Literature Study & Survey

Pretreatment of seawater RO-plants

Overview 1997-2007

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Note: All the articles in each of the sections are in chronological order

Report Introduction

The world's supply of fresh water is running out. Already one person out of five has no access to safe drinking water. Water covers about two-thirds of the Earth's surface, admittedly. But most is too salty for use. Only 2.5% of the world's water is not salty, and two-thirds of that is locked up in the icecaps and glaciers [1]. With the ever-increasing population and growing economy, demands for fresh water are continuously rising. Thus, many countries including China have devoted considerable effort to the field of seawater desalination. Desalination refers to any of several processes that remove excess salt and other minerals from water. As the requirement for fresh water is still increasing since many years, the demand for building desalination plants to use seawater as a potable source of drinking water is also increasing. Fig 1 shows how number of desalination plants all over the world has been changed through 60 years. The biggest rapid started in 70’s when reverse osmosis desalination membrane process has been commercially used.

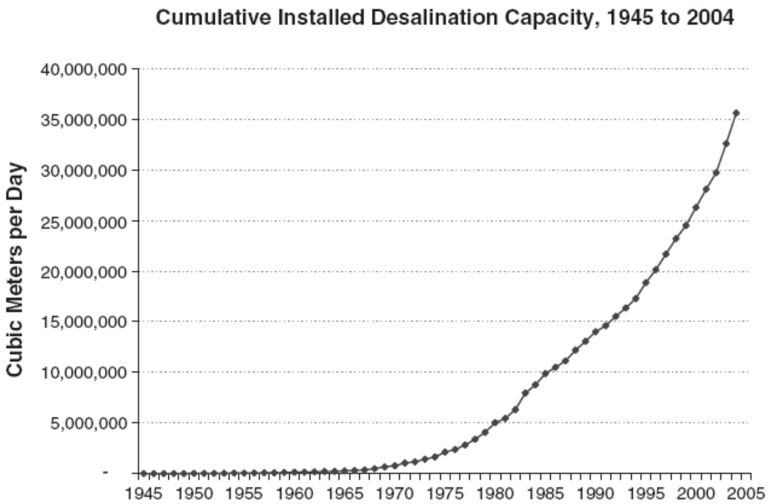

FIGURE DT 22.1 Cumulative installed desalination capacity, 1945–2004.

Retrieved from *http://www.worldwater.org/data20062007/Table22.pdf*

Currently, reverse osmosis (RO) is one of the most prevalent methods for seawater desalination. However, a crucial drawback of RO membranes is their susceptibility to fouling due to the presence of colloidal, particulate, dissolved organics and inorganic matter in feed water, as well as biological growth in the RO system. As a result, the sticking point for a successful SWRO plant is pretreatment, which can reduce the fouling potential of the feed-in seawater and provide consistently high quality feed to SWRO membranes.
Fouling and scaling of the membranes is the biggest danger which decreases the efficiency of the seawater desalination reverse osmosis plant. So far many kinds of pretreatment were already used and tested, and still new technologies are under investigation. Seawater desalination plants have to achieve variety aims to operate effective, i.e. increase recovery rate and flux permate, and long-term performance stability, and increase reliability.

In the time when membranes started to play important role in the desalination process as a pretreatment (Integration Membranes Systems), the reverse osmosis process became more and more effective economically. Because the biggest amount of money is spent on pretreatment and energy put to create appropriate reverse osmosis pressure research on costs reduction still lasts. As many reports have shown, use of microfiltration and ultrafiltration can reduce total costs of ownership comparing to conventional methods. Conventional pretreatment, based on mechanical filtration and chemical dosing systems, can be quite expensive. Mechanical filtration may consist of coarse screens, sand filters, media filters and micro cartridge filters. Dosage of a series of chemical products, such as disinfection agent (NaClO), flocculent agent (FeCl3), chlorine scavenger agent (NaHSO3) and anti-scaling agent (H2SO4), increase the cost and may be always in excess.[2]
Therefore, beneficial economical level has to be achieved.

> "People think water is free because it falls from the sky," says Seidel of US Filter. "Well, it is-but treated, filtered, and piped water isn't."[3]

Thus, society has to be educated how to carry on households to save water sources and stop to produce unbelievable high amount of waste water.

This **Literature Study and Survey** over the last 10 years was created to bring closer reverse osmosis desalination process pretreatment and show news and changes in the scientific world. It provides an interesting overview of membrane pretreatment and also gives reliable reports from desalination plants dealing with different water/process problems. The last section contains new membrane technologies - news from the biggest membrane manufactures (i.e. Millipore, Hydranautics). By this literature research reader is able to find variety of pretreatment methods and details with them connected.
To find required information easier and faster the literature research was divided into few main areas which are separating this paper in logical way. The publications are in the chronological order, as well.
By clicking in the main menu reader can be easily send to the adequate area of interest. Also each of the publication has the hyperlink to the PDF file presenting the original version of the publication.

Monika Pyzalska

References

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http://news.bbc.co.uk/hi/english/static/in_depth/world/2000/world_water_crisis/default.stm
[2] A pilot study of UF pretreatment without any chemicals for SWRO desalination in China Jia Xu, Guoling Ruan, Xizhang Chu, Ye Yao, Baowei Su, Congjie Gao
; Accepted 9 August 2006 Desalination 207 (2007) 216–226
[3] The Coming Water Crisis Many billions of dollars will be needed to quench America's thirst, but is private business the answer? US NEWS & WORLD REPORT Marianne Lavelle and Joshua Kurlantzick Posted 2002
http://www.usnews.com/usnews/biztech/articles/020812/archive_022254_6.htm

Pretreatment of RO seawater desalination

With UF membranes

Content:

- A pilot study of UF pretreatment without any chemicals for SWRO desalination in China
- The pretreatment with enhanced coagulation and a UF membrane for seawater desalination with reverse osmosis
- The case for UF/MF pretreatment to RO in seawater applications
- Economic evaluation of a new ultrafiltration membrane for pretreatment of seawater reverse osmosis
- Pilot testing of two inside-out UF modules prior to RO for highturbidity seawater desalination
- Pretreatment of seawater: Results of pilot trials in Singapore
- Comparison of MF/UF pretreatment with conventional filtration prior to RO membranes for surface seawater desalination
- Assessment of UF pretreatment prior RO membranes for seawater desalination

A pilot study of UF pretreatment without any chemicals for SWRO desalination in China

Desalination, *Volume 207, Issues 1-3*, *10 March 2007*, *Pages 216-226*
Jia Xu, Guoling Ruan, Xizhang Chu, Ye Yao, Baowei Su and Congjie Gao

