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Cold water operating experience of Seaguard UF as pretreatment to SWRO

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ABSTRACT

Numerous tests around the world have proven that ultrafiltration (UF) provides optimum pre-treatment for seawater desalination based on reverse osmosis membranes (SWRO). Ultrafiltration will remove all suspended solids and will provide a substantial reduction in microbiological activities. Plugging of RO spacers is completely eliminated and the RO cleaning frequency can be substantially reduced. The main obstacle against use of ultrafiltration membranes for SWRO pre-treatment has always been the higher operating cost of ultrafiltration when being compared with conventional pre-treatment. A new membrane has been designed with the aim of achieving the lowest whole of life cost while enabling membrane desalination of the most difficult to treat seawater.

This article will describe operational experience of several other pilots operating at lower temperatures in the UK and China. It shows how the results of pilot projects can be translated into a technical and commercial evaluation of the best pretreatment option for the desalination of water from low temperature water sources.

The technical details of design of a demonstration plant in the Netherlands are described. The Evides demonstration plant uses the new Seaguard ultrafiltration membranes. This plant is fed from the river delta formed by the Meuse, the Scheldt and the Rhine river in the south western part of the Netherlands. The ultrafiltration pretreatment to seawater reverse osmosis is a prerequisite to use of this seawater for membrane desalination.

It furthermore explains the decision making process for selection of pretreatment for the Thames Gateway SWRO project. This plant is fed by water from the river Thames that is strongly influenced by tidal effects.

1. Introduction

Historically seawater desalination has been employed in many arid areas of the world such as the Middle East, the Mediterranean, and the Caribbean. The Middle East alone has close to 50% of the worlds seawater desal capacity installed [1].

By nature the arid regions are located in zones with warm climates. So the vast majority of the desalination plants are being operated on warm water, ranging from 20 °C up to almost 40 °C. Historically very few desalination plants have been constructed that operate on cold seawater (below 20 °C). This was only limited to a few plants located on off shore production platforms and small islands.

For warm water as well as for cold water, the trend favors membranes as desalination technology over thermal desalination. The main driver for using membranes over thermal desalination is the lower operating cost.

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The current climate change leads to a decrease in available water even for parts of the world that have been considered non arid. Furthermore water consumption increases because of population increase and higher agricultural and industrial usage. This was recognized 10 years ago already by companies, such as Anglian Water in the UK, who subsequently piloted membrane desalination on North Sea water.

Operational data from desalination plants operated in warm water can not be linearly translated to cold water. Several factors will affect the performance of the desalination plant:

- Viscosity of the water. At lower temperature the viscosity of the water will be higher. This will lead to an increase in energy consumption.
- Temperature fluctuations. Seasonal influences will affect the feed water temperature. Especially in shallow estuarine water the seawater temperature can fluctuate. This will not only change the required operating pressure of the reverse osmosis system but it can also lead to sudden changes in feed water quality such as e.g. upwellings.
- Salinity. Cold water typically has a salinity of 30,000–35,000 ppm TDS. This is typically lower than warm water, having 35,000–45,000 ppm TDS. Because of the lower osmotic pressure and the higher achievable recovery this will reduce the energy consumption of the desalination plant.
- Fine silt. Typically low temperature water contains more fine silt than warm water. Turbidity is typically higher and transparency is lower.
- Organic loading. At low temperatures organics will decompose slower than at warm temperatures. Therefore it is to be expected that low temperature feed water will have a higher Total Organic carbon content (TOC) than warm temperature water.
- Biological activity. Lower temperature will decrease the biological activity of the water. Biofouling will occur at a slower rate.

