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Fujairah SWRO — management of membrane replacement

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ABSTRACT

Fresh water shortage is a growing problem facing the world, especially in the Middle East. With the rapid increase in fuel price, seawater reverse osmosis (SWRO) is increasingly becoming a popular option for water supply. To date several seawater reverse osmosis desalination plants have been built in the United Arab Emirates (UAE) to meet the growing demand for fresh water in the country. The Fujairah Water and Power Plant was acquired in 2006 by a joint venture company between the Abu Dhabi Water and Electricity Authority and Sembcorp, forming the Emirates Sembcorp Water and Power Company (ESWPC). The plant is operated under agreement by Sembcorp Gulf O&M Company (SGOMC). The Fujairah Water and Power Plant is comprised of a hybrid system with a configuration of 37.5 MIGD reverse osmosis and 62.5 MIGD of multi stage flash desalination capability, and it is the largest SWRO plant in the UAE and second largest in the world. The plant has been in successful operation since June 2003. SGOMC started maintenance and operation of this plant on 26 September 2006. Initially, there was some apprehension in operating such a large SWRO plant as there were concerns regarding the design of the systems upstream, operation of systems upstream and proper monitoring of membrane performance with timed countermeasures. After review of the current operating performance and conditions, it was decided that 25% of the membranes would be replaced to improve the operation of the plant. Hydranautics (HN), the world's leader in membrane technology, initially provided 17,136 SWC3 membranes for this installation and 4,088 ESPA1 elements for partial second pass. Since the plant start up and initial tuning of the system, membranes are performing to expectation and providing the required quality as well as quantity of product water. The decision for replacement was critical in view of selecting of the right membranes for replacement and identifying the right membranes to be rejected. Finally the decision was made to select the highest rejection membrane, the SWC4+. The new membranes offer a nominal salt rejection of 99.8% and 93% boron rejection when operated at standard test conditions with a pH of 7. After 5 years of operation with almost zero replacement in the Fujairah SWRO plant, SGOMC and Hydranautics chose to gradually replace some of the SWC3 elements with new higher rejection and higher area SWC4+ membranes which provide advantages for plant operation such as operation at increased recovery and increased train capacity while producing better product water quality. A detailed account of the reasons for this change and the approaches to membrane replacement will be discussed and explained in the course of this paper. The authors hope further that this paper can be a useful reference for future development of SWRO plants, membrane selection and membrane replacement management in the Middle East as well as globally. Fujairah SWRO offers

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an excellent example where close cooperation between the plant management and the membrane supplier, together with optimization of individual process units upstream of membranes contribute significantly in the reliable and successful long term operation of an RO plant.

Keywords: Fujairah SWRO; Plant management; Membranes

1. Introduction

Emirates Sembcorp Water and Power Company (ESWPC) is the owner of the sixth IPP Project in the UAE. For Sembcorp, the Singapore partner of ESWPC, the Fujairah IWPP represents an opportunity to build on it operations and maintenance track record in manning a brown field facility with a capacity of 535 MW power and 100 MIGD water supplies. The Fujairah IWPP power capacity will be further increased to 760 MW starting February 2009. The Fujairah Seawater Reverse Osmosis (SWRO) plant had been part of the large complex since its inception in early 2001. It fulfills the Fujairah IWPP's requirement of 500 MW (net electricity on the electrical grid) and 100 MIGD water productions. The original aim of the proposal was to use a hybrid plant for the water production, i.e. 62.5 MIGD from 5 MSF units coupled with the power plant and 37.5 MIGD (170,500 m^3/d) from seawater reverse osmosis. This concept provided a more flexible system as the RO system helps to sustain the electricity demand when there is a mismatch between the water and electricity demand. The RO plant in Fujairah IWPP at present is the second largest SWRO plant as well as the largest hybrid desalination plant in the world. RO part of desalination plant employs partial second pass to achieve product TDS below 180 mg/l. The RO plant started to produce at full capacity successfully in June 2003. Membranes used in the first pass are Hydranautics — SWC3 type and second pass uses Hydranautics ESPA1 elements. Brief schematic plant outline is given in Fig. 1. The Fujairah Desalination Plant meets its obligations.

2. Membrane maintenance program

The new management after the plant takeover decided to emphasize the Membrane Management Program. The membrane manufacturer specification on membrane life is 5–8 years and this requires a replacement rate of around 14.3% per annum. But what should the criteria for replacement be? There is limited knowledge shared publicly for membrane maintenance of large capacity seawater RO systems [5–7].

Throughout the operational period of the RO desalination plant, membranes are one of the major critical parts for plant availability and performance. Additionally, these are the major spares expenses. For example, suppose a plant like Fujairah needs to change all first pass membranes at the end of the sixth year, the operator would be looking at a substantial sum of a few million US$. Membrane replacement rate is always critically influenced by quality of pre-treated water and design and performance of processes upstream of membranes. For this, it is very essential to do continuous and close follow up and improvement of pre-treatment performance as well as to have a prepared membrane replacement plan. This is a complex task and the best solution is to bring together the membrane supplier with a long term agreement to cap the warranty replacement beyond a certain ascertained number per annum. It is therefore essential to decide on the membrane to be replaced in each year in a organized manner so that the maximum life of the membrane can be used and the membrane budget can be segregated in years. Sembcorp divided our approach to membrane replacement in the following few steps:

1. Selection of membrane supplier
2. Evaluation of required work together with membrane supplier
3. Selection of the best replacement method
4. Regular membrane replacements
5. Membrane reuse

2.1. Selection of membrane supplier

For selection of membranes for replacement, Hydranautics and the other main membrane suppliers were contacted and their offers evaluated in detail. Finally, Hydranautics was chosen. The main reason for selecting Hydranautics was the warranty terms for the complete first pass membranes. After a detailed study of plant conditions and with a proposal of replacing 25% of the membranes; Hydranautics agreed for a long term warranty covering 5 years. Membrane replacement of 25% was decided upon considering the fact that this was the first time membrane replacement had taken place during the four years of plant operation.