Abstract
The critical issue for a successful Sea Water Reverse Osmosis (SWRO) plant is pretreatment, which could provide consistent and high quality feed to SWRO membranes. In China, most pretreatment prior to SWRO use conventional ones, e.g. sand filtration, media filtration, cartridge filtration, et al, which have shown some drawbacks due to significant and unpredictable variation of seawater quality. For pretreatment of open seawater intake, membrane filtration may be a better choice. In this study, UF system utilizing hollow fiber membranes was used as pretreatment prior to SWRO desalination at Qingdao Jiaozhou Bay, the Yellow Sea in China. A different approach, focused on optimizing the design of a hybrid UF–RO system by maximum net product flow, i.e., an optimum correlation between filtration and backwash duration that can ensure best reliability of UF pretreatment was described. Operation of different recovery rate and flux of UF system was investigated to evaluate the performance of UF system. The results of the UF–SWRO system indicated that UF pretreatment could enable the RO pilot plant to be run stably and successfully. During the experimental periods, no chemical was injected into the UF–RO system, which showed that the UF–SWRO system performed well without any chemical cleaning.
Keywords: Ultrafiltration; Pretreatment; Seawater reverse osmosis; Desalination

Conclusions
Based on the results obtained in the present study, conclusions can be drawn as follows:

- Performance of the UF system is excellent with the following optimum backwash parameters: backwash duration τ = 30 s, filtration duration t = 40 min, and backwash flow rate is 1800 l/h.
- The operation of the UF system in high recovery–low flux mode (80%, 60 l/m2h) might be the best and should be adopted.
- The quality of UF permeate was very good, with 100% of turbidity below 0.01 NTU and 95% of the SDI15 below 3.0, which can totally satisfy the need of SWRO feed water.
- Performance of the SWRO system is excellent with a stable TMP of averaged 5.5 MPa and stable calibrated permeate flow. The conductivity of RO permeate was in the range of 350–500 µS/cm.
- During all the experimental periods, the UF– RO system can be run safely and successfully, without any chemicals required for disinfection, flocculation, enhanced chemical backwash (CEB) and cleaning.

The pretreatment with enhanced coagulation and a UF membrane for seawater desalination with reverse osmosis

Desalination, *Volume 203, Issues 1-3*, *5 February 2007*, *Pages 256-259*
Wei Ma, Yaqian Zhao and Lu Wang

Abstract
The application of reverse osmosis (RO) for desalination process has increased rapidly with the construction of large RO plants.

Although there have been considerable improvements in membrane materials and operation experience, the fouling of membranes is a significant problem up to the present. There have been many instances of fouling of RO membranes caused by the presence of iron and silica. Biomineralization is usually believed to be caused by microorganisms metabolizing at iron and silica present. Its formation process was studied and described first in the present work, then the enhanced coagulation with Fe(VI) and UF membrane treatment process for pretreatment of reverse osmosis for desalination has been investigated in a laboratory for 3–4 months. The main aim is to reduce the feed water pollution, such as turbidity, iron, silica and algae, microbial contamination in order to control biofouling and mineralization on the membrane surface. The results showed that the biomineralization formation process is the adsorption of organism and the biosorption of inorganics onto the organic matrix. The pretreatment results show that turbidity is less than 0.5 NTU, iron concentration never exceeds 0.2 mg/l, silicon concentration must not exceed 0.1 mg/l; and the removal rate of algae and microbial is more than 98%.
Keywords: Enhanced coagulation; Pretreatment; Ultrafiltration; Reverse osmosis

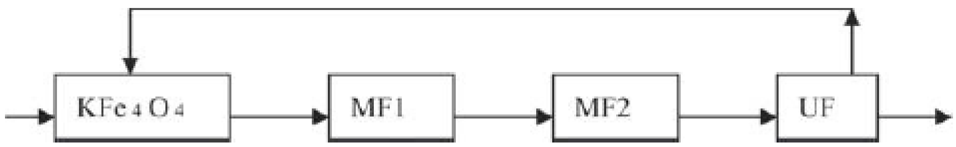


Fig. 1. The scheme of the pretreatment.

Conclusions:

- The biomineralization formation process is adsorption of organism and biosorption of inorganic onto the organic matrix, the growth of the biomass depends on the feed water quality.
- The results of pretreatment with enhanced coagulation and a UF membrane show that turbidity is less than 0.5 NTU, iron concentration never exceeds 0.2 mg/l, Si concentration must not exceed 0.1 mg/l, and the removal rate of algae and microbial is more than 98%. Thus the biomineralization formation is avoided.

The case for UF/MF pretreatment to RO in seawater applications
Desalination, *Volume 203, Issues 1-3*, *5 February 2007*, *Pages 286-295*
G.K. Pearce

Abstract
UF has gradually gained acceptance as the preferred pre-treatment to RO, with a steadily increasing list of references from UF/MF suppliers, in a range of seawater, brackish water, and wastewater applications. However, although perceived as desirable, UF/MF is also thought to be an expensive option, and consideration of UF/MF is sometimes restricted to applications which are thought to be especially problematic. In wastewater treatment applications, UF/MF is the pretreatment technology of choice due to the highly fouling nature of the feed.

Also, brackish water feeds also often utilize UF/MF pretreatment, since the higher RO fluxes which can be employed as a consequence of improved pretreatment give a clear advantage to the overall system cost. However, the case for UF/MF pretreatment in seawater applications is less clear cut. For beach well sources, conventional pretreatment, probably only consisting of cartridges, is sufficient, and there would be little advantage in using UF/MF. Surface water sources, which make up the majority of seawater duties, would benefit from UF/MF in terms of technical performance, but the economic case is often a close decision. This paper considers the factors which favour UF/MF pretreatment for seawater applications, employing an open intake. The performance advantage of UF/MF, and the resulting improvement in RO costs, will be weighed against the additional capex costs of pretreatment. The advantages of UF/MF are examined for a case study for an Eastern Mediterranean feed. In the Study, it is shown that the additional cost of UF/MF is paid for simply by the savings on chemicals and consumables. The additional cost of UF in terms of capex and membrane replacement is 2.9 cents/m3. However, UF reduces RO replacement, saving 1.2 cents/m3, and reduces chemical cost for both dosing, and RO cleaning. If the RO cleans are reduced from three cleans/y to two cleans/y, the saving amounts to 1.7 cents/m3, which with the RO replacement saving pays for the UF/MF. If two cleans are saved, UF/MF becomes cheaper than conventional pre-treatment by 0.7 cents/m3. This ignores other potential benefits arising from the 33% space saving of UF/MF, and the opportunity to increase RO flux and recovery. These factors will be the subject of a follow up paper.
Keywords: Ultrafiltration; Microfiltration; Reverse osmosis; Desalination; Seawater; Pre-treatment; Total water cost

