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Performance of high area spiral wound elements in waste water reuse RO system

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ABSTRACT

Increasing global water demand and reduction of fresh water resources puts more and more pressure on municipalities all over the world to use membrane technology for reclamation of their wastewaters. Earlier pilot studies followed by full scale installations have proven that membrane pretreatment (MF, UF or MBR) in combination with RO technology can be the right answer to wastewater reclamation challenge. As energy consumption is one of the major contributors to the running cost of RO plants, use of high area and low pressure membranes can have significant impact on reclamation plant running cost.

Latest developments in membrane technology towards the energy saving, high area, high rejection and high flow membranes gives further opportunities to membrane plant designers to lower the capital cost of membrane plant as well as cost of water production. As the new features in membrane development have various influences on final membrane performance, it is very important to understand their consequences in order to select right membrane for particular application. Ideally, one would like to have combination of highest area, highest flow, highest rejection and lowest pressure in one element and almost certainly the future development in RO technology will lead to product combining all these features.

On brackish water applications, the high area 40.9 m^2 (440 ft^2) elements have been successfully used in many applications, including surface and well water treatment, treated secondary effluent (TSE) polishing wastewater applications and for the second pass in seawater systems. Generally, these applications have a higher quality feed water being supplied to the RO membranes, particularly when membrane pretreatment is used upstream. This allows the RO plant to be designed and run at higher fluxes, saving thus on total number of elements required to produce design permeate flow. One example of such application is the 147,000 m^3/d waste water treatment plant in East Asia.

Newly developed elements will also have significant advantage when used as replacement on existing installations. Their new features will allow to produce more permeate without additional changes to the system components like feed pumps head, pretreatment size, etc.

This paper will present the data of the 40.9 m^2 (440 ft^2) ESPA2+ elements under operation at the wastewater reclamation plant in East Asia and compare it with other treatment plant performance where standard 37.2 m^2 (400 ft^2) elements are used. RO performance data, including flux, differential pressure, and salt passage will be presented as well as analysis of RO elements from site after extended operating periods. It will also briefly inform about high area membranes

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developed for seawater application and describe advantages and flexibility they can offer to design engineers.

Keywords:

1. Introduction

Increasing global water demand due to population increase and industrial development, and reduction of fresh water resources, puts more and more pressure on municipalities and industries all over the world. Natural brackish water resources are getting rare in some areas and the quality of these resources could be also affected by environmental pollution. Most of natural water resources will require heavy treatment before they can be used as drinking water or process water for industry. Wastewater reclamation has become an effective alternative to maintain or supplement water supplies in water-short regions.

At the same time the detection level of organic or inorganic micro pollutants has considerably improved, norms for water are following these improvements and are getting more constringent. Reverse osmosis can cost-effectively reduce total dissolved solids, heavy metals, organics pollutants and others dissolved contaminants to the levels required by drinking or industry standards.

The use of RO technology in waste water reuse has increased recently due to the increased water demand but also due to development of the membrane pretreatment. Improvement on pretreatment and RO membranes technology have also strongly contributed to the reclamation of municipal wastewater.

Earlier pilot studies followed by full scale installations have proven that membrane pretreatment (MF, UF or MBR) in combination with RO technology can be the right answer to wastewater reclamation challenge.

Latest developments in membrane technology towards the energy saving, high area, high rejection and high flow membranes gives further opportunities to membrane plant designers to lower the capital cost of membrane plant as well as cost of water production. As the new features in membrane development have various influences on final membrane performance, it is very important to understand their consequences in order to select right membrane for particular application. Ideally, one would like to have combination of highest area, highest flow, highest rejection and lowest pressure in one element and almost certainly the future development in RO technology will lead to product combining all these features.

2. Experience in municipal waste water reclaim with 400 ft^2 membranes

Numerous large-scale commercial 37.2 m^2 (400 ft^2) membranes plants are now being used to reclaim municipal waste water. One of them is the Orange County Water District (OCWD) plant in California which has started its operation in April 2004.

