DESALINATION

Desalination 182 (2005) 293–300

www.elsevier.com/locate/desal

UF membranes for RO desalination pretreatment

Peter H. Wolf*, Steve Siverns, Sandro Monti

ZENON Environmental Inc. Oadville, ontario canada
Tel. +43 662 83068133; e-mail: hp.wolf@zenon-europe.de

Received 27 April 2005; accepted 5 May 2005

Abstract

After difficult times in the nineties, Reverse Osmosis (RO) desalination nowadays gains again acceptance around the world and plays a larger and more important role in the municipal desalination market for small, medium and large scale applications. Since RO desalination plants depend on high quality feed water to ensure reliable and stable operation of the RO system, pretreatment with UltraFiltration (UF) membranes must be given strong consideration. UF membranes, having been proven in a wide range of much more difficult liquid environments such as municipal and industrial wastewaters, have become the preferred pretreatment solution. UF pretreatment also allows the economical utilization of RO membranes in areas where membrane desalination has not been considered as the appropriate technology due to difficult raw water conditions. Furthermore, using UF membrane technology to produce high quality pretreated feedwater allows troublesome RO installations to be brought to design productivity levels. UF, unlike conventional pretreatment technologies, provides a physical barrier to particulate and colloidal material and ensures that RO plants can operate on a continuous basis, at high and stable fluxes, at higher recovery rates, and also allow a better control of Boron limit values. All of these allows an increase in RO productivity and a decrease in life time costs.

Keywords: Ultrafiltration pretreatment; Reverse osmosis; Seawater desalination

1. Introduction

Seawater Reverse Osmosis (RO) desalination technology had a difficult time in the 1990s caused by some malfunctioning installations. Today, RO desalination for seawater and brackish water applications is again rapidly becoming the technology of choice in a world plagued with increasingly limited water resources; seawater RO and nanofiltration desalination plants with a total capacity of about 3.3 million m^3/day were contracted in the period from 2000 until 2004.

Arabian Gulf water has many times been accused to be one among the worst to be treated by seawater RO technology and operational experiences at earlier installations have proven that consistent high quality pretreatment of raw water is critical for a

*Corresponding author.

long-term successful operation. Today, plant engineers are seriously considering ultrafiltration (UF) membrane pretreatment; a technology enabling RO membrane units to provide decades of reliable high quality product water.

2. Pretreatment—Why?

RO membranes are susceptible to a wide variety of organic and inorganic foulants. To mitigate membrane fouling, RO systems require sufficient, reliable pretreatment to produce superior quality RO feedwater that will ensure stable, long-term performance of RO membrane elements; regardless of the turbidity variations of the raw water.

Ineffective or unreliable pretreatment can lead to problems with the RO system including high rates of membrane fouling, high frequency of membrane cleanings, lower recovery rates, high operating pressure, poor product quality and reduced membrane life; all having a direct impact on plant productivity and operational costs. Accordingly, pretreatment optimization is the key factor for a successful RO desalination system.

3. RO pretreatment types

Conventional RO pretreatment (mostly using chemical addition and sand filtration, followed by a security finefilter system) has been widely applied in the past for seawater RO plants to lower the Silt Density Index (SDI) and to remove suspended solids and excessive turbidity.

With the cost of membrane pretreatment constantly declining and quality of feedwaters deteriorating, an increasing number of plant owners are nowadays considering the use of membrane based pretreatments to replace less efficient, conventional pretreatment systems, which do not represent a positive barrier to colloids and suspended solids and produce unsteady quality of RO feedwater.

3.1. Conventional RO pretreatment

Classical conventional pretreatment systems usually consist of an open seawater intake, screens for coarse prefiltration, chemical additions (break-point chlorination, acid addition, in-line coagulation, addition of a flocculation aid) followed by a single- or double-stage sand filtration. Filtration is either performed in pressurized lined steel/GRP vessels or gravity driven concrete chambers to remove a portion of the coagulated organic and inorganic particulate and colloidal matter present in the raw water. The final step of pretreatment is a cartridge- or bag type guard filter with a mesh size of five to 10 microns to protect the RO membranes. Accordingly, particles larger than five microns only are removed (Fig. 1).