2. Membrane pretreatment

The different characteristics of the cold feed water seawater reverse osmosis makes proper pretreatment more critical:

- The potential for sub zero ambient temperature requires proper precautions for making the pretreatment frost-proof. This requires either indoors installation or insulation and heating of critical components.
- The sudden changes in feed water characteristics will require an adequate control system to adjust the pretreatment system if necessary.
- The increase in seawater reverse osmosis (SWRO) recovery leads to a higher concentration of foulants at the RO tail elements and to sub-optimal flow velocity at either the lead elements or the tail elements. This makes the RO elements more prone to plugging and fouling.
- Fine silt will build up over time on the RO feed spacer. This also can potentially plug the RO elements.
- The higher organic load of the feed water will increase the fouling rate of the RO elements. This will more than offset the reduction in biofouling due to lower biological activity.

These factors favour membrane pretreatment over ‘‘conventional’’ pretreatment for seawater reverse osmosis desalination:

- A membrane pretreatment system is fully closed, without open tanks. Furthermore the footprint is smaller. Therefore installation indoors is easier and lower cost.
- A membrane pretreatment system is an absolute barrier. It will remove fine silt and colloidal matter, independent of the feed water quality. The larger organics and the organics attached to fine silt will be effectively screened from the water.

In 2005 Norit X-Flow introduced an ultrafiltration membrane that is specifically designed for pretreatment to SWRO [2]. This membrane uses inside out hollow fibre technology. The membrane fibres are fed from the lumen side with the clean water permeating the wall of the fibres. The hollow fibre membrane technology is well suited for removing suspended solids and microbes. Ultrafiltration membranes will not remove any dissolved matter; therefore the mineral content will remain unchanged.

The Norit X-Flow membrane designed for SWRO pre-treatment is called the Seaguard membrane. It has been specifically designed as a pre-treatment UF membrane for large capacity SWRO desalination plants. The main characteristics for this new membrane are:

- Ultrafiltration for good removal of suspended solids, resulting in low turbidity and SDI.
- Hydrophilic polyethersulfone/PVP, for high permeability and low fouling tendency.
- Operated in dead-end mode in order to minimize the energy consumption.

Fig. 1. Seaguard UF membranes loaded in a typical skid

- Pressurized inside-out filtration, allowing for direct feed from the intake works into the RO high pressure pumps.
- Use of short cleaning cycles, so called chemically enhanced backwashes (CEB). This mode of operation minimizes the flow fluctuations to the RO system.

The Seaguard membrane modules have an outside diameter of 200 mm (8 inch) and they are installed in glass fibre reinforced epoxy (GRP) pressure vessels. This makes the design of the UF unit very similar to the design of a SWRO unit with spiral wound reverse osmosis membranes. Fig. 1 shows a typical ultrafiltration unit with the Seaguard membranes being loaded.

The Seaguard ultrafiltration membrane has been employed in both warm as well as cold climates. The following case studies describe some of the operating experinece of Seaguard ultrafiltraton on cold feed water.

3. Felixstowe – United Kingdom

In 1998, a 4 month trail was conducted in Felixstowe, Suffolk. This pilot used ultrafiltration pretreatment followed by spiral wound reverse osmosis. The pilot was split into two separate stages:

1. In stage one the ultrafiltration system was fed by two beach wells. No further pretreatment was being used.

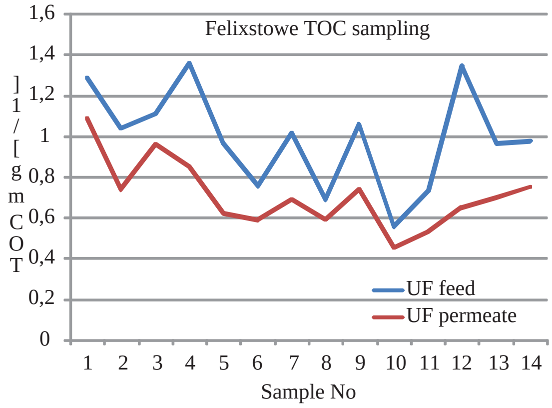

Fig. 2. TOC values of UF feed and UF permeate water

2. In stage two the ultrafiltraton plant was fed from open intake seawater.The pretreatment prior to UF was a 50-µ strainer.