2.1. Performance of OCWD demonstration plant with ESPA2 membranes

Plant capacity was 18,900 m^3/d (5 MGD) and it was equipped with Hydranautics energy saving ESPA2 membranes. In fact it was the demonstration plant which was operated at the OCWD to supply reclaimed water for injection wells before and during construction of the 265,000 m^3/d (70 MGD) system. The RO feed water was provided by the municipal waste water plant and the water produced by RO was further treated using UV with hydrogen peroxide and used for groundwater recharge and coastal injection to protect the existing freshwater basin from seawater intrusion. Final blended product has to meet the California DHS Standards.

The ESPA2 (37.2 m^2 (400 ft^2)) was selected after extensive tests on site side by side with other membranes from different suppliers which taken place in 2001–2002. At that time the ESPA2 membranes were only available with surface area of 37.2 m^2 (400 ft^2) and this surface area was also membrane industry standard for municipal water reclamation. The ESPA2 elements have shown excellent and very stable long term performance.

Outside-in MF membrane pretreatment has been used for pretreatment to RO (Table 1).

The three stages system operated at a recovery of 85% and permeate flux of 20.4 L/m^2/h (12 gfd).

The demonstration plant provided valuable lessons for the operation of the full scale plant. Within the first 4 months of operation, the membranes experienced severe biofouling and particulate fouling which led to a 40% loss in permeability and a 30% increase in differential pressure (Figs. 1 and 2). A high pH cleaning reduced differential pressure and recovered 80% of the original membrane flux, but performance continued to decline soon after restarting the system. Additional

Table 1
Typical RO feed water composition for Orange County

		OCWD
pH raw		7.6
pH feed		6
Chloramine	mg/L	2–3
Temp	mg/L	19–27
SDI	mg/L	<3.0
Turbidity	mg/L	0.1–0.5
Ca	mg/L	77
Mg	mg/L	23
Na	mg/L	213
NH_4	mg/L N	20.1
PO_4	mg/L	2.7
Alk	mg/L $CaCO_3$	264
Cl	mg/L	219
Fluoride	mg/L	1.1
Sulfate	mg/L	254
Nitrate (NO_3)	mg/L	4
SiO_2	mg/L	21.9
TOC	mg/L	10.5
Iron (Fe)	mg/L	0.22
Manganese (Mn)	mg/L	0.05
TDS	mg/L	1167

high pH cleanings produced a similar cycle of improved performance followed by rapid fouling. In 2005 and early 2006, several adjustments were made to the system to bring the rate of fouling under control. However, it is clear from numerous studies that some degree, usually 20–30%, flux decline should be expected due to organic fouling. Activated sludge treated wastewater always contains high level of dissolved organics which adsorb to the membrane surface and reduce permeability.

2.2. *Performance of OCWD full scale plant 70 MGD (265,000 m^3/d) with ESPA2 membranes*

The full scale plant has started in November 2007. The design of the plant was made at early stage based on OCWD demonstration plant which is using ESPA2 membranes. ESPA2+ membranes were already available since 2 years on the market but only ESPA2 were used and tested on site. The OCWD plant consists of 15 trains (14 in operation with one train as standby) with a capacity of 18,900 m^3/d (5 MGD) per train. The array for each train is three stages (78:48:24) with seven elements per vessel. The OCWD design has a flux at 20.4 lmh (12 gfd) and a recovery of 85% (Figs. 3–5).

2.3. *Increase of the membrane surface area with time*

Over the past 10–15 years of development, both brackish and seawater elements have undergone the changes which resulted in the following major improvements:

- Membrane area have increased from 33.9 m^2 (365 ft^2) to 37.2 m^2 (400 ft^2), and most recently to 40 m^2 (430 ft^2) or 40.9 m^2 (440 ft^2)
- Membrane permeate production have been increased from 0.95 m^3/h (6000 GPD) to current 1.89 m^3/h (12,000 GPD) per element

