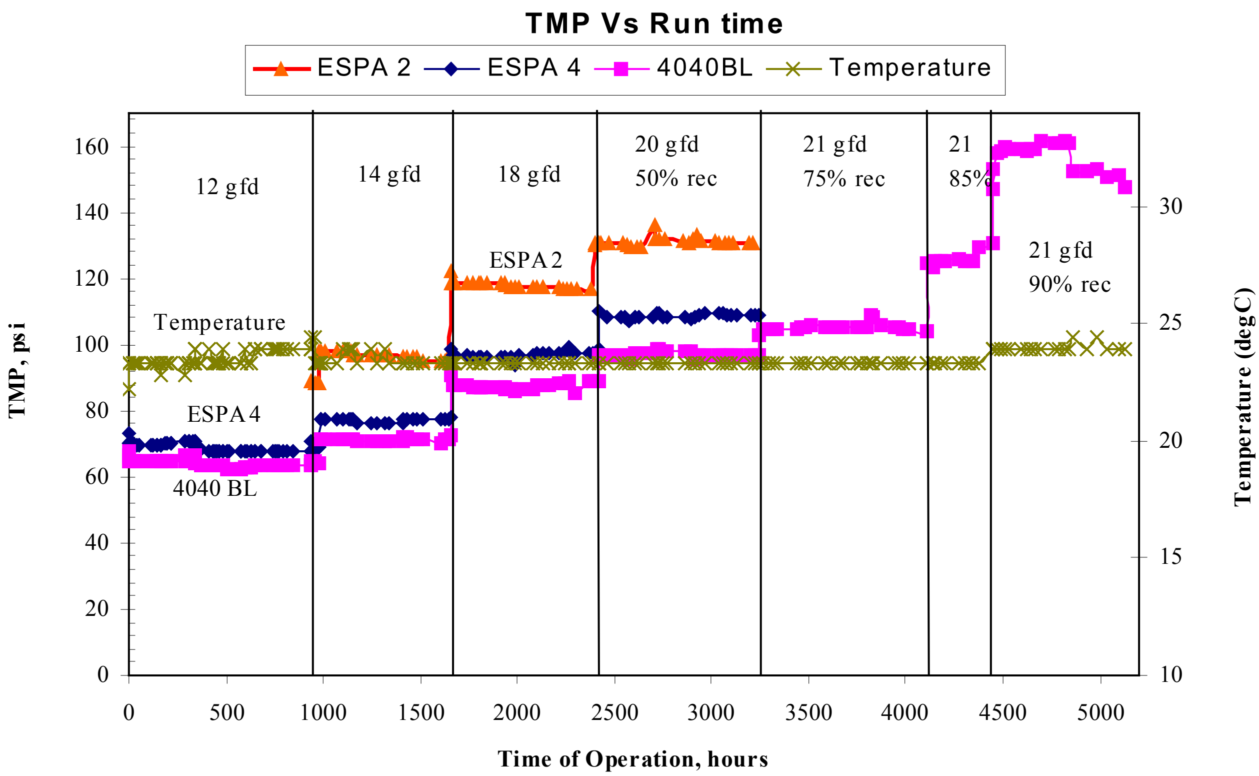
Also it can be seen that between the two new generation membranes the TMP for the Saehan 4040 BL membrane is lower than the Hydranautics ESPA 4 membrane. Consequently the specific flux for the 4040BL membrane is higher. Also the rejection for the 4040BL membrane is higher than the ESPA 4 membrane in all testing periods except when the operating flux was 20 gfd. The TMP for the ESPA 4 membrane is higher than the 4040BL membrane by 5-7 percent. This difference is not substantial but is still consistent over the range of fluxes tested so this was used as a basis for selecting the 4040BL membrane for the second phase of the testing.

During the four testing periods the flux decline in the membrane was minimal as can be seen from summary comparison charts in Figure 1. This indicates that fouling if present was insignificant.

Phase II Testing

In this phase of testing the Saehan 4040 BL membrane was operated at higher recoveries to collect information the performance of this membrane under more difficult operating conditions. Through this phase the flux was maintained at about 20 gfd and the recover gradually increased from 75 to 90%.

Figure 2 shows the TMP and Specific Flux evolution during the 5000 + total hours of testing (including Phase I and II). From the chart it can be seen that under each testing condition there is minimal increase in TMP indicating that the membrane did not show significant fouling during the whole period of the testing.