Some RO systems are fed with seawater from beachwells. Provided that the beachwell system is well developed and maintained and provides a constant and continuous yield, low suspended solids water can be received. In such cases, it is possible to achieve 15-min

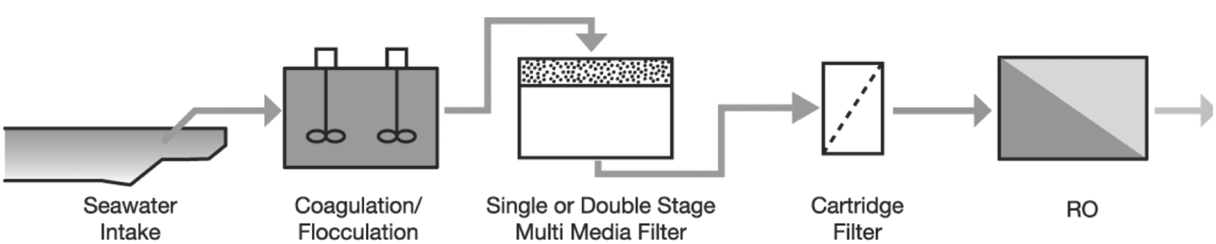

Fig. 1. Typical conventional pretreatment.

SDI values (SDI_{15}) well below 3 using single stage sandfiltration without coagulant or even by simple cartridge- or bag-filters only.

Backwashing of the conventional filter system is carried out with filtered water and air. Backwash frequency is at least once a day, usually after a preset differential pressure across the filter is reached. The frequency of replacement of filter cartridges or bags absolutely depends on the quality of the raw water as well as the performance of the pretreatment section and ranges from about every two to eight weeks.

Above described pretreatment systems may produce feed water of an acceptable quality when properly tuned and with good and constant raw seawater quality. However, upsets result in changes in water quality that are detrimental to the operation of the RO and well tuned conventional pretreatment systems are not always capable of achieving SDI_{15} values that meet the requirements set by the RO membrane manufacturer; typically less than three or four.

Several major disadvantages of a conventional pretreatment treating surface seawater contribute to higher rates of RO membrane fouling and shorter RO membrane life expectancy including:

- Significant fluctuations of the quality of RO feed caused by changing raw water conditions.
- Difficult to achieve a constant $SDI_{15} < 3.0$ especially during high turbidity feed water conditions.
- Low removal efficiency of particles smaller than 10–15 microns.
- Possibility of breakthrough during filter backwash.
- Carry over of high concentrations of colloidal particles immediately following a filter backwash.
- Coagulant impact on RO membranes.

In addition to the above, slow filtration velocities also result in large land foot print requirements for a conventional pretreatment system.

3.2. Ultrafiltration based RO pretreatment

UF membranes have originally been developed and proven for many years in a wide range of much more difficult liquid environments than seawater, such as highly polluted municipal and industrial wastewaters.

Unlike conventional pretreatment systems, UF membranes provide a positive barrier to particulates and pathogens and protect the RO by physically separating the solids. This ensures a consistent and excellent RO feedflow quality, regardless of raw water turbidity even during storm events and algae blooms and is also considered to be the best choice for pretreatment of seawater that contains colloidal silica.

As a result they are being increasingly considered for new RO desalination installations, especially when treating surface seawater and for retrofit upgrades to existing conventional RO pretreatment systems.

At present immersed plate-, pressure driven capillary-, pressure driven spiral wound and immersed hollow fiber membranes are commercially available.

Immersed, outside-in, hollow fiber UF membranes use a slight vacuum to draw clean water into the hollow fiber through the membrane pores while rejecting particles at the outside fiber surface. The advantages of such a system compared to traditional pressure driven membranes include less risk of plugging the pores with particulate matter and overall lower energy costs due to a lower *trans*-membrane pressure (TMP).

In seawater RO plants equipped with immersed UF membrane pretreatment, chemical dosing is significantly reduced or eliminated. The seawater is typically supplied from an open intake line, which can be much shorter than for a conventional pretreatment, prefiltered at least by a mechanical screen and is then fed to the concrete or lined steel UF-membrane process tank. UF membrane fibers like the ZeeWeed® 1000 are arranged horizontally and housed in durable membrane modules and have many operator-friendly features such as a lightweight design, easy and safe handling and the ability to visually inspect the fibres. The modules are assembled in compact, corrosion resistant rectangular, modular membrane cassettes that can be easily immersed into a compact process tank, which allows for a smaller system footprint.