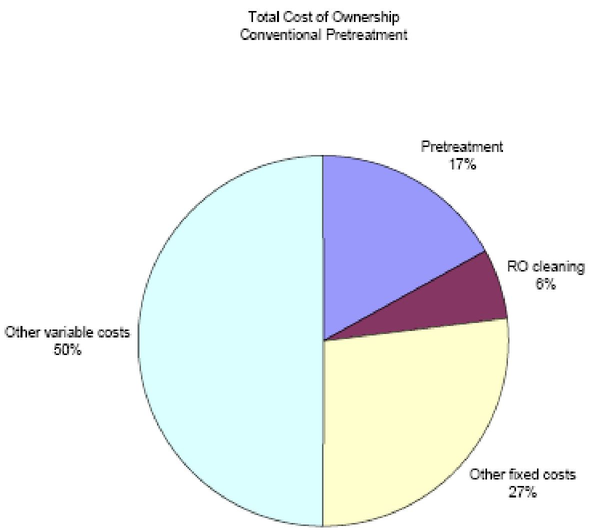
Conclusions

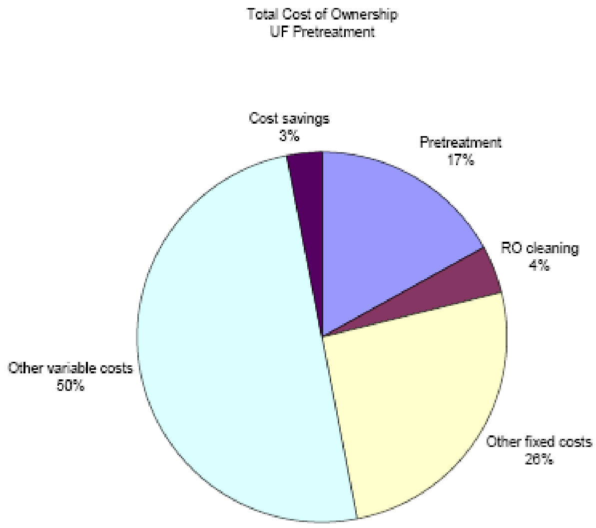
• UF/MF provides an excellent treated water quality for RO, since it provides an absolute barrier to particles, and consistent treated water quality from a variable feed source.
• The benefits of UF/MF pre-treatment are widely accepted for brackish and wastewater sources.
• For seawater sources, feeds with low to medium salinity have benefits of improved RO performance, in addition to reduced RO operating cost.
• For high salinity feeds of 38,000 ppm TDS and above, higher RO flux and recovery may be limited, but operating cost benefits can still justify the use of UF/MF pre-treatment.
• A case study has been examined for one of the more difficult cases to justify, i.e. a feed from the Eastern Mediterranean.
• The study shows that saving one RO clean per year, the total water cost of UF/MF pre-treated RO system is equivalent to that of conventional pre-treatment, purely based on savings in RO replacement costs, chemicals, and cleaning downtime.
• For a further RO clean/year saved, there would be a 0.7 cent/m3 benefit.
• UF/MF provides improved security and on stream time to the RO system.

Economic evaluation of a new ultrafiltration membrane for pretreatment of seawater reverse osmosis

Desalination, *Volume 203, Issues 1-3*, *5 February 2007*, *Pages 300-306*
Frans Knops, Stephan van Hoof, Harry Futselaar and Lute Broens

Abstract
Numerous tests around the world have proven that ultrafiltration (UF) provides optimum pretreatment for seawater desalination based on reverse osmosis membranes (SWRO). Ultrafiltration will remove all suspended solids and will provide a substantial reduction in micro biological activities. Plugging of RO spacers is completely eliminated and the RO cleaning frequency can be substantially reduced. The main obstacle against the use of ultrafiltration membranes for SWRO pretreatment has always been the higher operating cost of ultrafiltration when being compared with conventional pretreatment. Up until now this higher cost has prevented implementation of UF in all but a few SWRO plants. A new membrane has been designed with the aim of tailoring it towards lowest total cost of ownership. Typical operating conditions have been used to quantify the following parameters for a potential large scale desalination system (UF + SWRO): amortization of investment in UF membranes and equipment; operating costs of the UF system; reduction in operating costs of the SWRO desalination plant, when being compared against a conventional pretreatment + SWRO system; the increased output of the SWRO desalination plant due to higher availability and shorter construction time. The total cost of ownership of a UF based SWRO desalination plant has been determined (expressed in US$/m3 of water produced). Taking all factors into account the total cost of ownership of a dual membrane desalination plant (Seaguard UF + SWRO) will be 2–7% lower than the total cost of ownership of a SWRO plant based on conventional pretreatment.
Keywords: Desalination; Seawater; Pretreatment; Ultrafiltration; Capillary membrane