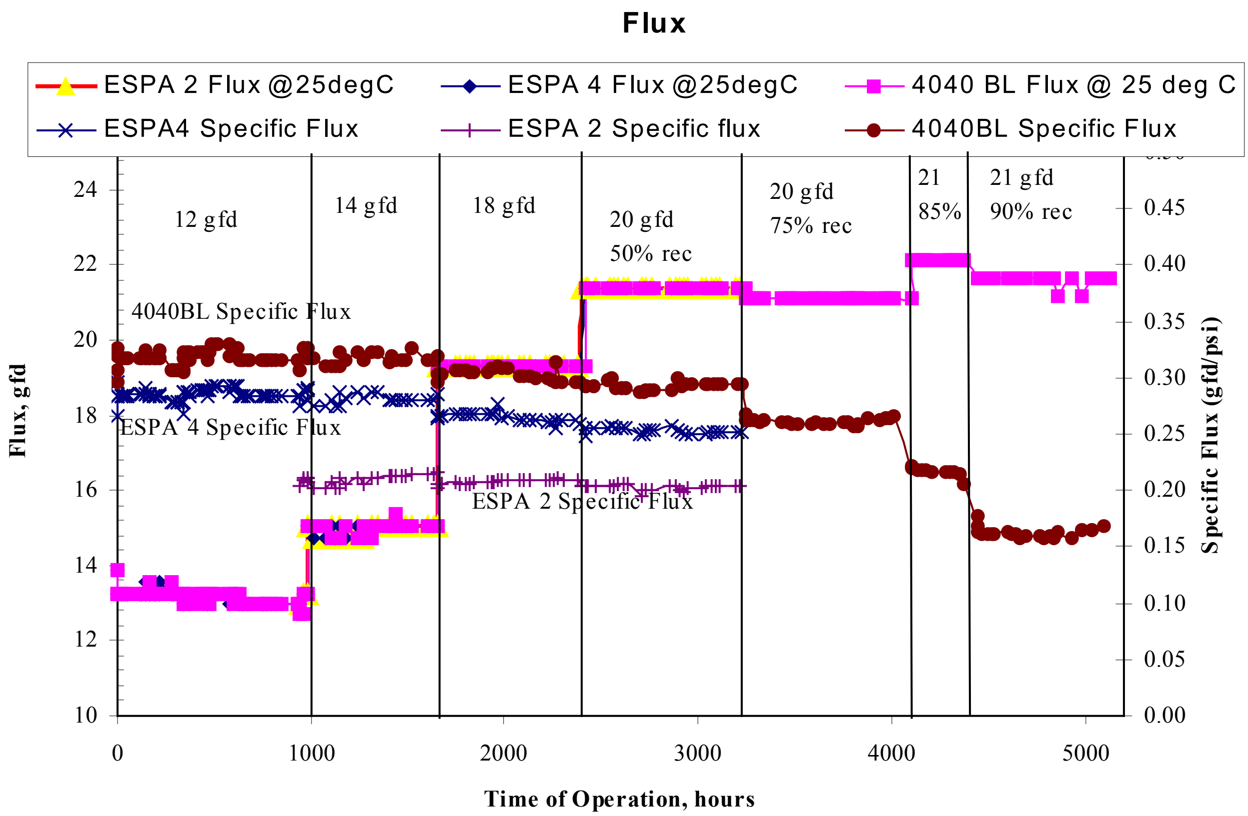


Figure 2: TMP, Flux and Specific Flux Results

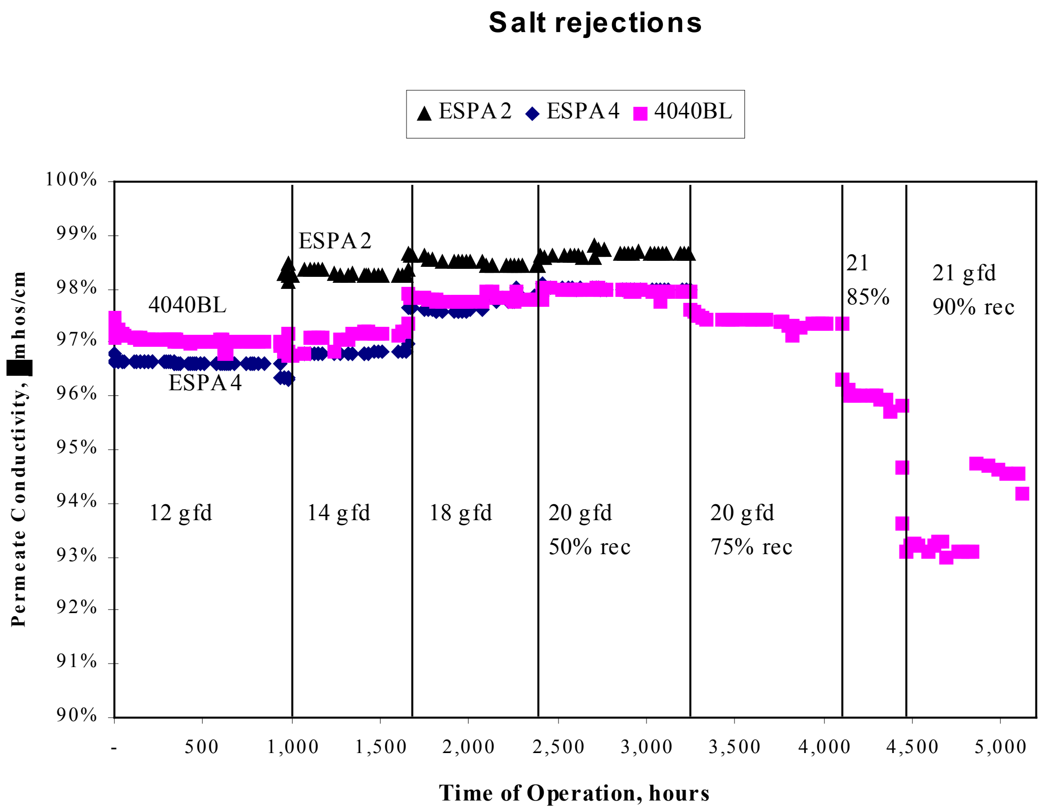


Figure 3: Salt rejection Results

During the second phase of the testing the membrane remained operable until the high recovery rate of 90%. However a decrease in the salt rejection was seen at this high recovery rate. The changes in the rejection at 90% recovery rate are due to sudden changes in feed conductivities attributable to well operation. The salt rejection changes under the different operating conditions are shown in Figure 3.

Conclusions

- The new generations show a great improvement over the older generation membranes in terms of operating pressure, which could lead to substantial cost savings. The salt rejection capabilities of these membranes are however slightly lower
- Extensive testing of the new Saehan 4040BL membrane has demonstrated that this membrane could be operated at high fluxes (about 20 gfd) and high recoveries (85-90%). No flux decline due to fouling or scaling was observed during limited testing under these operating conditions
- Further long term testing of these new generation membranes are suggested