2.2. Evaluation of required work

2.2.1. Work and actions on site

- Personal assistance and supervision of replacement during membrane sorting and their preparation for loading
- Personal assistance during replacement of first trains.
- Random check and control of shimming
- Assistance during start and performance evaluation
- Advices and help with disposal or recycling of old and non – usable elements

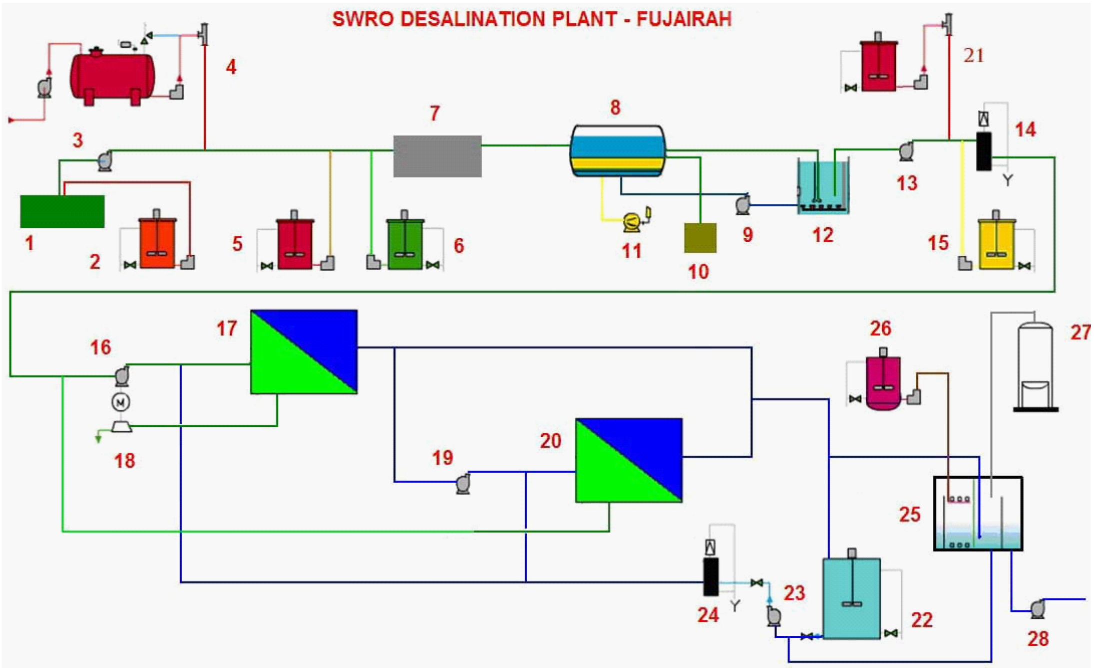

Fig. 1. Fujairah SWRO — brief schematic plant outline.
Plant description [1–4]: Plant location: Fujairah, UAE; Commissioning: 2003; Plant capacity: 170,500 m^3/d; Recovery: 43% in first pass and 90% in second pass; Seawater pumps: 1 + 1 standby; Filtration: open sand filters (14 open gravity filters); Cartridge filters: 18; Coagulation: static mixer and coagulation tanks; Chemical dosing: coagulant (flocculant if required), antiscalant; Booster pumps: 5; Number of trains: 18 in first pass and 8 in second pass (these ones with 2 stages); Number of PV's: 136 per train in first pass and 50: 32 per train in second pass; Number of membranes per PV: 7 in both passes; Original membrane type: SWC3 first pass (total 17,136 pcs) and ESPA 1 in second pass (total 4,088 pcs); High-pressure pumps: 18 in first pass (one per train) and 8 in second pass (one per train); Energy recovery system: Pelton wheel; Chemical cleaning pump: 3.
Legend: 1. Seawater intake — open intake; 2. Hypochlorite dosing system — elctrochlorination; 3. Seawater pumps; 4. Sulfuric acid dosing system (not in use); 5. Coagulant dosing system; 6. Organic flocculant dosing system (when required); 7. Coagulation–flocculation; 8. Open gravity dual media filters — 14 DMFs; 9. Backwash pump for sand filters; 10. Backwash water collection tank; 11. Air blowers; 12. Filtered water tank; 13. Booster pumps (5 bar); 14. Cartridge filters (5 micron) 15. Sodium bisulphite dosing system; 16. High-pressure pumps — first pass; 17. RO membrane racks — first pass; 18. Energy recovery turbine first pass (Pelton wheel); 19. High-pressure pumps — second pass; 20. RO membrane racks — second pass; 21. Antiscalant dosing system; 22. Chemical cleaning tank; 23. Chemical cleaning pump; 24. Cartridge filter (from chemical cleaning system); 25. Permeate and MSF distillate water tank; 26. Lime dosing system; 27. CO_2 dosing system; 28. Product pumps for distribution.