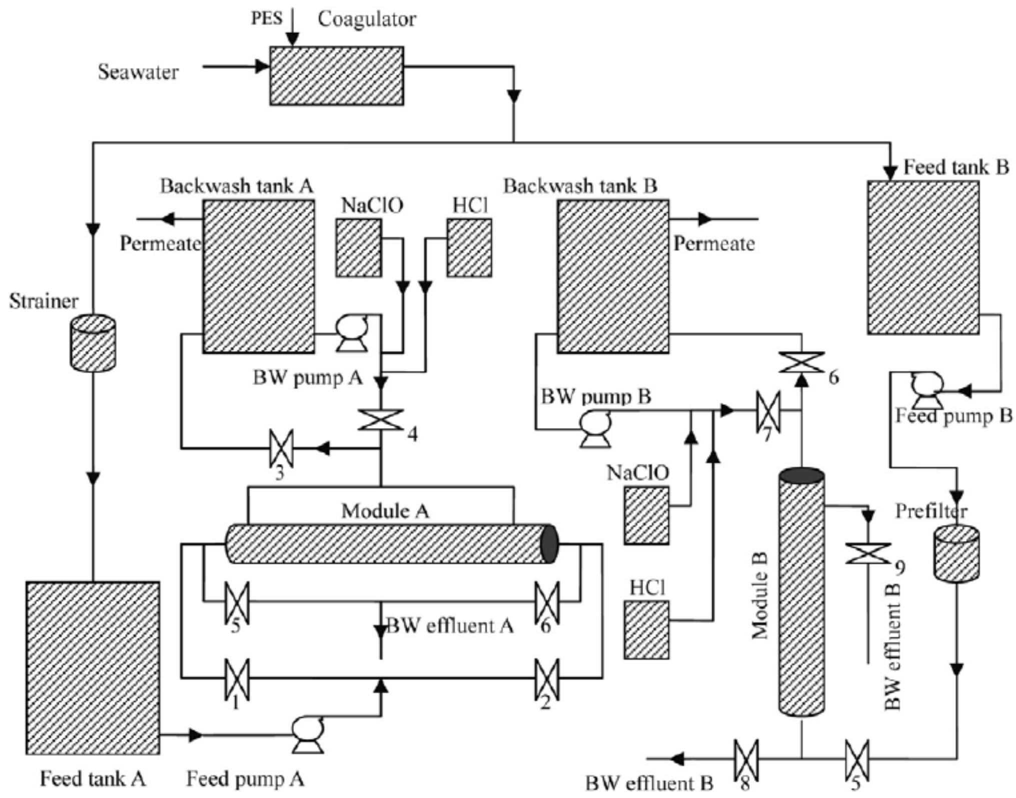


Conclusions
With conventional pretreatment, the total cost of ownership of the SWRO desalination plant is approximately 85–90 US cents/m3. With UF as pretreatment the total cost of ownership of the dual membrane desalination plant will be 79–to 88 US cents/m3. This provides a reduction in TCO of 2–7%, when being compared with conventional pretreatment

Pilot testing of two inside-out UF modules prior to RO for highturbidity seawater desalination
Desalination, *Volume 196, Issues 1-3*, *5 September 2006*, *Pages 66-75*
Jingjong Zhang, Sunming Gao, Huiming Zeng, Fang Zhang, Changzhen Li, Yanwei Liu, Dongkang Fu and Chunsong Ye

Abstract
To a seawater reverse osmosis (SWRO) plant, an appropriate pretreatment procedure is one of the most important factors for its steady and safe performance. Many researchers have shown their interest in replacing conventional seawater pretreatment with ultrafiltration (UF) because of the stable product water quality it offers. The purpose of the pilot testing was to evaluate two inside-out UF modules (Module A and Module B) used for pretreatment of highturbidity seawater after coagulation. A pilot-testing UF system was set up at the seashore on the southeast coast of China. Operation parameters such as flux, backwash (BW) time, BW frequency, and frequency of chemically enhanced backwash were varied. Modules A and B were operated at a flux ranging from 69–95 L/m2h and 86–130 L/m2h, respectively; the corresponding transmembrane pressure was 0.18–0.25 bar and 0.30–0.45 bar. The filtrateSDI15 of Module A was maintained below 3 during the test, and the permeateSDI15 of Module B was less than 3.37. These permeates met the requirement of the feed water quality of SWRO. A NaClO concentration of 6 mg/L proved to have little influence on decreasing the filtrateSDI15. Other parameters of water quality such as total Fe, COD, colloidal Si and total bacterial count were also measured. The UF trial was successful in achieving stable membrane permeability.
Keywords: Inside-out; Ultrafiltration; SWRO; Pretreatment; SDI; Seawater; Desalination

Conclusions
The two UF membrane modules were able to perform well in respect to stable operation and permeate quality. The permeate SDI15 of Module A was always maintained below 3, and the permeate SDI15 of Module B was maintained below 3 for most of the time of the trial. High flux, high recovery and low TMP promise to reduce plant costs. The turbidity of permeate was less than 0.17 NTU; the permeate TOC was less than 0.1 mg/L; the concentration of colloidal silica, COD and Fe were low and the filtered water had nearly no bacteria. A small amount of NaClO in the feed water was beneficial to UF Module A, reducing TMP effectively, and also had a good effect on UF Module B. This pilot study demonstrated that when the turbidity of the coagulated seawater was about 10 NTU, these two UF modules provide permeate with good, constant quality under coagulated sea water conditions that enhanced the reliability of the RO desalination plant. A longer test is now needed to confirm this preliminary pilot testing data.



Schematic diagram of the two UF systems

Pretreatment of seawater: Results of pilot trials in Singapore
Desalination, *Volume 159, Issue 3*, *5 November 2003*, *Pages 225-243*
K. T. Chua, M. N. A. Hawlader and A. Malek

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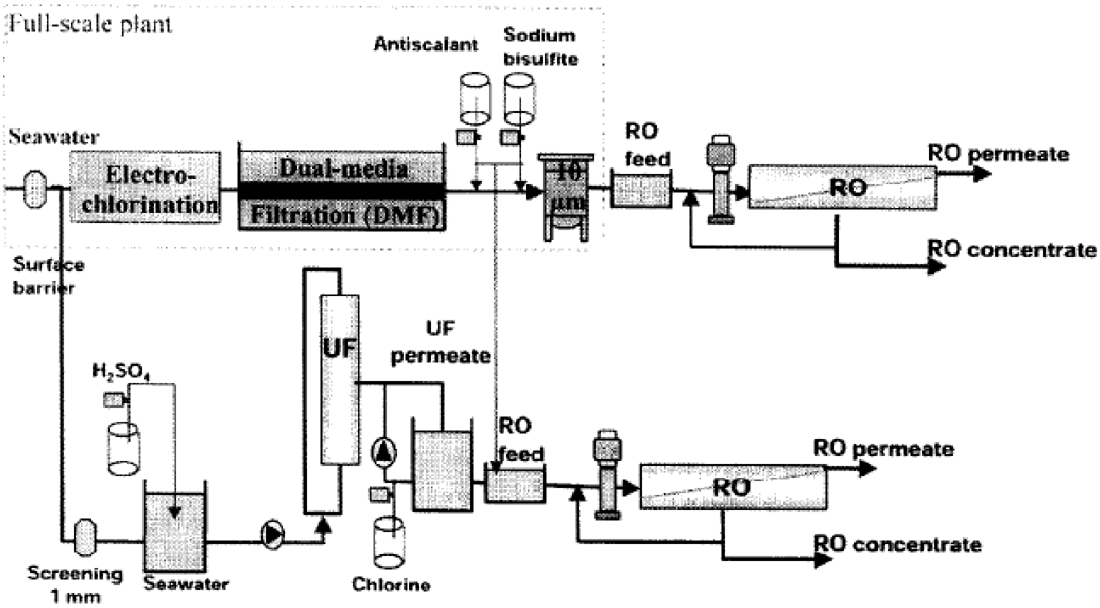
Comparison of MF/UF pretreatment with conventional filtration prior to RO membranes for surface seawater desalination
Desalination, *Volume 144, Issues 1-3*, *10 September 2002*, *Pages 353-360*
A. Brehant, V. Bonnelye and M. Perez

Abstract
Proper pre-treatment is the most critical factor for successful long-term performance of reverse osmosis seawater desalination plant. The objective of the study was to assess the potential of ultrafiltration (UF) pre-treatment prior to reverse osmosis (RO) for desalting seawater with high-fouling tendency. AUF pilot plant equipped with an Aquasource membrane directly operated on Gibraltar surface seawater in dead-end mode. The competitiveness of UF pretreatment towards conventional pre-treatment was assessed by looking at the impact on RO hydraulic performances. The study showed that ultrafiltration provided permeate water with high and constant quality resulting in a higher reliability of the RO process than with a conventional pre-treatment. The combination of UF with a pre-coagulation at low dose helped in controlling the UF membrane fouling and providing filtered water in steady state conditions.

