The New Generation for Reliable RO Pretreatment

Peter H. Wolf\textsuperscript{1} and Steve Siverns\textsuperscript{2}
\textsuperscript{1}Director Desalination ZENON Environmental Inc.
\textsuperscript{2}Ultra Pure Global Product Mngr.ZENON Environmental Inc.

Abstract

As Reverse Osmosis (RO) desalination gains acceptance around the world and plays a larger and more important role in the desalination market for small-, medium- and large- scale applications, it is critical to address the pretreatment sensitivity of RO plants.

Since an RO plant depends on high quality feed water to provide reliable and stable operation, ultrafiltration (UF) membrane based pretreatment should be given strong consideration.

UF membranes, having been proven in a wide range of much more difficult liquid environments, are being increasingly considered for new RO desalination installations and for retrofit upgrades to existing conventional RO pre-treatment systems.

Using UF membrane technology to produce high quality pretreated feedwater allows troublesome RO installations to be brought to design productivity levels. Furthermore, UF pretreatment 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.

UF, unlike conventional pretreatment technologies, provides a physical barrier to particulate and colloidal material and ensures that RO plants can operate at high and stable fluxes. This allows an increase in RO productivity and a decrease in life time costs.

This paper discusses the advantages and performance of UF membrane pretreatment and compares overall life-cycle costs.

1. Introduction

After difficult times in the 1990s caused by some malfunctioning seawater Reverse Osmosis (RO) plants in the Middle East, RO desalination for seawater and brackish water applications is once again rapidly becoming the technology of choice in a world plagued with increasingly limited water resources.

According to the 2004 IDA Worldwide Desalting Plants Inventory Report No.18, seawater RO and nanofiltration desalination plants with a total capacity of about 1,1 million m\textsuperscript{3}/day were contracted in 2003. In contrast, the comparing figure for 2002 was about 0,25 million m\textsuperscript{3}/day, about 1,1 million m\textsuperscript{3}/day in 2001 and about 0,5 million m\textsuperscript{3}/day in 2000.

Operational experiences at earlier seawater RO installations have shown that upstream pretreatment of raw water is the most critical part to efficiently and effectively operating the desalination plant. Today, plant engineers are seriously considering ultrafiltration (UF) membrane pretreatment; to enable the RO membrane units to provide decades of reliable high quality product water.
2. The need of pre-treatment for RO plants

Reverse Osmosis is a mature technology that has progressed from only small specialized applications 30 years ago to a wide range of applications covering small, specialized separation applications to very large municipal drinking water preparation. RO uses pressure to drive water molecules through a semi-permeable membrane which does not allow particulate matter or dissolved ions and organic molecules to pass through.

The configuration of RO membranes makes them very 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 pre-treatment 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, reduced membrane life and reduced plant productivity.

3. Types of pre-treatments

In the past, RO pre-treatment was provided by conventional systems mostly using chemical addition and sand filtration followed by a security cartridge filter system.

With the quality of feedwaters deteriorating and the cost of membrane pretreatment constantly declining, an increasing number of plant owners are considering the use of membrane based pretreatments to replace less efficient, conventional pretreatment systems.

![Figure 1: Bacteria, mineral salts and shell fragments on SDI filter paper](image1)

![Figure 2: Filtration Spectrum](image2)
3.1 Conventional Pretreatment

Seawater RO plants with conventional pretreatment usually consist of: a seawater intake system, rotating screens for coarse pre-filtration, break-point chlorination, acid addition, in-line coagulation, addition of a flocculation aid, followed by a single- or double-stage sand filtration. Filtration is performed in pressurized lined steel vessels or open, gravity driven concrete chambers to remove a portion of the coagulated organic and inorganic particulate and colloidal matter present in the raw water. Sodium bisulphite is added to remove any residual chlorine present in the RO feedwater and antiscalants may be added to inhibit scale formation in the RO membranes. The final step of pretreatment is a cartridge- or bag type guard filter with a mesh size of five to ten microns to protect the RO pump and RO membranes.

Backwashing of the filter system is carried out with filtered water and air, by means of a backwash pump and backwash blower, at least once a day, usually after a pre-set differential pressure across the filter is reached. The frequency of replacement of filter cartridges or bags 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.

Such conventional pretreatment systems may produce feed water of an acceptable quality when properly tuned and with good raw seawater quality. However, upsets result in changes in water quality that are detrimental to the operation of the RO. Accordingly, well tuned conventional pretreatment systems are not always capable of achieving 15-minute silt density index values (SDI$_{15}$) that meet the requirements set by the RO membrane manufacturer; typically less than three or four. An example is the recent case of the desalination system in Tampa Bay, Florida, which is further examined in section 6 of this paper.