- Selection and test of first pass elements (one complete pressure vessels) in Oceanside laboratories:
  1. Selected elements should be used for retest at standard sea water conditions as well as for cleaning tests.
  2. Selected elements should serve also for ΔP measurement of individual element across the whole pressure vessel.
  3. Position of every individual element must be recorded as well as position of the pressure vessels (PV) in the rack.
  4. PV should be selected from trains with the worst performance.
  5. Selected PV should have typical performance. It is inevitable that conductivity profile of all pressure vessels in trains is measured prior the selection and removal of the elements.
  6. Selected elements must be flushed with permeate and preserved with 1% SBS before shipping.

2.2.2. *Suggested laboratory tests*

- Vacuum test
- Bubble test
- Tests at standard conditions — each individual element should be retested
- Autopsy of selected elements
- Dye test
- SEM/EDAX of selected elements
- Cleaning with different cleaning chemicals – standard testing after every cleaning step

2.2.3. *Criteria for selection of RO trains for replacement*

First pass trains performance was analyzed in detail for all trains with respect to actual product quality, actual product quantity, normalize salt passage, normalized flow and normalized ΔP were sorted in accordance with the merit order for replacement.

The above must be supported with logical sequence for replacement of individual trains, preparation of detailed procedure for replacement and shut down cum start up procedures.

2.3. Selection of best replacement method

For the evaluation of the best replacement method, one pressure vessel was selected and all elements were removed and sent for detailed autopsy and investigation of their physical situation as well as performance at standard conditions and compared with original factory test data. In summer 2007, all seven elements were removed from one selected pressure vessel with typical performance in train 4, Line A. Performance of every individual element was investigated to the highest detail and some of these elements were autopsied. We believe that this is the best method to obtain proper and detailed information of real membrane status and what can be expected from the future performance of the plant. Extrapolations for performance of membranes can be made based on obtained results; of course, assuming that a vessel with typical performance is selected.

A wet test replicating the specification test conditions is performed in order to obtain accurate information as to the element performance in terms of rejection, flow and differential pressure (ΔP). The retest results are then compared to the original test values obtained during manufacture. The test conditions are standardized and based on the type of element being investigated. Test conditions per element are located on the individual element specification sheets.

Based on the comparative performance values, a determination can be made as to the need for further investigations and the form such an investigation should take.

2.3.1. Test conditions

The stated performance is based on the following conditions (data taken after 30 min of operation):

- 32,000 ± 2,000 PPM NaCl solution
- 800 psi (5.5 MPa) applied pressure
- 77°F (25°C) operating temperature
- 15% permeate recovery
- 6.5–7.0 pH range

Obtained test results as well as original factory tests results before elements were shipped first time to site are summarized in Table 1.

Figs. 2 and 3 as described will now present measured data during re-test of elements at standard conditions. First chart (Fig. 2) presents differential pressure increase in absolute figures as well as compared to factory original data. Measured values are in psi. First two elements have differential pressure exceeding 15 psi what represents 400% and 500% ΔP increase as compared to wet test data during factory testing, before elements were shipped to site. Differential pressure of both elements exceeds 10 psi which is maximum acceptable ΔP. High ΔP created by fouling resulted in a movement and extrusion of feed/brine spacer. Element in position #3 has ΔP which might be still reduced by an effective cleaning regime and save this element for future operation. Individual tests of elements at standard conditions had also shown that differential pressure in elements 4–7 is changed just marginally. It confirms that there is large amount of particles which were passing from pre-treatment as well as organic and colloidal fouling — most probably biofouling. The results from wet tests and cleaning tests also showed that first two elements could not be used anymore and must be replaced.

In 2008, the test was taken again. One full pressure vessel and each individual element were tested. Obtained results are very consistent with data obtained during investigation in 2007 and are following the same pattern.

Table 1
Wet test data

Standard re-test performance data							
Serial number	Original		Re-test			% change	
	Rejection (%)	Flow (GPD)	Rejection (%)	Flow (GPD)	Drop in pressure	Salt passage	Flow (GPD)
A609590 – Position 1 (lead)	99.70	5,268	99.56	3,330	> 15.0	+47	–37
A609572 – Position 2	99.70	5,684	99.63	3,056	> 15.0	+23	–46
A609568 – Position 3	99.80	5,760	99.60	3,580	7.1	+100	–38
A609656 – Position 4	99.70	5,943	99.58	4,037	2.8	+40	–32
A611240 – Position 5	99.70	6,007	99.59	4,050	3.7	+37	–33
A619550 – Position 6	99.70	6,219	99.63	3,909	1.9	+23	–37
A608298 – Position 7 (tail)	99.70	6,316	99.37	3,885	2.3	+110	–38