The performance of RO membranes downstream UF exceeded the usual operating conditions encountered in seawater desalination. The combined effect of higher recovery and higher flux rate promises to significantly reduce the RO plant costs.
Keywords: Seawater; Desalination; Reverse osmosis; Ultrafiltration; pretreatment



Conclusions

This study showed the relevance of small compounds with the critical micron-size range and below that make the fouling properties of seawater and on which the RO performances depend. The objective of the pre-treatment to reduce the concentration of these fouling constituents was achieved by ultrafiltration. The surface seawater SD1 of 13-25 was reduced below 1 whereas the conventional pre-treatment failed to reduce it below 2.5. The UF pre-treatment also provided filtered water with high and constant quality that enhanced the reliability of the RO desalination plant. The combination of UF with a precoagulation at low dose helped in controlling the UF membrane fouling and providing filtered water in steady state conditions. Finally, the performance of RO membranes downstream UF exceeded the usual operating conditions encountered in seawater desalination. The combined effect of higher recovery and higher flux rate promises to significantly reduce the RO plant costs. Longer runs are now required to confirm these preliminary operating data.

Assessment of UF pretreatment prior RO membranes for seawater desalination

Desalination, *Volume 125, Issues 1-3*, *1 November 1999*, *Pages 89-96*
A. Teuler, K. Glucina and J. M. Laîné

Abstract

Among the desalination technologies available, reverse osmosis is currently considered as the most economical process.

However, while RO membranes have been continuously improved over the years, they have had one major shortcoming; the susceptibility to fouling. Indeed, it appears that RO technology is limited in hydraulic performance by the raw water quality. In the case of direct seawater intake, extensive treatment is required upstream the RO process. Thus, the objective of this study was to evaluate the ultrafiltration membrane process as a RO pretreatment. The trials were conducted at Fuerteventura, Canary Island. The preliminary results showed that the Aquasource ® UF membrane does not seem sensitive to high salinity of the seawater. Indeed, the mechanical resistance, as well as the specific flux of the UF membrane, remained stable. The dead-end filtration mode coupled with operation at low pressure allowed for very low power consumption, approximately 0.1 kWh per m 3 of permeate. Concerning the RO membrane evaluations, the hollow fine fiber (HFF) membrane was more efficient in terms of salt rejection, but the thin film composite spiral wound (SW) membrane operated at lower pressure (i.e. lower energy consumption). To date, the study continues in order to develop an integrated membrane system (UF/RO) to treat surface seawater.
Keywords: Reverse osmosis; Ultrafiltration; Seawater; Membrane; Desalination

Conclusions

The Aquasource ® UF membrane does not seem sensitive to high salinity of the sea water. Indeed, the mechanical resistance as well as the specific flux of the UF membrane remained stable. The dead-end filtration mode coupled with operation at low pressure allowed a very low power consumption, approximately 0.1 kWh per m 3 of permeate. These results, however, have to be confirmed on surface intake. Comparison between RO modules, each one manufactured with a different technology, shows that hollow fine fiber (HFF) membranes operate at greater pressures than thin film composite (TFC) membranes to obtain similar permeated flows. This necessarily results in higher specific electrical consumption for the HFF modules. However, the resulting HFF permeate quality is superior than that produced with TFC membranes. Thus, the type of membrane selected for a specific situation depends on the final water quality required and the associated efficiency needed (i.e. water cost). At the time of preparation of this paper, further trials are on-going (flux at 140 L/h.m 2) in order better define the limits of the UF membrane. Following this test, UF will be tested on surface intake and the UF water will feed the RO pilot. The RO pilot tests will be conducted side by side to evaluate the impact of the pretreatment on the RO hydraulic performances.

With NF membranes

Content:

- Performance restoration and autopsy of NF membranes used in seawater pretreatment
- A demonstration plant based on the new NF—SWRO process
- Nanofiltration as a means of achieving higher TBT of ≥ 120°C in MSF
- A new approach to membrane and thermal seawater desalination processes using nanofiltration membranes (Part 1)

Performance restoration and autopsy of NF membranes used in seawater pretreatment

Desalination, Volume 178, Issues 1-3, 10 July 2005, Pages 261-271
Ahmed S. Al-Amoudi and A. Mohammed Farooque

Abstract

To evaluate the newly developed configuration of a NF-SWRO system on a commercial scale, the single Umm Lujj SWRO desalination plant was converted to a dual NF-SWRO desalination process by introducing NF membrane pretreatment ahead of the SWRO desalination train. The permeate flow from the dual NF-SWRO system was increased to 130 m3/h compared to 91.8 m3/h permeate flow from the single SWRO desalination process. After about 6000 h of continuous operation of the NF unit, one pressure vessel was isolated from the NF unit for chemical cleaning at low pH, followed by high pH as the plant permeate flow was reduced from 234 m3/h to 200 m3/h and the feed pressure increased from 30 bar to 38 bar as a result of a decrease in feed temperature from 32 to 23°C, as well as suspected fouling. The chemical cleaning test resulted in improvement of the NF permeate flow, i.e., 100% recovery of the permeate flow, but with a slight reduction in hardness rejection. Thereafter, low and high pH cleaning was successfully carried out on the entire NF unit to restore its performance. After about 2000 h from the first cleaning of the NF unit, the permeate flow was again gradually reduced to 190 m3/h from 234 m3/h. Only a high pH cleaning in the presence of sodium dodecyl sulfate surfactant, in addition to other components, was carried out on the NF unit to restore its performance on the second occasion. The permeate flow returned to 234 m3/h whereas the rejection of hardness ions was reduced as in the first cleaning. Hence, an autopsy of two NF membranes was carried out to determine the reason for decline in permeate flow. Before doing the autopsy, both lead element and end element membranes were subjected to a performance evaluation, and it was found that the performance of the end element was much better than the performance of the lead element. Autopsy and analyses results showed that the lead element surface was covered with thick reddish-brown slimy deposits whereas the end element was relatively clean, with only slight deposits. The deposits mainly consisted of primary organic matter, iron, chromium and fungus, in addition to the chemical constituents usually found in seawater. Even though few diatoms could be seen on both membrane surfaces, bacteriological analyses and the amount of primary organic matter indicate that the membranes were not biofouled during the 9000 h operation of the NF unit. Moreover, the lead element was found to be more fouled than the end element, which is an indication of typical organic fouling. Based on the autopsy results, measures were taken to reduce fouling and chemical cleaning frequency, which included replacement of the first two lead elements as well as addition of more NF membranes to the NF rack, resulting in reduced feed flow to membranes while maintaining the same recovery. This resulted in lowering of flux rates in the lead elements, which ultimately improved the NF performance and lowered the chemical cleaning frequency during the rest of the operation period.