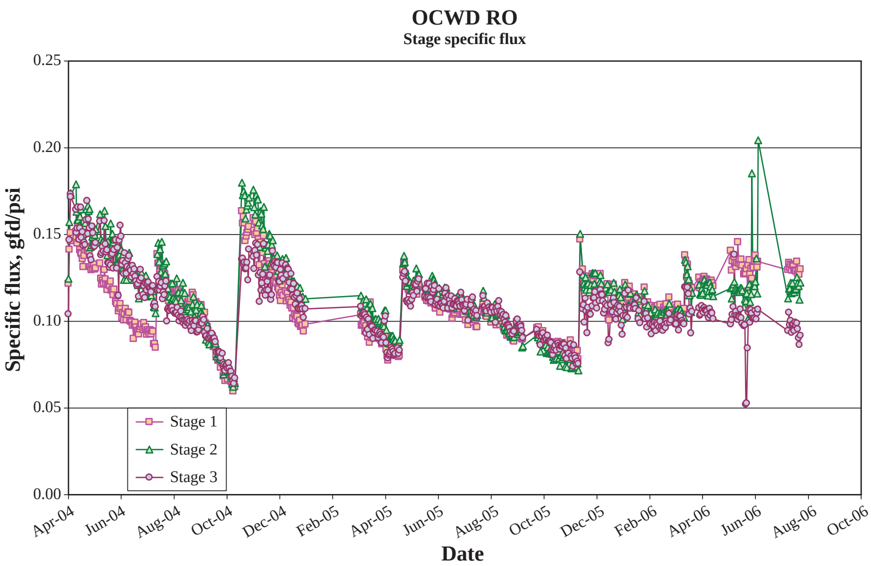

Fig. 1. OCWD 5 MGD RO demonstration plant – stage specific flux. [1]

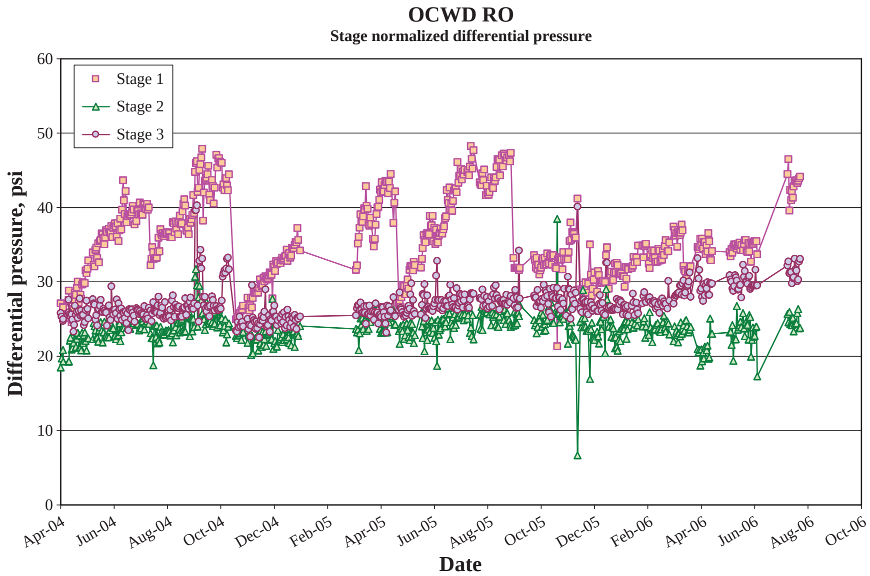

Fig. 2. OCWD 5 MGD RO demonstration plant – stage differential pressures. [1]

- Feed pressure required to produce same volume of permeate was reduced by introduction of energy saving elements
- Above improvements have been achieved without significant compromising on salt rejection

Newly developed elements will also have significant advantage when used as replacement on existing installations. Their new features will allow to produce more permeate without additional changes to the system components like number of pressure vessels, feed pumps head, pretreatment size, etc.

Above advantages will also apply to seawater systems as development of high area and high flow elements is similar to brackish water membranes. Particularly, low pressure elements will bring more savings on running cost as the feed pressure requirements on seawater systems are much higher.

For most of the projects the standard element size in the membrane industry is 8 in. module diameter. Increasing the membrane surface area, while keeping the standard element diameter and length, is a real challenge. It is even more difficult for waste water reclamation, where slight modification could easily impact the overall performance of the RO plant.

It is very important to keep the same performance of membranes in such difficult applications like municipal reclamation. With improved materials and manufacturing techniques, it is now possible to make spiral wound elements with higher water production while using the same feed spacer. For example the ESPA2+ element which has 440 ft^2 has the same brine spacer as the 400 ft^2 ESPA2 element (0.66 mm (26 mil).