The feed temperature was initially 8–9 °C (start up in March/April 1998) and increased to approximately 20 °C when the pilot test entered the summer period. The ultrafiltration system and the downstream SWRO operated well during both piloting phases [3]. Neither the UF nor the SWRO experienced permanent fouling. Feed SDI was reduced from 5.5 to 6.2 to less than 3 by the ultrafiltration. TOC was reduced by 25% by the ultrafiltration, see Fig. 2.

The ultrafiltration screened all microbiological parameters to below detection limits.

The recovery of the SWRO was gradually increased from 33% to 45%. This did not affect the SWRO performance. No cleaning was required during the piloting period. This clearly confirms that ultrafiltration pretreatment performed very well.

4. Qingdao – China

In 2008/2009 a 10 months pilot was conducted in Qingdao, China. This pilot started in March 2008 (feed water temperature approximately 10 °C). During the first 5 months of piloting the temperature increased to over 25 °C. The highest feed water temperature recorded is 28 °C (on 14 Aug 2008). In the following 5 months the temperature decreased to less than 5 °C with a lowest recoreded temperature of 0.5 °C on 14 January, 2009 [4].

The ultrafiltration TMP varied between 0.25 bar at high temperature and 0.55 bar at low temperature (@ 85–90 lmh flux rate). Corrected for the difference in viscosity the TMP varied between 0.3 bar at high temperature and 0.45 bar at low temperature. This

Fig. 3. Algae bloom at Olympic venue in Qingdao

clearly indicates the additional fouling experienced at low temperature.

Although operation of the Seaguard UF was affected by the temperature variation, this did not affect the filtrate quality of the UF system. Even during the algae bloom event that threatened the Olympics (see Fig. 3), the UF kept performing as expected.

The table below gives UF feed and permeate samples collected ruing the algae bloom event. TOC reduction was 45%, with full removal of micro biology.

5. Jacobahaven – The Netherlands

In the period September to November 2008, a demonstration plant was commissioned, using Seaguard ultrafiltration and a two pass reverse osmosis system. The capacity of this system is 13.5 m^3/h at a feed conductivity of 50,000 μS/cm and a temperature range of 5–25 °C [4].

This demonstration plant has the following characteristics:

- Pretreatment by means of an auto backwash filter. The screen size can be selected between 50 and 200 microns. Initially 50 microns is piloted in order to investigate the removal of algae and barnacle eggs.
- Coagulant dosing downstream of the prescreen. This can be used for lowering the organics in the SWRO feed. Initially the demonstration plant is operated

UF feed and filtrate samples, collected 1 july 2008, Qingdao

Item		Feed	Permeate
COD (mg/L)		1.05	0.18
BOD (mg/L)		1.16	0.88
TOC (mg/L)		2.66	1.47
Chlorophyll (μg/L)		18.2	0.12
phytoplankton	diatom species amount	13	Non-detected
	Pyrrophyta species amount	4	Non-detected
	Other species amount	1	Non-detected
	Total species amount	18	Non-detected
	diatom total amount	5.41^*10^6/L	Non-detected
	Pyrrophyta total amount	1.6^*10^4/L	Non-detected
	Other total amount	6.0^*10^3/L	Non-detected
	Total amount	5.43^*10^6/L	Non-detected

Fig. 4. Grundfos BMEX system on SWRO unit

without coagulant dosing. During the second phase of the project Norit's patented SMART technology will be employed to optimize the coagulant dose.
- An ultrafiltration unit using X-Flow Seaguard membranes. This unit can be backwashed either with UF permeate or with SWRO brine. Using SWRO brine solution for backwash will increase the recovery of the UF unit and might be beneficial in removing microbiology because of the increase in osmotic pressure. Initially UF permeate will be used for backwashing.
- A SWRO unit using Dow Filmtec membranes. A newly developed membrane has been employed: SW30XHR-400i. The recovery is initially set at 40%. The SWRO unit uses a Grundfos BMEX high pressure system consisting of a multistage centrifugal high pressure pump and pressure exchanger, see Figure 4.
- A brackish water RO (BWRO) unit using Dow Filmtec membranes. This BWRO unit is a second pass RO designed to lower the Boron concentration to within the limits set by Dutch drinking water guidelines. This unit uses LE400 membranes. Initially it will treat all SWRO permeate operate at a feed pH of 9.0–9.5 and 90% recovery. The set up is flexible and will allow for more advanced configurations, such as partial second pass or split second pass operation (Fig. 4).