Keywords: Fouling; Autopsy; Chemical cleaning; NF; SWRO

Conclusions

Both low pH followed by high pH cleaning as well as high pH cleaning with SDS of NF membranes leads to the restoration of permeate flow. However, hardness ions rejection of the NF unit was reduced as well as salt rejection following each chemical cleaning. Autopsy of both lead and end NF membrane elements showed that both elements are mainly fouled by organic matter, with the lead element containing much higher deposits of foulant (about 3.5 times) compared to the end element, which is the typical behaviour of organic fouling. Based on the autopsy results, the lead elements were replaced and membranes were operated at lower flux, which resulted in better performance of the NF membranes as well as lead to lower chemical cleaning frequency.

A demonstration plant based on the new NF—SWRO process

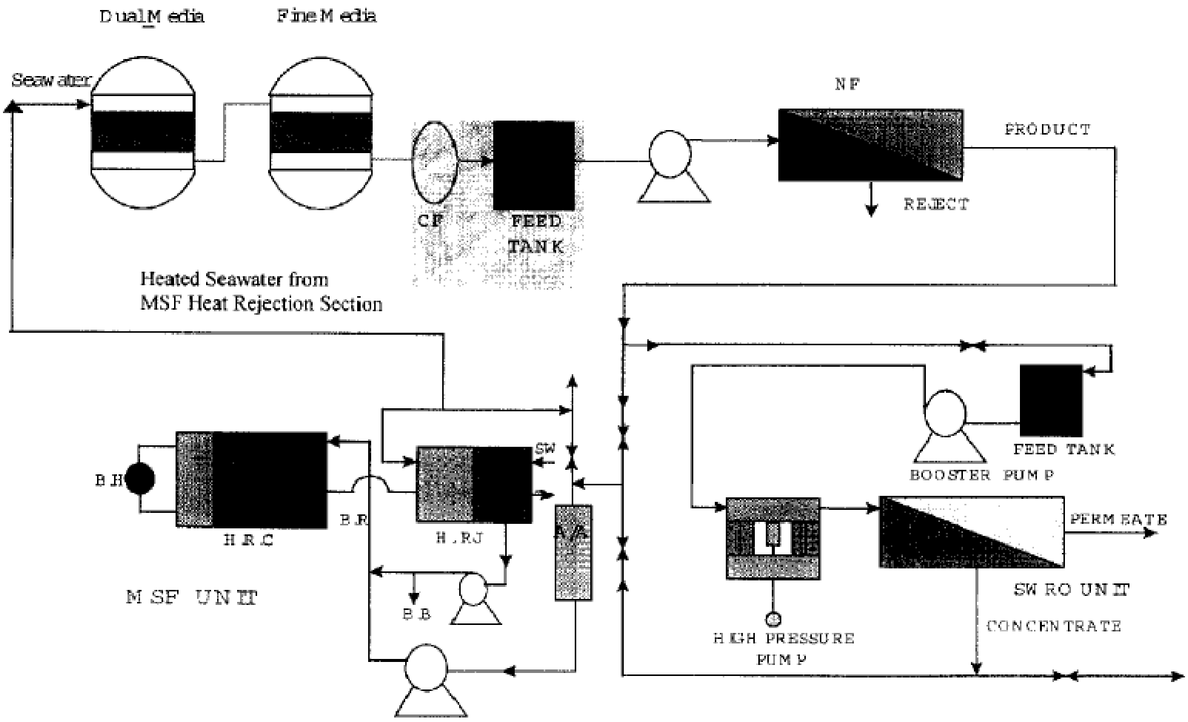
Desalination, *Volume 131, Issues 1-3*, *20 December 2000*, *Pages 157-171*

A. M. Hassan, A. M. Farooque, A. T. M. Jamaluddin, A. S. Al-Amoudi, M. A. K. Al-Sofi, A. F. Al-Rubaian, N. M. Kither, I. A. R. Al-Tisan and A. Rowaili

Abstract

Earlier work at Saline Water Conversion Corporation (SWCC) R&D Center showed that nanofiltration (NF) pretreatment of seawater feed to seawater desalination plants removed from it turbidity and microorganism, caused significant rejection of the scale forming hardness ions, reduced TDS in Gulf seawater and produced a new, partially desalinated seawater product, considerably different and superior to seawater in qualities and without the problems normally associated with seawater of high concentration of scale forming ions, high TDS, high turbidity and high bacteria count. Integration of the NF unit with one of the conventional desalination processes to form for example an NF-SWRO lead to a significant improvement in the seawater desalination processes, for example by doubling the SWRO product water output and recovery ratio and the production of high purity permeate (TDS <200 ppm) from one single stage SWRO. However, all previous works were done on a pilot plant scale by integrating NF spiral wound membrane elements in series, size 4"x40", with a SWRO unit employing 2.5"x40" membrane elements. In view of the positive and encouraging results obtained on a pilot plant scale, trial on an NFSWRO demonstration unit was not only logical but essential to determine the operating conditions as well as to establish plant performance parameters for commercial size NF-SWRO plants. The demonstration unit built for this purpose consisted of 6 NF spiral wound membrane elements, size 8"x40" arranged in series followed by a SWRO unit comprising 3 HFF SWRO elements 8"x40" or 9"x40" also arranged in series. The paper describes the NFSWRO demonstration unit along with the experimental approach used in this investigation dealing with the performance of several selected NF membranes integrated with SWRO membrane to form an NF-SWRO desalination system. The results obtained from the demonstration unit confirm the earlier results which were obtained from the pilot plant study. The results shall be utilized in the operation of the now under construction NFSWRO plant at Umm Lujj, Saudi Arabia.

Keywords: Seawater desalination; Nanofiltration; Seawater reverse osmosis; NF-SWRO



Conclusions

Results obtained from NF-SWRO Demonstration plant (utilizing 8") <40" for both NF and SWRO membranes confirms earlier results obtained from pilot plant (utilizing 4") <40" membranes in combination with 2.5"x40" SWRO membranes). Conclusions drawn from this investigation are same as in reference [7]. Moreover, the study allowed for the establishment of operating parameters for future NF-SWRO plants. These operating parameters shall be utilized in the operation of the now under construction NF-SWRO plant at Umm Lujj, Saudi Arabia.