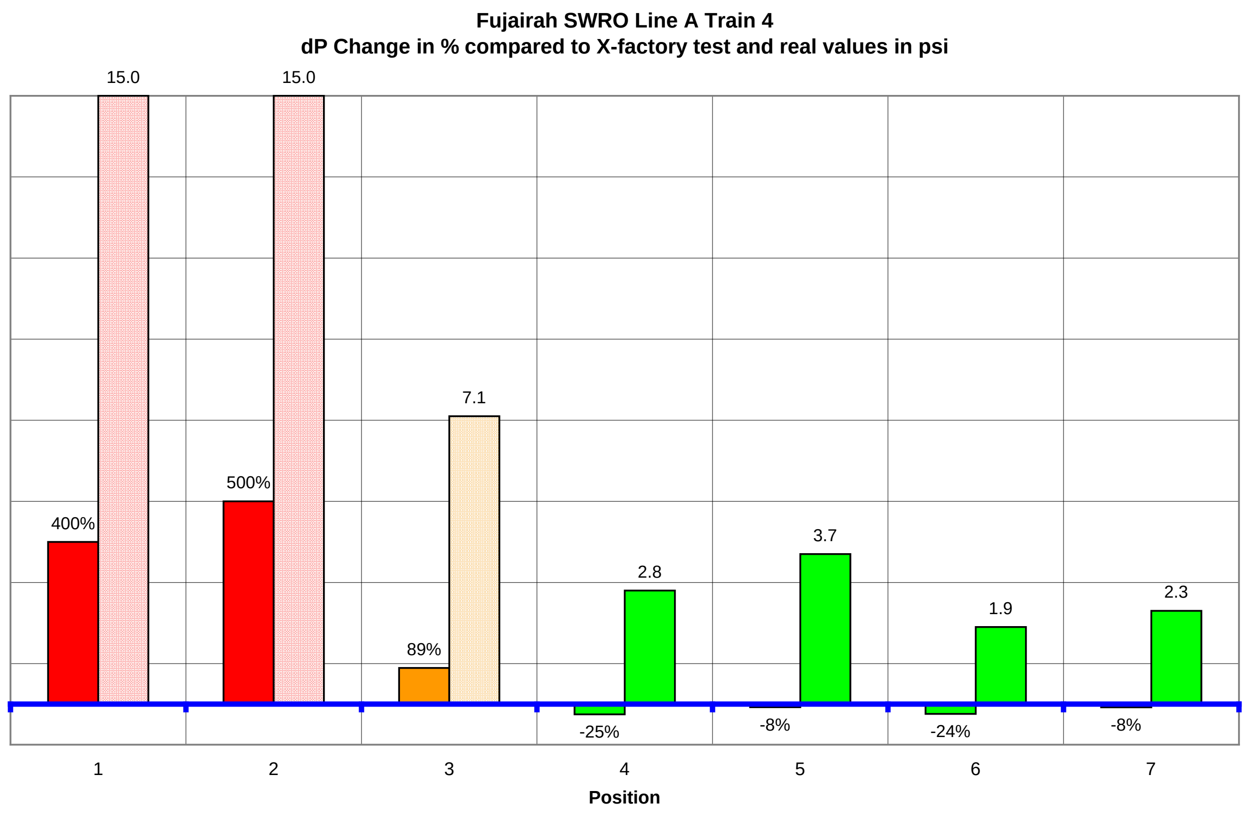

Fig. 2. Differential pressure changes across PV.