A piloting programme has been set up to optimize operation of all membrane units.

6. Thames Gateway – United Kingdom

From January to June 2003 ultrafiltration was piloted as pretreatment to reverse osmosis in the city centre of London. The feed water is tidal water from the river Thames. The feed water temperature ranged from 6 °C in February to 21 °C in June. Over this period the feed water conductivity showed large fluctuations, both seasonal as well as daily, see Fig. 5. The conductivity ranged from a low of 1.136 μS/cm–10,109 μS/cm.

The plant is fed with water that has been pretreated by coagulation/flocculation, lamella clarification and RGF and GAC filtration. Feed water turbidity to the UF system ranged from 0.03 to 2.5 NTU, with an average of less than 0.5 NTU. This extensive pretreatment has probably removed the majority of the organics prior to the ultrafiltration

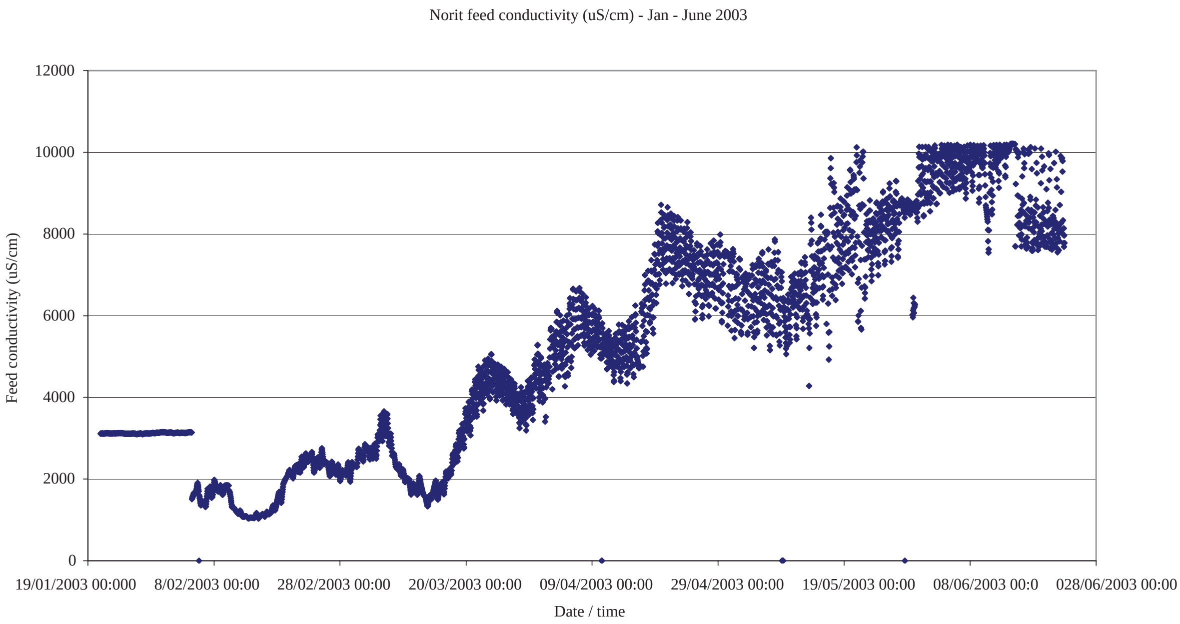

Fig. 5. Thames Gateway water conductivity

unit, unfortunately no raw water data are available. The ultrafiltration unit shows very little removal of TOC, see Fig. 6.

The excellent feed water quality to the UF system allowed for high operating fluxes. Throughout the pilot study a flux of 100–120 l/m^2 h was maintained.