Nanofiltration as a means of achieving higher TBT of ≥ 120°C in MSF

Desalination, *Volume 118, Issues 1-3*, *20 September 1998*, *Pages 123-129*

Mohammad A. K. Al-Sofi, Ata M. Hassan, Ghulam M. Mustafa, Abdul Ghani I. Dalvi and Mohammad N. M. Kither

Abstract

The Saline Water Conversion Corporation, Research and Development Center (SWCC-RDC) carried out exploratory research study to evaluate the adaptability of the brackish water softening nanofiltration technique as a permeation pretreatment of feed to seawater reverse osmosis (SWRO) and as make-up to MSF. This exploratory work was designated as part I of an applied research project that was carried out from March 1997 to May 1998. Based on initial remarkable results, SWCC applied for a patent on the process during 1997. This paper reports on the pretreatment approach and its application to thermal desalination using MSF. The work carded out in part I of this project is reported where make-up to a 20kiloliter/d MSF pilot plant distiller was either fresh nanofiltration permeate (NFP) or SWRO reject (while SWRO was fed with NFP).

This paper also addresses the plan of elevating MSF top brine temperature (TBT) to as high as 160 ° C since operation at TBT of 120 ° C with very little or no scale control treatment gave excellent results.
Keywords: Pretreatment; Permeation; Nanofiltration; Reverse osmosis; MSF distillation; TBT; Hardness and total alkalinity

Conclusions
SWCC-RDC have come up with a true breakthrough in operating MSF with low to no scale control chemical treatment other than nanofiltration of make-up. Moreover, MSF operation utilizing SWRO reject again with very limited scale control chemical treatment became feasible, i.e., the hybrid concept. These achievements were possible at a TBT of 120°C in either case.

A new approach to membrane and thermal seawater desalination processes using nanofiltration membranes (Part 1)
Desalination, *Volume 118, Issues 1-3*, *20 September 1998*, *Pages 35-51*
A. M. Hassan, M. A. K. Al-Sofi, A. S. Al-Amoudi, A. T. M. Jamaluddin, A. M. Farooque, A. Rowaili, A. G. I. Dalvi, N. M. Kither, G. M. Mustafa and I. A. R. Al-Tisan

Abstract
In this new approach to membrane and thermal seawater desalination processes developed by the Saline Water Conversion Corporation (SWCC), R&D Center, a nanofiltration (NF) membrane unit, which received non-coagulated filtered seawater feed, was placed ahead of the SWRO and the MSF pilot plant units to form, for the first time ever, fully integrated desalination systems of an NF-SWRO, NF-MSF, and NF-SWROreject-MSF. Preliminary results were presented at the IDA World Congress, Madrid '97. Further results obtained in this investigation at a pressure of 22 bars showed that the NF unit reduced turbidity and microorganisms, removed hardness ions of Ca ++, Mg ++, SO~, HCO~, and total hardness by 89.6%, 94.0%, 97.8%, 76.6% and 93.3%, respectively. The system also resulted in the reduction of the monovalent ions of Cl-, Na ÷, K ÷ each by 40.3% and the overall seawater TDS by 57.7%. The seawater (NF permeate water) produced by this process is considerably different in composition from (Gulf) seawater, and quality-wise is far superior to it as a feed to seawater desalination plants, and moreover without the problems normally associated with high concentration in seawater of scale forming ions, high TDS, high turbidity and microorganisms. This made it possible to operate both the SWRO and MSF pilot plants at high water recovery: 70% and 80 %, respectively. It also allowed for the successful operation of the MSF unit at top brine temperature of 120 ° C without the addition to the make-up of antiscalant or acid or antifoam. The said desalination arrangements lead to significant improvement in the seawater desalination processes by lowering their energy consumption, by about 25-30%, and reducing chemical consumption thereby making the process friendlier to the marine environment. The observed increases in their product water output and recovery ratio by more than 70% resulted in the ultimate benefit of lowering the estimated cost of fresh water production by more than 27%. The SWRO permeate produced from the NF-SWRO arrangement has very low TDS, ~200 ppm, making the requirement for a second-stage RO treatment of the SWRO permeate unnecessary. Moreover, the use of the desalination arrangement NF-SWRO~-MSF should allow for the conversion of up to 90% of the NF product into fresh water, where about 65% of the NF product is converted to fresh water by the SWRO unit and 25% of SWRO reject is converted by the MSF unit.

Definitely, the achievement of the above results represents a milestone in seawater desalination technology. The paper describes the results obtained, the experimental approach used in this investigation along with description of the NF-SWRO, NF-MSF and NF-SWROreject-MSF pilot plants employed in this study. A simulated desalination model which compares the operation of existing SWRO plants with and without the NF modification is also described along with the technoeconomics of process analysis.
Keywords: Nanofiltration; Membranes; NF-MSF; NF-SWROreject-MSF

Conclusions
The NF membrane treatment of noncoagulated dual-media filtered seawater feed to desalination plants removes from it (1) very fine turbidity, (2) residual bacteria, (3) scale forming hardness ions, in some case by up to 98% and (4) lowers its TDS, depending on operation conditions by more than 50%. With this NF feed treatment the otherwise complex conventional seawater desalination process is simplified since the effects on seawater desalination by the above four factors, which constitute the major problems in seawater desalination by the conventional processes are eliminated. Feeding of the said NF product to desalination plants, whether based on the thermal or the membrane processes, not only allows for their operation with less or no chemicals normally used in the conventional process (i.e., antiscalants, and in case of MSF also antifoam) and by raising significantly their permeate and distillate recovery ratios to 70% and 80%, respectively, but also by lowering their energy consumption with the ultimate benefit of lowering potable water production cost. The combination of NF with MSF process makes it possible to operate MSF plants on NF-product or SWROreject from NF-SWRO unit at high distillation temperature of 120°C to 160°C with high distillate recovery, and again without chemical addition or at reduced level thereof. Similarly, the NF-SWRO process makes it feasible to produce high purity permeate from a single-stage SWRO process without the need for a second desalination stage. Also, this process significantly improves the quality of permeate from otherwise low-performance SWRO membranes. In short, it can be concluded that operation of seawater desalination plants when combined with this new NF membrane pretreatment is superior in performance to their operation without the NF pretreatment.