There are several major disadvantages of a conventional pretreatment which 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
- the possibility of breakthrough during filter backwash
- carry over of high concentrations of colloidal particles immediately following a filter backwash.
- coagulant impact on RO membranes

Slow filtration velocities also result in large land footprint requirements for a conventional pre-treatment system.
3.2 UF Membrane based RO Pre-treatment

UF membranes provide a positive barrier to particulates and pathogens and have been proven for many years in a wide range of much more difficult liquid environments than seawater, such as highly polluted industrial and municipal wastewaters.

As a result they are being increasingly considered for new RO desalination installations and for retrofit upgrades to existing conventional RO pre-treatment systems.

At present the following types of UF membranes are commercially available:
- immersed hollow fiber;
- immersed plate membranes;
- pressure-driven capillary;
- pressure-driven spiral wound membranes.

This paper focuses on an immersed, outside-in, hollow fiber UF membrane system. This type of 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 (fouling the membrane) and overall lower energy costs due to a lower trans-membrane pressure (TMP).

In seawater RO plants equipped with immersed UF membrane pre-treatment, the seawater is typically supplied from an open intake, pre-filtered by a rotating screen and a mechanical screen with a mesh size of about 1 mm and is then fed to the membrane process tank.

While conventional pretreatment systems typically use large quantities of chemicals for pretreatment, chemical dosing is eliminated or significantly reduced for UF systems.

UF membrane systems like the ZeeWeed® are configured in compact, modular cassettes and immersed directly into the process tank which allows for a smaller system footprint.

This arrangement also simplifies plant expansions and retrofits of plants that are currently using conventional sand filters by allowing the insertion of the UF membrane cassettes directly into existing gravity filter tanks.

Immersed membranes are loosely suspended in the process tank and employ a low-pressure (up to 0.8 bar) vacuum to draw water through the pores in the UF fibers. 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 SDI results which are typically less than 2.5 and often less than 1.5 even with high influent turbidity feed water.

The vacuum to draw the permeate through the UF fibers is provided by the UF permeate pump. 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. Using UF membrane pretreatment eliminates the need for guard filters in front of the RO system in cases where the UF permeate is fed directly to the RO.

**Figure 4:** Typical UF membrane pre-treatment
Immersed membrane systems like the ZeeWeed® are fully automated. A Programmable Logic Controller (PLC) performs the back-pulsing (backwashing) and in-situ cleaning procedures when needed. This ensures the highest possible net production rates and the greatest time between membrane cleanings. The membranes are backpulsed 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 back-pulse 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. Completely controlled by the plant PLC, a back-pulse cycle typically lasts for one to two minutes every twenty to sixty minutes. Although this frequent back-pulse 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.

By incorporating UF pretreatment in a seawater desalination system, the rate of RO membrane fouling and the frequency of RO membrane cleaning are significantly reduced while the lifetime of RO membrane elements is extended. UF pretreatment ensures excellent RO feed water 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. Other benefits include:

- 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

The physical barrier characteristic, coupled with the immersed hollow fiber outside-in filtration direction make this UF membrane system inherently more robust than conventional pre-treatment and ensures high quality permeate 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.
4. Summary technical comparison

The following table provides a comparison of the impact of UF pre-treatment on an RO based sea water desalination plant.

**Table 1:** A comparison of the impact of UF pre-treatment on an RO based sea water desalination plant.

<table>
<thead>
<tr>
<th>Treated Water Quality</th>
<th>UF pre-treatment: ZeeWeed® 1000 immersed hollow fiber</th>
<th>Conventional pre-treatment: in-line coagulation and 2 stage sand filters</th>
</tr>
</thead>
<tbody>
<tr>
<td>• SDI &lt; 2.5, 100% of the time, usually &lt; 1.5</td>
<td>• SDI &lt; 4 ~90% of the time</td>
<td></td>
</tr>
<tr>
<td>• Consistent, reliable quality</td>
<td>• Fluctuating quality</td>
<td></td>
</tr>
<tr>
<td>• Positive barrier to particles and pathogens - no breakthrough.</td>
<td>• not a positive barrier to colloidal and suspended particles</td>
<td></td>
</tr>
<tr>
<td>• Turbidity: &lt; 0.1 NTU</td>
<td>• Turbidity: &lt; 1.0 NTU</td>
<td></td>
</tr>
<tr>
<td>• Bacteria: &gt; 5 log removal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Giardia: &gt; 4 log removal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Virus: &gt; 4 log removal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typical Lifetime</td>
<td>• UF Membranes: 5 - 10 years</td>
<td>• Filter media: 20 - 30 years</td>
</tr>
<tr>
<td>• Cartridges : often not needed</td>
<td>• Cartridges: 2 - 8 weeks</td>
<td></td>
</tr>
<tr>
<td>Average RO Flux</td>
<td>~ 18 lmh</td>
<td>~ 14 lmh</td>
</tr>
<tr>
<td>SWRO replacement-rate</td>
<td>~ 10% per year</td>
<td>~ 14% per year</td>
</tr>
<tr>
<td>SWRO cleaning frequency</td>
<td>~ 1 - 2 times per year</td>
<td>~ 4 - 12 times per year</td>
</tr>
<tr>
<td>Pre-treatment foot-print</td>
<td>~ 30 - 60 % (of conventional)</td>
<td>100 %</td>
</tr>
</tbody>
</table>

5. Life cycle cost comparison

Technical superiority of the pretreatment capabilities of UF membranes over conventional coagulation and sand filtration is clear. The economic comparison of the two technologies depends on a large number of parameters including, most significantly, raw seawater quality, membrane replacement rates and utility costs.