Following this piloting a contract for a 140 MLD desalination plant was awarded to Acciona (formerly Pridesa). The following process was selected:

- During low tide water of reduced salinity is stored in basins. This water has approximately $^1/_3$ of the salinity of normal seawater. In this way the operating pressure and the energy consumption of the RO unit can be reduced by a factor two. During high tide the feed water intake from the river is stopped and feed water is taken from the storage basins.
- Pretreatment by means coagulation followed by lamella clarification. The low salinity feed water is characterized by high turbidity and a high organic content. Therefore extensive pre-treatment will be necessary.
- Media filtration. Seventeen horizontal pressure sand filters.
- X-Flow Seaguard ultrafiltration. The ultrafiltration skids are pressurized and UF filtrate is directly fed into the RO high pressure pumps. No intermediate buffertank and transfer pump is installed, see Fig. 7.
- First stage SWRO system. Nine two stage RO units, each with inter-stage booster pumps
- Second stage RO system. Three two stage RO units, each with inter-stage booster pumps. The RO systems are concentrate staged in order to maximize the overall recovery. The use of the low salinity feed water allows for an overall RO recovery of 80%, which is unusually high for seawater.

The project is currently in the construction phase and on schedule for completion in 2009.

7. Conclusions

The United Kingdom and the Netherlands are countries that in public perception have an abundant supply of water. The fact that these countries are reverting to seawater desalination emphasizes the fact that stress on water supply is occuring on a global scale. Seawater desalination by means of reverse osmosis is a mature technology that will be more and more

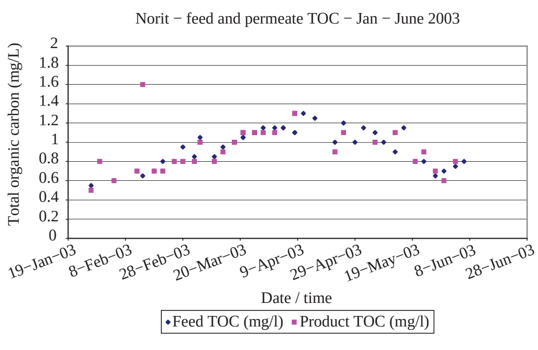

Fig. 6. TOC values of UF feed and UF permeate water

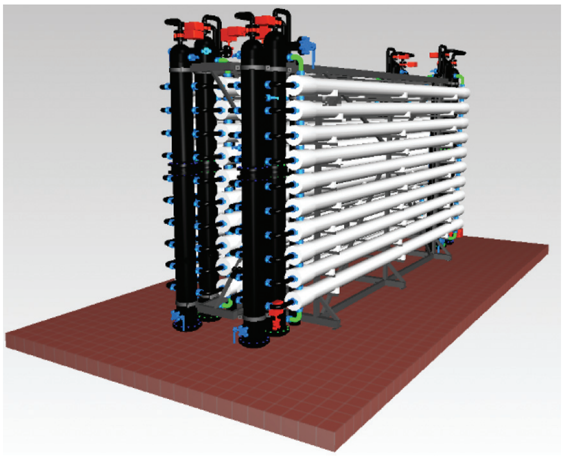

Fig. 7. Seaguard ultrafiltration rack

employed beyond its traditional limitations: small scale and only in arid countries.

Care has to be taken however in translating operational experience from desalination of high temperature seawater to designing desalination in low temperature seawater. Several factors have to be taking into account for evaluation of technical and economical feasibility of desalination in colder climates.

Multiple pilot plants employing X-Flow Seaguard technology have successfully treated highly fouling seawater. These plants show that it is possible to treat seawater that only a few years ago was deemed unsuitable for desalination using reverse osmosis and also shows that ultrafiltration pretreatment for SWRO is a mature technology, capable of being employed in a wide range of feed water conditions.

Large scale seawater desalination that employs ultrafiltration as pre-treatment technology will be the desalination technology of choice for challenging regions in the world. The first plants over 100 MLD net capacity are already being constructed and because of its excellent scalability construction of even larger plants is a mere matter of time.

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