More recently, these improved technologies have resulted in the first offering of high area, 440 ft^2 seawater membrane elements. Again, the higher area construction is achieved without compromising on brine spacer thickness. The higher area is achieved by control of glue line and fold protection to minimize wasting too much active membrane surface area (Table 2 and 3).

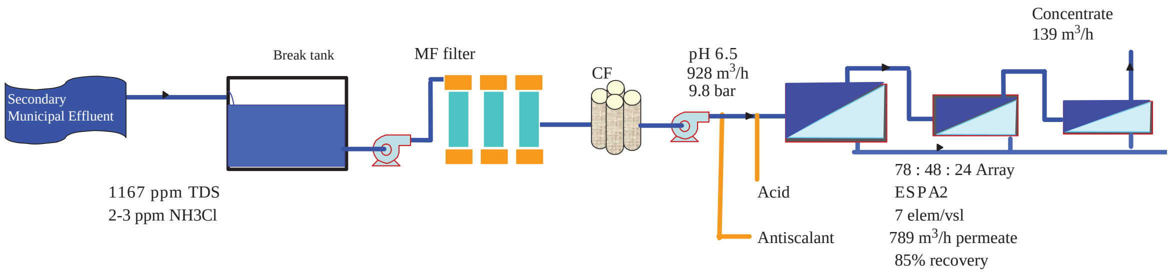

Fig. 3. Process flow diagram of the OCWD system.

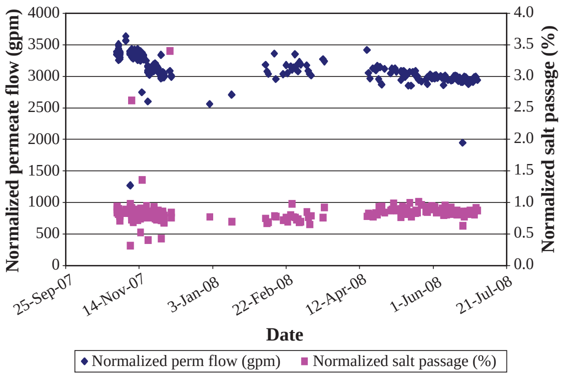

Fig. 4. OCWD 70 MGD RO full scale plant – specific flux and normalized salt passage.

4. Experience in municipal waste water reclaim with 440 ft^2 membranes

On brackish water applications, the high area 440 ft^2 elements have been successfully used in many applications, including surface and well water treatment, treated secondary effluent (TSE) polishing wastewater applications and for the second pass in seawater systems. Generally, these applications have a higher quality feed water being supplied to the RO membranes, particularly when membrane pretreatment is used upstream. This allows the RO plant to be designed and run at higher fluxes, saving thus on total number of elements required to produce design permeate flow. One example of such application is the 147,000 m^3/d site at an East Asian Waste Water Treatment Plant (WWTP).

4.1. Performance of WWTP pilot plant

Piloting for the WWTP site started on March 11, 2006, with a two stages, 4:2 array and seven elements per vessel. The pilot operated at conditions identical to that of the full scale system with a target flux of 18 lmh. Out-in MF membranes pretreatment have been considered and used for pretreatment to RO (Figs. 6 and 7).

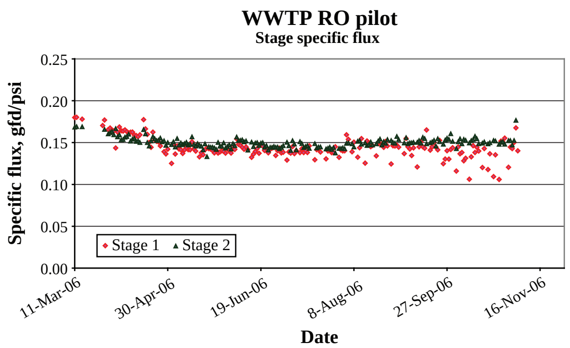

Fig. 5. WWTP RO pilot – stage specific flux.

4.2. Performance of WWTP full scale plant

The full scale plant has started in February 2007 and the water produced is mainly used for semiconductor industry. This facility was designed with 13 trains in a 64 by 36 array using 440 ft^2 ESPA2+ high area, high rejection and low pressure brackish water elements. The system, which operates at flux of 18 lmh, has 10% less elements and pressure vessels when compared with 400 ft^2 element design because of the use of the high area elements. The plant has now been operating well for over a year with these elements.