Immersed membranes are loosely suspended in the process tank, do not require pressure vessels and employ a low-pressure (up to max. 0.8 bar) vacuum to draw water through the surface of the membrane in an outside-in flow path. The vacuum to draw permeate through the fibers is provided by the UF permeate pump.

With a nominal pore size of 0.02 microns, the membrane forms a physical barrier against suspended particles, colloidal materials, algae and bacteria leading to excellent RO feedwater results which are typically: SDI_{15} less than 2.5 and often less than 1.0; Total Suspended Solids values less than 2 mg/L and turbidity less than 0.1 NTU, even with high influent turbidity feed water. Antiscalant to inhibit scale formation and sodium bisulphite when any residual chlorine is present in the RO feedwater are injected downstream of the UF permeate pump as necessary to protect the RO membranes (Fig. 2).

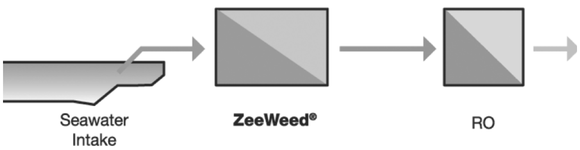

Fig. 2. Typical UF membrane pretreatment.

Using UF membrane pretreatment eliminates the need for guard cartridge or bag-filters in front of the RO system in cases where the UF permeate is fed directly to the RO.

Backpulsing (backwashing) and in-situ cleaning procedures, when needed, are fully automated and controlled by a PLC. This ensures the highest possible net production rates and the greatest time between membrane cleanings. Backpulsing of membranes is performed with filtered water (UF permeate) by reversing the flow from outside in to inside-out. This frequent but brief flow reversal ensures that the surface and pores of the membrane are kept clean and in turn greatly reduces fouling. Air scouring is used during the backpulse cycle to accelerate removal of particles and foulants that deposit on the outside of the fiber, thereby allowing operation at a high overall flux rate and/or a lower TMP. A backpulse cycle typically lasts for one to two minutes every 20 to 60 mins. Although this frequent backpulse cycle slightly reduces the overall net permeation rate from a UF system, the benefits of stable and reliable operation at a reduced cleaning frequency more than compensate (Fig. 3a and b).

The physical barrier characteristic, coupled with the immersed hollow fiber outside-in filtration direction make this UF

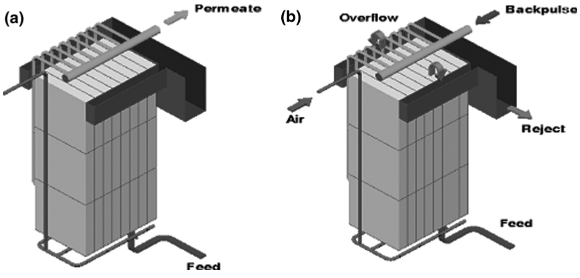

Fig. 3. a; ZeeWeed® 1000 Cassette in filtration mode. b; ZeeWeed® 1000 Cassette in backpulse mode

membrane system inherently more robust than conventional pretreatment and ensures consistent high quality RO feed to protect the RO system from fouling.

The high surface area offered by the membranes in a compact arrangement means that UF plants are also significantly smaller than their conventional counterparts, easing space constraints during expansions or retrofits and providing potential savings in land acquisition.

Other UF pretreatment features and benefits:

- Much shorter seawater intake line
- Significantly reduces RO membrane fouling and frequency of membrane cleaning
- Extends the life of RO membranes
- Lower consumption of operational and cleaning chemicals
- Lower requirement of operations staff due to complete automation
- Higher RO membrane operating flux (therefore fewer RO membranes, pressure vessels, manifolds and space), resulting in lower total water cost even considering the higher RO energy input required
- Greater plant availability resulting from consistent production of excellent RO feedwater and reduced cleaning requirements
- Module design enables simple and efficient sand filter retrofits

4. Operational experience with a conventional pretreatment system

Tampa Bay's, Florida 94.000 m^3/day seawater desalination facility began producing drinking water from seawater more than two years ago. Problems with the facility's pretreatment system, coupled with some other operational difficulties have significantly watered down the plant's performance. The existing plant design uses a two-stage dual sand pretreatment system to remove turbidity, algae, organic material and other particulate matter from the incoming raw seawater. The SDI_{15} recommended by the manufacturer for the RO membranes is <4; however, the existing pretreatment could not consistently meet these parameters to protect the RO system. As a result, the RO membranes foul too quickly and the desalination plant cannot achieve peak drinking water production. The higher SDI of the feed water means that the desalination plant faces frequent cleaning of the RO membranes, which significantly increases operating costs through higher energy consumption, increases chemical usage for cleaning and requires more frequent RO membrane replacement. Moreover, the plant only operates intermittently and produces less drinking water than it is designed to deliver.