Costs for two comparable systems are presented based on the following assumptions:

Seawater RO desalination plant: 74 000 m³/day (20 MGD)
Seawater TDS: 35 000 ppm
Raw water quality: poor, high/variable turbidity, SDI₁₅ immeasurable
RO flux: 10 gfd after UF / 8 gfd after two stage sand filters
Power cost: US$ 0.045/kW-hour
Interest rate: 6.5%
Plant life: 25 years
Second pass RO: for boron removal as needed
Table 2: Specific Investment costs (figures in US$/m³/day)

<table>
<thead>
<tr>
<th>Component</th>
<th>UF + SWRO</th>
<th>UF + PWRO</th>
<th>in-line coagulation + 2 stage sand filtration</th>
<th>UF + SWRO + PWRO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infrastructure (buildings, tanks, intake, transfer station)</td>
<td>$205</td>
<td>$203</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretreatment system</td>
<td>$202</td>
<td>$143</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Desalination system</td>
<td>$572</td>
<td>$625</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total investment costs</td>
<td>$979</td>
<td>$971 *)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*) excluding costs for land acquisition

Table 3: Operational costs (figures in US$/m³)

<table>
<thead>
<tr>
<th>Component</th>
<th>UF + SWRO</th>
<th>UF + PWRO</th>
<th>in-line coagulation + 2 stage sand filtration</th>
<th>UF + SWRO + PWRO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment costs</td>
<td>$0.2377</td>
<td>$0.2452</td>
<td></td>
<td>$0.2452</td>
</tr>
<tr>
<td>Replacement for UF membranes / sand filter material + Cartridges</td>
<td>$0.0234</td>
<td>$0.0026</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Replacement RO membranes</td>
<td>$0.0161</td>
<td>$0.0275</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process and cleaning chemicals</td>
<td>$0.0411</td>
<td>$0.0488</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power consumption</td>
<td>$0.1773</td>
<td>$0.1712</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spare parts</td>
<td>$0.0382</td>
<td>$0.0411</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manpower – O&amp;M</td>
<td>$0.0286</td>
<td>$0.0360</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overhead</td>
<td>$0.0196</td>
<td>$0.0196</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total water costs (US$/m³)</td>
<td>$0.5819</td>
<td>$0.5921 **)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**) not considering any penalties for alternative water supply in case of plant underperformance caused by pre-treatment

6. Operational experience – conventional system

Nearly two years ago the Tampa Bay, Florida seawater desalination facility began producing drinking water from seawater. As North America’s largest seawater RO desalination plant, the 94 000 m³/day facility is intended to provide up to 10 percent of the drinking water required by Florida’s Tampa Bay area and is part of the Master Plan to create an environmentally friendly, drought-proof supply of drinking water and reduce the need for groundwater pumping. Problems with the facility’s pretreatment system, coupled with other operational difficulties have significantly watered down the plant’s performance.

Currently the plant uses a two-stage dual sand pre-treatment system to remove turbidity, algae, organic material and other particulate matter from the incoming raw seawater. The manufacturer recommended SDI₁₅ for the RO membranes is <4.0; however, the existing pre-treatment cannot consistently meet these parameters to protect the RO system. As a result, the RO membranes foul too quickly and the 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 late 2003, 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. During the pilot test the teams did gather on-site performance data of their technologies to demonstrate their capabilities of producing feed water within specified parameters. The technologies tested at the plant included diatomaceous earth (DE) precoat filtration, high rate settling and immersed, low-pressure outside-in UF membranes.

Of the solutions that were evaluated, Zenon’s ZeeWeed® immersed UF membranes significantly outperformed the others, providing exceptional pre-treatment results and consistently producing feed water with an SDI$_{15}$ of $< 1.0$, regardless of the turbidity of the raw water.

![Graph showing performance of different pretreatment options](image)

**Figure 6:** Tampa Bay pre-treatment performance

### 7. Conclusion

Considering the high level of investment involved in the installation of an RO desalination system as well as the costs associated with maintaining and repairing a system equipped with an unreliable pretreatment system, careful consideration must be given in the design phase to a pretreatment system that can supply high quality RO feedwater during all seasons.

UF pretreatment systems have proven to be simple to operate, much more reliable and more economical over the life of a project than conventional pretreatment, particularly when the raw feedwater is highly loaded with suspended solids and colloids permanently, or during a part of a season.

### 8. References

2. Lisa Henthorne, P.E., Vice President CH2M Hill “Evaluation of Various Pre-treatments for SWRO” – August 2004