Each of the thirteen WWTP trains produces 12,300 m^3/d (3.25 MGD) for a total of 148,000 m^3/d (39 MGD). Twelve of the 13 trains are in continuous operation with one as standby. The average system flux is 18 lmh (10.6 gfd) and system recovery is 80%. Each train is configured as a 64:36 two stage array with seven elements per vessel. A turbo booster is operated between the two stages (Fig. 8–10).

4.3. Advantages of ESPA2+ compare to ESPA2 in the case of WWTP full scale plant

4.3.1. Considering same flux

By using high area 440 ft^2 elements, we need 10% less modules therefore we need 10% less pressure vessel including the associated piping. In the case of WWTP we have 1300 pressure vessel, which correspond to a saving of 130 pressure vessel or $200,000 just by using ESPA2+ high surface area membrane and this exclude extra saving on piping or footprint. It also saves maintenance cost, by example the membranes loading will take 10% less time or 10% less manpower.

4.3.2. Considering the same number of modules

By using high area 440 ft^2 elements and keep same number of modules as the standard area 400 ft^2 elements, we can reduce the flux by 10%. Reducing the flux will minimize fouling on the membrane, improve the operating condition for the membrane and also reduce the feed pressure. The feed pressure is a key parameter which affects directly the cost of the water produce. By using ESPA2+, we save in this case and in average, more than 1 bar pressure which is an important amount of energy saved for 148,000 m^3/d plant.

Table 2
Evolution of membranes surface area

Products	Area in m^2 (ft^2)	Flow in m^3/d (gpd)	Rejection (%)	Year
CPA2*	33.9 (365)	37.9 (10,000)	99.5	1990
CPA3*	37.2 (400)	41.6 (11,000)	99.6	1996
ESPA2**	37.2 (400)	34.1 (9000)	99.6	1998
ESPA2+**	40.9 (440)	45.4 (12,000)	99.6	2005
Products***	Area in m^2 (ft^2)	Flow in m^3/d (gpd)	Rejection (%)	Year
SWC3	34.4 (370)	22.3 (5900)	99.7	2001
SWC3+	37.2 (400)	26.5 (7000)	99.8	2003
SWC4+	37.2 (400)	24.6 (6500)	99.8	2003
SWC5	37.2(400)	34.1 (9000)	99.8	2004
SWC5 MAX	40.9 (440)	37.5 (9900)	99.8	2008
SWC4 MAX	40.9 (440)	27.3 (7200)	99.8	2008

* Test conditions: 1500 ppm NaCl solution, 1.55 MPa, 25°C, 15% recovery, pH 6.5-7.0.
** Test conditions:1500ppm NaCl solution, 1.05 MPa, 25°C, 15% recovery, pH 6.5–7.0.
*** Test conditions: 32,000 ppm NaCl solution, 5.5 MPa, 25°C, 10% recovery, pH 6.5–7.0.

5. Conclusion

Important process information has been developed based on our extensive experience in waste water reclamation application. We have seen that for Orange County and WWTP the selection of the membrane has been always a long process. Extended pilot has been done in three phases for OCWD and in two phases for UP.

It appears that high rejection, energy savings (ESPA2) membrane type has been the most suitable membrane for these municipal reclamation water treatment plants. We have developed high area, high rejection, energy savings (ESPA2+) membranes which offer 10% higher surface area than the traditional 400 ft^2 membrane elements. For OCWD the ESPA2+ (with 440 ft^2) was not available for initial piloting phase therefore the full scale plant has been design with ESPA2 despite the availability of ESPA2+. WWTP was designed more recently and elected to use the high area elements. This full scale plant has 10% less elements and pressure vessels when compared with 400 ft^2 element design because of the use of the high area elements.