In April 2004, two teams began a three-month pilot test of alternative pretreatment technologies that could remedy the problems at the plant and restore its performance to optimal design specifications. The technologies tested at the plant included immersed low-pressure outside-in UF membranes, diatomaceous earth (DE) precoat filtration and high rate settling. ZeeWeed® immersed UF membranes significantly outperformed the others, providing exceptional pretreatment results and consistently producing feed water with an SDI_{15} of <1.0, regardless of the turbidity and other quality characteristics of the raw water. A comparison of the results showed that the SDI varied more after DE precoat filtration and high-rate-settling than it did with the UF unit and seldom produced feedwater within the same low SDI range as the UF (Fig. 4).

5. Costs

The economic comparison of the two technologies depends on a large number of

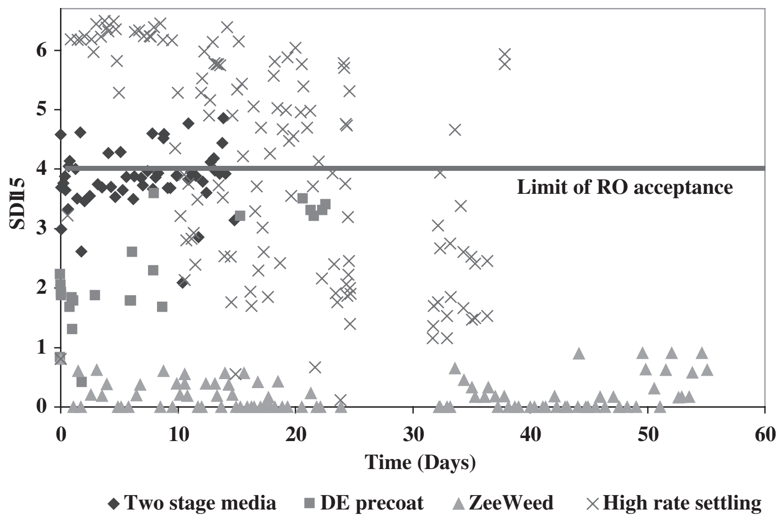

Fig. 4. Tampa Bay pretreatment performance.

parameters including, most significantly, raw seawater quality, membrane replacement rates and utility costs (Figs. 5 and 6).

Costs for two comparable systems are presented based on the assumptions as shown on the next page:

6. Ultrafiltration pretreatment in large scale seawater RO plants

UF systems have been piloted for several years in various environments such as the Mediterranean, Arabian Gulf, Pacific and Atlantic to prove its ability to and advantages when treating seawater.

Today, large-scale UF applications are under design and construction to pretreat seawater prior to RO desalination plants such as in Japan, in the Kingdom of Saudi Arabia and China. The latter being installed for a power

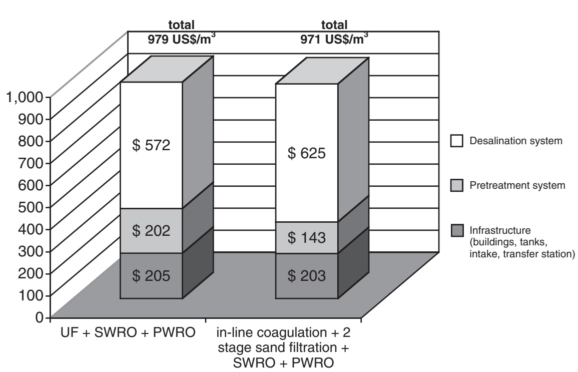

Fig. 5. Specific Investment costs (figures in US$/m^3/day). Remark: Above costs do not include land acquisition.