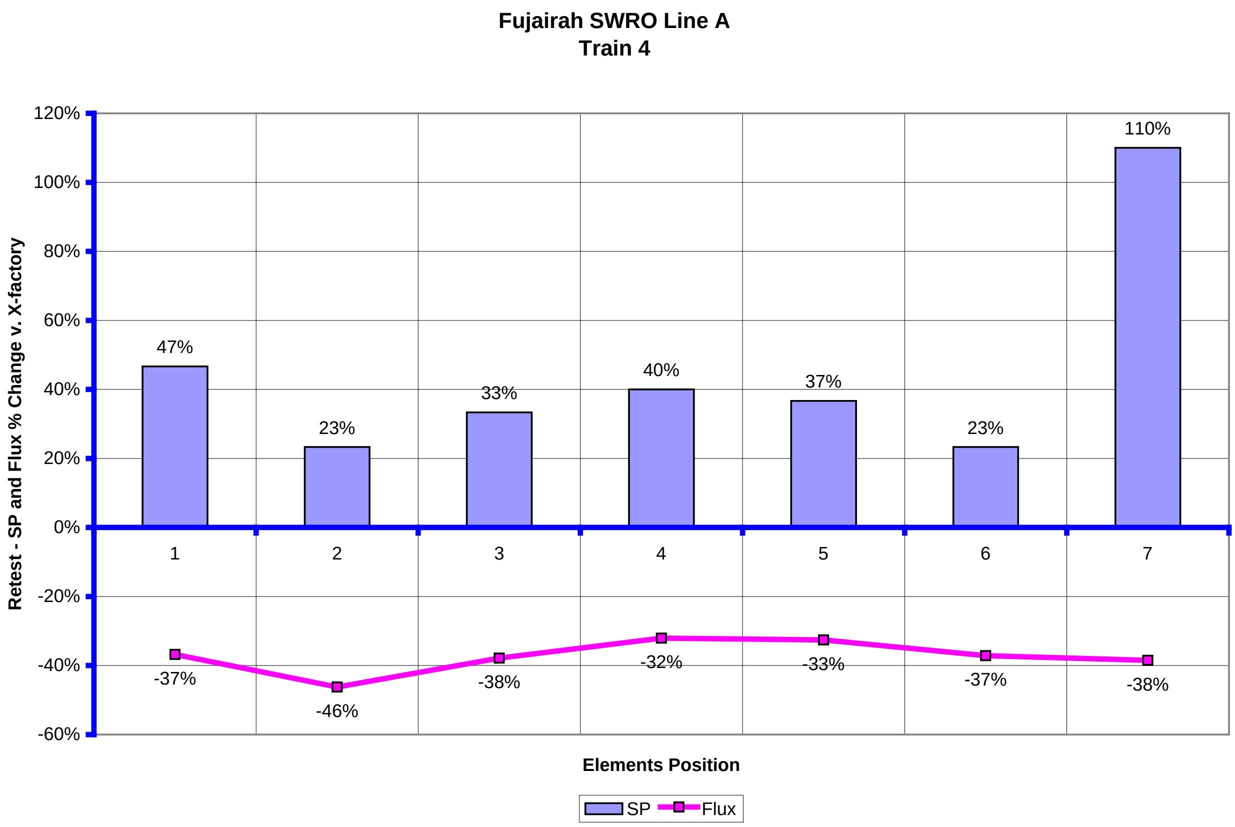

Fig. 3. Flux and SP changes across PV.

Next chart (Fig. 3) presents changes in salt passage and flows of individual elements in order as they are positioned in pressure vessel. Salt passage of each element is increased but the biggest increase is observed on lead element and tail element. Increased salt passage is created most probably by membrane oxidation which was demonstrated by positive Fujiwara test as well and was evident from de-lamination of the last element.

Each element had lost significant amount of production. Unfortunately loss of production is evenly distributed through the whole pressure vessel. This fact demonstrates that there is membrane surface fouling created by ingress of incompatible foulant. Unfortunately, FTIR result showed residues of organic polyelectrolyte as well as hydrocarbons which are foulants affecting permeability and production.

Recalculated averaged flux decline per annum results in 7.5% which corresponds to predictions during projections of plant performance in the design phase. Averaged increase in salt passage results in 8.6% per annum. Sharp increase in salt passage in the tail element was not taken into account. This element (A608298) was dyed prior to autopsy to help determine the cause for failure of the bubble and vacuum tests and increased salt passage. Delamination near the core tube on the brine end of the element was observed. The SEM also revealed dents on the membrane surface and embedded particles perforating membranes (Fig. 4). The dents, which possibly reduced membrane rejection, are caused by particles becoming embedded in the membrane. Dents on the membrane surface are irreversible damage. The reduced rejection/high salt passage could be attributed to the dents in the membrane as indicated in the SEM/EDAX report and the de-lamination near the core tube on the brine end.

Detailed investigation of individual elements and comparison of their performance led to the following conclusions:

- Tuning of the pre-treatment must result in elimination of organic polyelectrolyte. Used polyelectrolyte most probably accelerates flux decline and losses in production. The FTIR indicates that cationic polymer probably constitute some of the foulant. Also, executed compatibility tests of used PE and membranes show decline of the flux in the presence of polyelectrolyte.
- The FTIR indicates that hydrocarbons passed through pre-treatment and fouled RO membranes. Hydrocarbons are not compatible with membranes and irreversibly foul membranes and accelerates flux decline. Also there was indication of organic matter that originated from biofouling.
- Two lead elements should be the first to be replaced during the refurbishment process, since high ΔP can lead to element damage a premature failure.
- Remaining elements can be reused and they can work for a few more years.
- The membranes are fouled as evidenced by the loss of flow when tested at standard conditions and the fact that the SEM generally does not show the membrane surface being visible. Only foulant is observed on the membrane surface. Cleaning study had shown that proper cleaning can restore around 10% of flux.
- Rejection is still reasonably good, and that the elements with normal ΔP could continue in operation for few years more. For the purposes of using less energy, early replacement may be more effective to reduce operating cost.

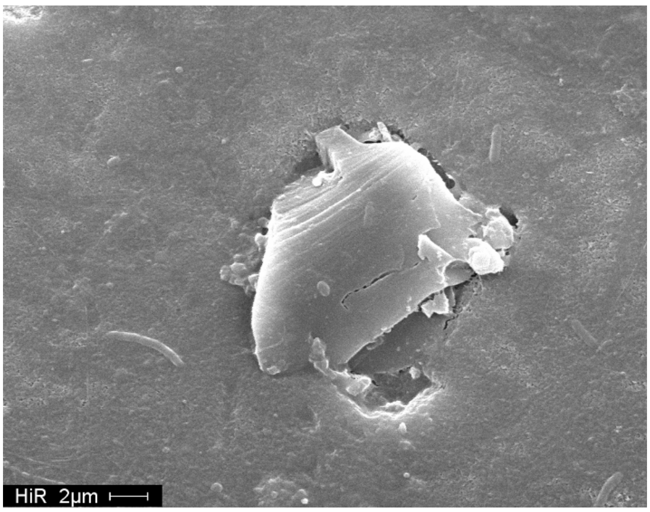

Fig. 4. Embedded particle in the membrane surface — tail element S/N A608298.

2.4. Membrane replacement

2.4.1. Comparison of design alternatives and use of SWC4+

The current generations of RO seawater membrane elements provide very good performance in respect of permeate salinity and operating pressure. The water permeability of commercial seawater membranes has increased by almost 60%, recently resulting in specific flux as high as 0.09 l/m²/h/bar, while still maintaining salt rejection of 99.8%. With good quality of feed water, proper system design and adequate operating conditions, RO membranes can maintain stable performance for many of years of continuous operation.