Municipal waste water applications are always challenging application. Pretreatment, antiscalant dosing, pH adjustment, the chloramine dosing and the cleaning regime are very important parameters which are affecting directly the performance of the plant. Frequent cleaning, salt passage increase and flux

Table 3
Typical RO feed water composition

		WWTP
pH raw		7
pH feed		6.8
Chloramine	mg/L	2–3
Temp	mg/L	28–32
SDI	mg/L	<3.0
Turbidity	mg/L	0.1–0.5
Ca	mg/L	36
Mg	mg/L	5
Na	mg/L	170
NH_4	mg/L N	8
PO_4	mg/L	15
Alk	mg/L $CaCO_3$	72
Cl	mg/L	271
Fluoride	mg/L	0.6
Sulfate	mg/L	70
Nitrate (NO_3)	mg/L	43
SiO_2	mg/L	8.4
TOC	mg/L	12
TDS	mg/L	677

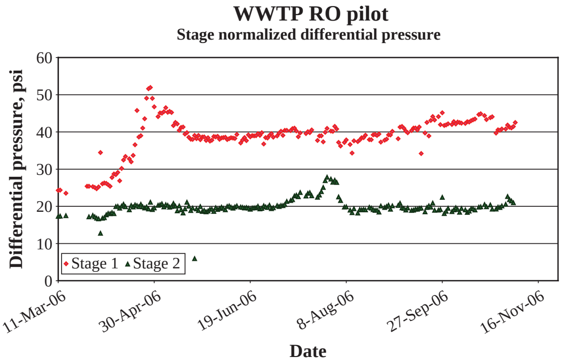

Fig. 6. WWTP RO pilot – differential pressure.

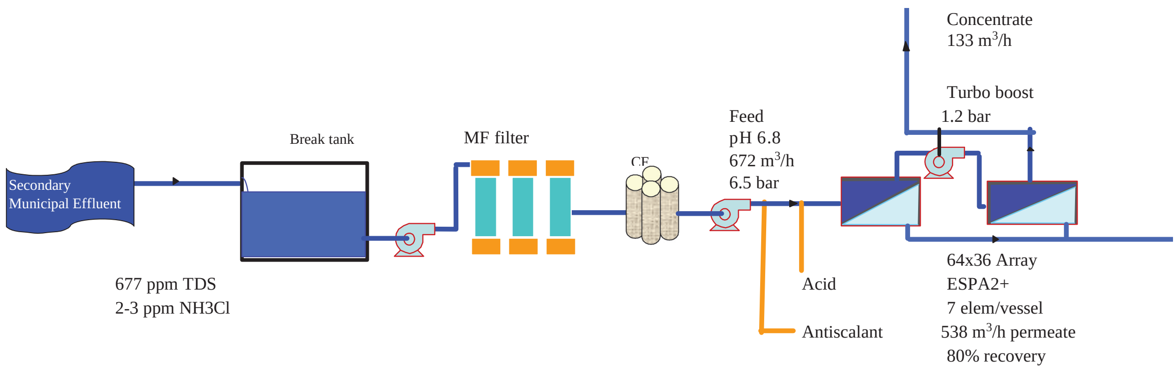

Fig. 7. WWTP single train process flow diagram.

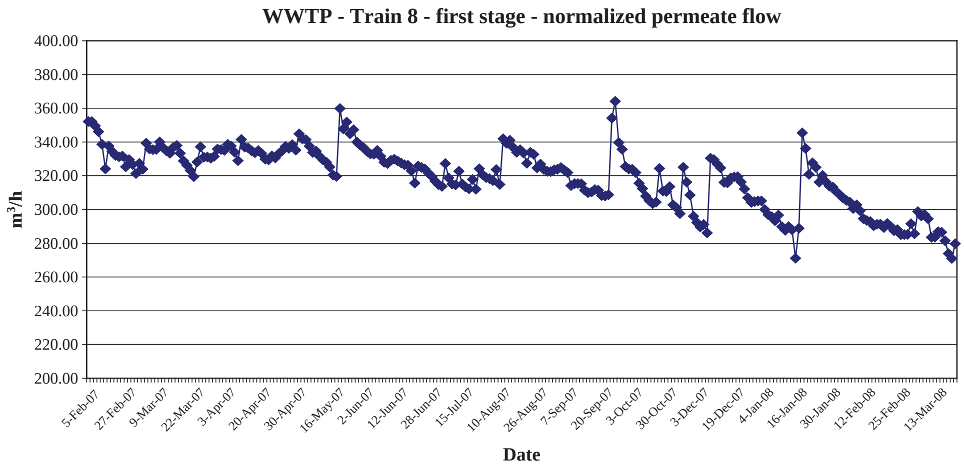

Fig. 8. WWTP full scale plant Train 8, first stage normalize permeate flow.