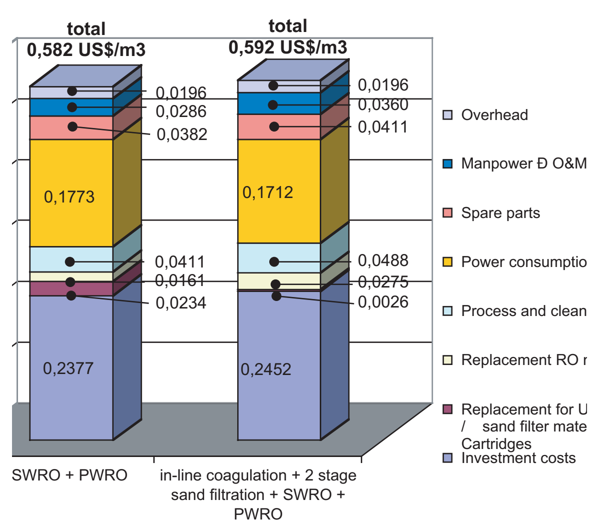

Fig. 6. Operational costs (figures in US$/m^3). Remark: Above costs do not include land acquisition and do not consider any penalties for alternative water supply in case of plant underperformance caused by pretreatment.

2-pass RO desalination plant:	74.000 m^3/day
Raw water:	Seawater 35.000 p.p.m. TDS, poor quality, high/variable turbidity, $SDI_{15} > 6$
Interest rate:	6.5%/plant life 25 years
Power cost:	US$ 0.045/kW-hour

plant located in Zhejiang Province, where immersed hollow fibre UF membranes will pretreat more than 76.800 m^3/day of seawater in the outside-in mode. The UF membrane system is arranged in 6 trains, each housing 4 cassettes and in total consists of 1.296 membrane modules. The design principal of the project was to ensure that the system has a continuous safe operation and the product water quality and quantity reaches the technical requirements. This UF seawater pretreatment system, being one of the world's largest installations of its type, will feed a double stage seawater desalination plant with a RO permeate capacity of 34,560 m^3/day.

7. Conclusion

The continuous production of superior quality feedwater, regardless of the turbidity of the raw water, is a critical requirement for ensuring optimum operation of an RO system and protects it from fouling.

By incorporating UF pretreatment for a seawater desalination system, operators can significantly reduce the rate of membrane fouling and extend the life of RO membrane modules. Other major benefits include much shorter seawater intake lines, simple and efficient sand filter retrofits, higher RO membrane operating flux, less footprint and reduced downtime, maintenance and operating costs.

Table 1
Technical summary UF vs. conventional pretreatment

	UF pretreatment: ZeeWeed® 1000 immersed hollow fiber	Conventional pretreatment: in-line coagulation and 2-stage sand filters
Treated Water:		
SDI_{15}:	<2.5, 100% of the time, usually <1.5	<4 for about 30% of the timer
Quality:	Consistent, reliable	Fluctuating
Barrier activity:	Positive barrier to particles and pathogens – no breakthrough	Not a positive barrier to colloidal and suspended particles
Turbidity:	<0.1 NTU	<1.0 NTU
Bacteria:	>5 log removal	N.A.
Giardia:	>4 log removal	N.A.
Virus:	>4 log removal	N.A.
Typical Lifetime:		N.A.
UF Membranes:	5–10 years	N.A.
Filter media:	N.A.	20–30 years
Cartridges:	often not needed	2–8 weeks
Average RO Flux:	~18 lmh	~14 lmh
SWRO replacement-rate	~10% per year	~14% per year
SWRO cleaning frequency	~1–2 times per year	~4–12 times per year
Pretreatment foot-print	~30–60% (of conventional)	100%

References

[1] D.I.K. Wangnick, 2004 IDA Worldwide Desalting Plants Inventory Report no. 18, June 2004.

[2] P.E. L. Henthorne, Evaluation of Various Pretreatments for SWRO, August 2004.

[3] M. Wilf, Improved performance and cost reduction of RO seawater systems using UF pre-treatment, October 2000.

[4] A. Jorge, Redondo, 'Brackish-, sea- and wastewater desalination, March 2004

[5] S. Siverns, R. Maness and B. Movahed, Alternative pre-treatment tests with UF yield excellent results at Tampa Bay, December 2004.

[6] V. Bonnelye, A. Brehant and M.A. Sanz, Surface Seawater pre-treatment upstream RO: long term test using UF membranes, September 2003