SWC4+ membrane is a membrane with the best salt rejection available in the market as well as a membrane with the best boron rejection recently available. Different possible alternatives of replacement were discussed in high detail between operator and membrane supplier. They are briefly summarized in Table 2.

Alternative 1 uses SWC4+ and same operational parameters as they were in the original design. Advantage of this alternative is better product water quality which will permit higher bypass and possibly reduce production in

Table 2
Summary of possible alternatives

	SWC3	SWC4+	SWC4+	SWC4+
Alternative No.	Design	1	2	3
TDS at 35°C, mg/l	548.2	361.0	391.6	362.1
Chlorides at 35°C, mg/l	323.3	211.9	229.9	212.6
Membrane age, y	3.2	3.2	3.2	3.2
Averaged flux, lmh	13.9	12.9	12.9	13.9
Production - 1st pass, m^3/d	186,082	186,082	186,082	200,600
Recovery, %	43	43	48	48
Flow through pretreatment, m^3/h	18,032.0	18,032.0	16,153.4	17,413.1

second pass. Reduced flux to 12.9 lmh will result in lower cleaning frequency due to reduced fouling.

Alternative 2 uses SWC4+ operating at increased recovery and keeping the same product quantity. There is obvious advantage in very good product quality as well as reduced averaged flux what will consequently result in reduced fouling and reduced cleaning frequency. Additional benefit is reduced amount of water through pre-treatment what should consequently result in improved membrane feed water quality. Volume of the water passing through the pre-treatment should be reduced by 10% and consequently filtration velocity in media filtration as well as it will impact energy consumption in intake station.

Alternative 3 uses SWC4+ running at increased recovery and with increased plant production which will impact the economy of the plant. Increased capacity from 17 first pass SWRO trains equals 14,518 m^3/d, which is a significant amount of water. Beside that — quality of the product is at an excellent level of 362.1 mg/l of TDS. Volume of the water flowing through the pre-treatment is still reduced — resulting in 4.5% less water flowing through the pre-treatment.

Selection of any of these alternatives should not increase power requirement of high pressure pumps. The plant design works with fixed speed pumps and fixed operational hydraulic point. Changing of the feed pressure due to seasonal changes in temperature and salinity is compensated by throttling on a permeate side. It means that selection of low pressure membranes will not benefit from this configuration. Benefits are still possible if high rejection membranes are used and consequently capacity of the second pass trains can be reduced and some second pass trains possibly kept out of operation.

Usually old plants have limited possibility in increasing production. Plant capacity can be possibly increased by:

- adding additional membrane area
- increasing recovery
- combination of both

Adding of additional area may be achieved also by different ways, but use of high surface area membranes with increased permeability and improved rejection is the easiest and fastest way. Unfortunately, increased production requires also higher amount of feed water and demands changes in pre-treatment if the same recovery is kept. Unfortunately, this possibility is not the case of Fujairah Desalination Plant. That is why the selected way was to increase recovery from 43% to 48% adding additional product capacity. Use of high rejection and high area membranes allows increase in production from rated 456 m^3/h to 500 m^3/h per train equipped with new SWC4+. At the same time, feed pressure of a train newly equipped with SWC4+ remains on the same level as when SWC3 membranes were in operation.

The first train refurbished with the new set of SWC4+ membranes was train 3 in line B. Removal of old elements and their marking, as well as sorting for the next reuse as loading of new elements took a few days and train 3 started production with increased recovery and capacity on 8 February 2008. The train is performing as expected. Real operational data collected after two months of operation are compared with IMSD software projections in Table 3. Feed pressure is 1.15 bar lower than projected and projected quality is consistent with real product quality.

Fig. 5 presents long term performance of the train 3B since September 2003 until August 2008. Increase in production is obvious since February 2008 when old SWC3 elements were replaced by new generation of membranes – SWC4+.

2.5. Reuse of old elements

It is obvious that testing and comparison of performance with original factory data as well as autopsy and SEM/EDAX analysis have shown that the first two elements are not suitable for any further use and must be discarded. To confirm these findings, 8 pressure vessels across the train were selected from removed old elements and each individual element was tested. The results were

Table 3
Train 3B — projected and real performance after 2 months

Calculation created by:	*SR					
Project name:	F1 B3 - after 2 months			Permeate flow:	499.00	m3/h
HP Pump flow:		1087.3	m3/h	Raw water flow:	1087.1	m3/h
Recommended pump press.:		71.1	bar	Permeate throttling(Variab.)	0.0	bar
Feed pressure:	66.95	**68.1**	bar	Permeate recovery:	45.9	%
Feedwater Temperature:		32.2	C(90F)			
Feed water pH:		8.1		Element age:	0.2	years
Chem dose, ppm (100%):		0.0	NaOH	Flux decline % per year:	7.0	
Acidified feed CO2:		0.79		Salt passage increase, %/yr:	10.0	
Average flux rate:		14.1	lm2h	Feed type:	Seawater - open intake	

Stage	Perm. Flow m3/hr	Flow/Vessel Feed m3/hr	Flow/Vessel Conc m3/hr	Flux l/m2-hr	Beta	Conc.&Throt. Pressures bar	Conc.&Throt. Pressures bar	Element Type	Elem. No.	Array
1-1	499.1	8.0	4.3	14.1	1.03	67.0	6.8	SWC4+	952	136x7