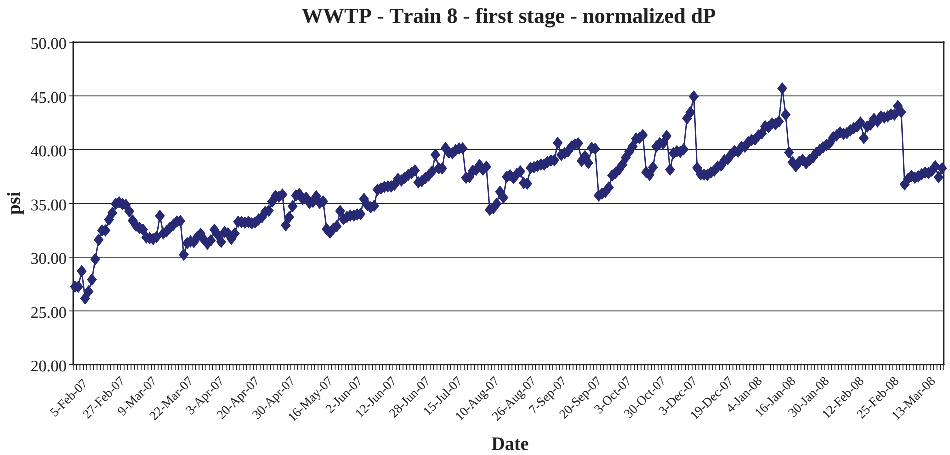

Fig. 9. WWTP full scale plant Train 8, first stage normalized dP.

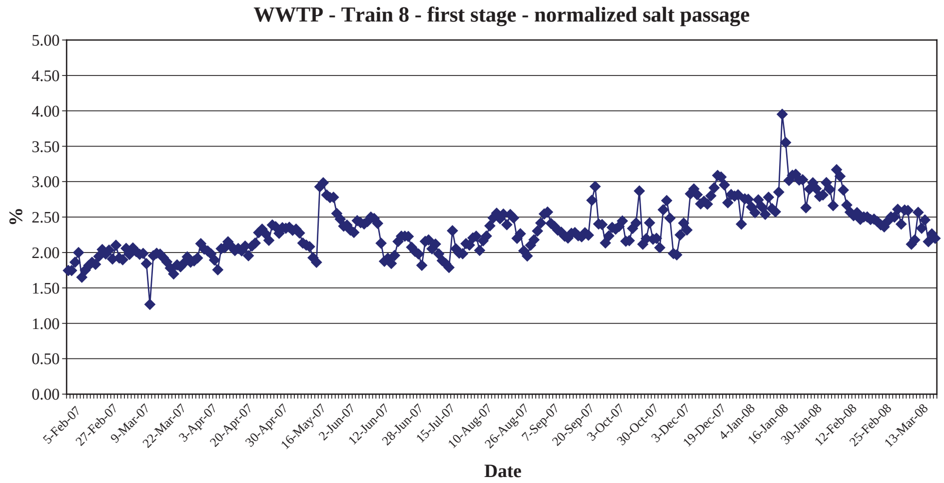

Fig. 10. WWTP full scale plant Train 8, first stage normalized salt passage.

decline are also characteristic of Municipal water reclamation. ESPA2 and ESPA2+ have shown very stable performance taking in consideration the application, the difficulties and individual characteristic of each feed water. Municipal waste water reclamation applications are always constringent for RO membranes and performance data curves are different than well water treatment or second pass RO.

Newly developed elements with high surface area will also have significant advantage when used as replacement on existing installations. Their new features will allow users to produce more permeate without additional changes to the system components like number of pressure vessels, feed pump head, RO plant footprint, etc. This technology has been used for some time on brackish water applications and is now also available for seawater applications as well. Because of the precision of element manufacture, the higher area elements have been produced using the same feedspacer which was used in the lower surface area elements.

The performance data from large-scale municipal reclamation plants confirms that the high area membrane elements show similar performance as the standard 400 ft^2 membrane elements. Because of this, it is expected that many new plants will take advantage of the more economical high area element designs.

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