Projected dP = 1.2 bar real dP = 1.6 bars

Ion	Raw water mg/l	Raw water meq/l	Feed water mg/l	Feed water meq/l	Permeate mg/l	Permeate meq/l	Concentrate mg/l	Concentrate meq/l
Ca	456.0	22.7	456.0	22.7	0.706	0.0	842.3	42.0
Mg	1422.0	117.0	1422.0	117.0	2.201	0.2	2626.6	216.2
Na	11973.1	520.6	11973.4	520.6	88.829	3.9	22056.6	959.0
K	480.0	12.3	480.0	12.3	4.449	0.1	883.5	22.7
NH4	0.0	0.0	0.0	0.0	0.000	0.0	0.0	0.0
Ba	0.100	0.0	0.100	0.0	0.000	0.0	0.185	0.0
Sr	9.800	0.2	9.800	0.2	0.015	0.0	18.102	0.4
CO3	1.0	0.0	5.3	0.2	0.000	0.0	9.8	0.3
HCO3	120.0	2.0	119.6	2.0	1.406	0.0	219.8	3.6
SO4	2085.0	43.4	2085.0	43.4	3.406	0.1	3851.1	80.2
Cl	22237.0	627.3	22237.0	627.3	145.142	4.1	40980.4	1156.0
F	1.9	0.1	1.9	0.1	0.025	0.0	3.5	0.2
NO3	4.2	0.1	4.2	0.1	0.203	0.0	7.6	0.1
B	5.00		5.00		0.788		8.57	
SiO2	0.7		0.7		0.00		1.3	
TDS	38795.8		38799.9		**247.2**	584.5 µS/cm	71509.2	
pH	8.1		8.1		6.4	or 268.9 mg	8.4	

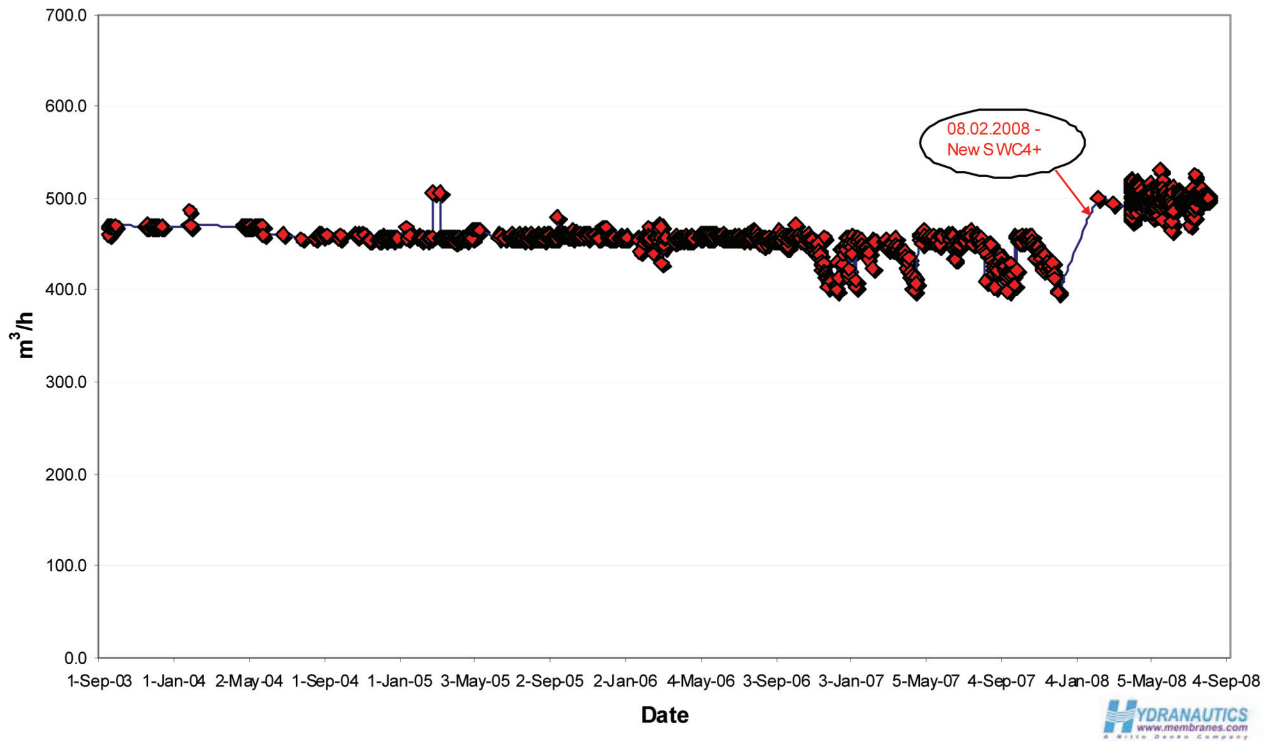

Fig. 5. Train 3 – line B – permeate flow since plant start and after replacement.

consistent with the tests executed in Oceanside and confirmed that only elements in position 3–7 could be reused.

All removed elements were properly marked when unloaded and they were reloaded to some trains following pattern. Membranes were discarded those were damaged irreversibly. Other membranes that were reoriented to different positions as per the test result to get the optimum performance during operation. Thus a rejuvenated rack is formed. The rack was finally chemically cleaned and flushed with permeate water and seawater and then restarted. Initial data was collected for future comparison.

2.6. Replacement in total

Until September 2006 a total of 527 elements were replaced in line A and 43 elements in line B, based on our information. Fig. 6 presents this number as a cumulative percentage in year 2006. It represents 2.7% of plant membranes.

In September 2007 one train was replaced (using SWC3 elements) and during the year of 2008 to date, 3 trains were replaced using SWC4+ and working with increased capacity. It represents an additional 4.7% and 13.5% respectively. Total cumulative replacement results in 20.9% during more than 5 years of operation to date.

3. Membrane service agreement

The open relationship and special cooperation that was partly described in this paper has led quite naturally to the long term membrane service agreement between Sembcorp and Hydranautics, together with extended membrane warranty period. The main points of the membrane service agreement between Sembcorp and Hydranautics can be briefly summarized:

- Regular review of normalized data as well as operational data and the RO plant performance monitoring
- Reviewing and evaluating the current O&M procedures and operational performance
- Providing periodic detailed expert reports with the recommendations for improving the O&M procedures, O&M practices and operational performance, particularly with respect to the projected replacement time of the RO membranes and the cleaning process
- Proposing from time to time revisions to improve the O&M procedures and the O&M practices if required
- Assessing the competence of the staff of the O&M contractor or its subcontractors engaged in the O&M of the existing RO plant and assisting in the training of such staff
- Advising and assisting the O&M contractor in all technical and contractual matters including the procurement of chemicals and membranes for the existing RO plant
- Pre-treatment optimization and recommendations and pilot testing
- Any other expert services required for the improvement in operation, availability, reliability and cost for the existing RO plant

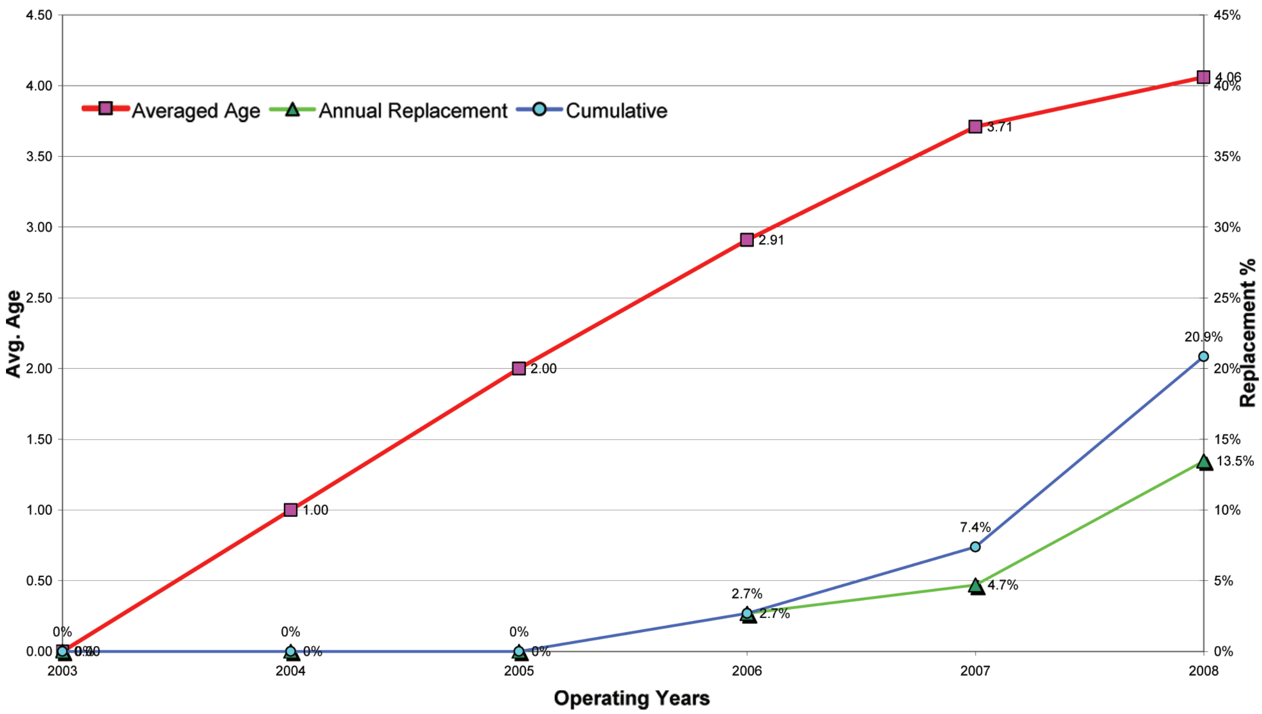

Fig. 6. Membrane age vs. annual and cumulative replacement.

4. Summary

Fujairah Water and Power Plant is one of the largest SWRO in the world and largest SWRO recently in operation in the Arabian Peninsula. The plant is already in five and a half years of successful operation. Operational experience had shown that RO membrane processes are already matured and are very reliable. Very close, open and formal long term contractual cooperation between the plant operator and membrane supplier leads to:

- stable long term membrane performance
- reduced membrane replacements through joint efforts
- reduced operating risk and cost
- reduced financial risk
- local and very swift support from membrane supplier
- increased plant capacity resulting from always using the latest membrane technology available.

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