With MF membranes

Content:

The case for UF/MF pretreatment to RO in seawater applications
Desalination, *Volume 203, Issues 1-3*, *5 February 2007*, *Pages 286-295*
G.K. Pearce

Go to the top of doc. >Pretreatment for RO seawater desalination with UF membranes or straight to the pdf file

The use of microfiltration membranes for seawater pre-treatment prior to reverse osmosis membranes'
Desalination, *Volume 153, Issues 1-3*, *10 February 2003*, *Pages 141-147*
D. Vial and G. Doussau

Abstract
Since the early 198Os, microfiltration and ultrafiltration have been widely used for drinking water applications. More recently, membranes have started to be used in membrane bioreactors or on secondary wastewater effluents for reuse application. Until recently, in desalination treatment plants seawater was pre-treated with a combination of conventional techniques such as air flotation, clarification, sand filtration and cartridge filtration prior to spiral wound reverse osmosis (RO) desalination membranes. Microfiltration or ultrafiltration membranes are now considered as an alternative solution for seawater pre-treatment. This paper describes pilot test results obtained on Mediterranean seawater using a 0.1 pm hollow fiber Microza module. A pilot rig was operated at different fluxes ranging from 80 to 140 L/h.m^2 with and without ferric chloride addition. Run cycles between chemical cleanings varied between 10 days and 30 days depending on the operating conditions and seawater quality. During the tests, seawater silt density index (SDI) ranged between 6 to non-measurable while the microfiltered water SD1 remained below 2 under the optimized operating conditions. With low and constant microfiltered water SD1 values, it is possible to design a full-scale plant with fewer RO membranes and to expect longer RO run cycles.
Keywords: Micro filtration; Reverse osmosis; Seawater; Silt Density Index; Pretreatment; Drinking water

Conclusions
Long-term seawater pilot testing has shown the 0.1 urn Microza hollow-fiber module's ability to provide clarified water for RO desalination systems. It has been shown that both seawater pre-treatment and the reagent used during backwashes have an effect on the rate of permeability decrease of the membrane as well as on filtrate quality. Seawater quality variations, membrane flux and transmembrane pressure have low impacts on the filtrate SD1 values. Longer runs between chemical cleans and better filtered water quality are obtained with ferric chloride addition to the raw seawater and by performing backwashes with sodium hypochlorite. Under these conditions, it is anticipated that Microza modules run with cycles between chemical cleans lasting more than 14 days while producing a treated water quality with SD1 (15 min) constantly below 2. Pall is a trademark of Pall Corporation. Microza is a trademark of Asahi Kasei Corporation.

Pretreatment of seawater: Results of pilot trials in Singapore
Desalination, *Volume 159, Issue 3*, *5 November 2003*, *Pages 225-243*
K. T. Chua, M. N. A. Hawlader and A. Malek
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Comparison of MF/UF pretreatment with conventional filtration prior to RO membranes for surface seawater desalination
Desalination, *Volume 144, Issues 1-3*, *10 September 2002*, *Pages 353-360*
A. Brehant, V. Bonnelye and M. Perez
Go to the top of doc. >Pretreatment for RO seawater desalination with UF membranes

Other

Content:

- Integrated membrane operations in desalination processes
- Integrated Membrane Desalination Systems – Potential Benefits of Combined Technology
- Options for recarbonation, remineralisation and disinfection for desalination plants
- An experiment with different pretreatment methods
- Study of seawater alkalization as a promising RO pretreatment method

Integrated membrane operations in desalination processes

Desalination, *Volume 122, Issues 2-3*, *7 July 1999*, *Pages 141-145*
E. Drioli, F. Laganà, A. Criscuoli and G. Barbieri

Abstract
Reverse osmosis is widely applied to water desalination because of the relatively low cost of the process. Besides the well defined role that this technology plays in the desalination scenario, in the last years, all over the world, demand for lower costs and higher quality of water has been advanced. Integrated membrane processes represent an attractive opportunity because of the synergic effects that can be reached, the simplicity of these units, and the possibility of advanced levels of automatisation and remote control. Moreover, the integration of different membrane units represents an interesting way for reaching the process intensification goals due to the possibility of overcoming the limits of the single units and, thus, to improve the performance of the overall operation.
Keyword: Membrane desalination; Integrated membrane systems; Process intensification

Conclusions

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In this work the potentialities of an integrated membrane desalination system have been experimentally verified. The achieved results confirm the interest in operating by combining different membrane units. In particular, the presence of the NF as pretreatment allows to increase the water recovery of the RO unit up to 50%. Moreover, introduction of a membrane crystallizer leads to a 100% recovery and elimination of the brine disposal problem, representing the pure crystals produced a valuable product. From this preliminary analysis, adoption of integrated membrane systems appears an interesting possibility for improving desalination operations and meeting the increasing pure water demand

Table 2
Comparison between the integrated system and the traditional one

	Integrated NF/RO/MC system	Conventional NF/RO system
Water recovery, %	100	50
Energy consumption, kWh/m³	10	4.57
Capital costs, $:		
Membranes	500	300
Brine cisposal	/	50
Chemical feed systems	114	114
Total capital costs	564	464
Operating costs, $/m³		
Energy[a]	0.7	0.32
Energy[b]	0.18	
Membrane replacement[c]	0.34	0.2
Brine disposal	/	0.0015
Chemical feed systems	/	0.025
Total operating costs – unit water cost	1.04	0.547
Total operating costs – unit water cost[c]	0.52	

Integrated Membrane Desalination Systems – Potential Benefits of Combined Technology

Craig Bartels Ph.D, Stefan Rybar Ph.D, and Rich Franks
Hydranautics, California

Source:http://www.hydranautics.com/docs/papers/New%20Folder/Gulf%20Industry%20Magazine%20-%20Hydranautics.pdf

Abstract

With the commercial introduction of modern ultrafiltration (UF) and microfiltration (MF) technologies, it was expected that these membrane filtration processes would provide the optimum pretreatment technology for reverse osmosis (RO) applications. These expectations have been realized in the reclamation of municipal wastewater. Practically, all new wastewater reclamation systems that use RO for salinity reduction apply UF or MF technology as a pretreatment step before RO. Effectiveness of membrane pretreatment in producing good quality RO feed water is proven and well documented. However, improved quality of MF/UF effluent, as compared to conventional pretreatment comes at a cost that is still significant and in most cases higher than the comparable cost of conventional pretreatment based on media filtration. In a wastewater reclamation process with integrated membrane pretreatment, the benefits of significantly lower fouling rates of RO membranes, low cost of chemicals and disposal of pretreatment waste stream, outweighs the higher cost membrane pretreatment equipment. Outside wastewater reclamation applications, the number of installations using Integrated Membrane Solutions ® (IMS) is relatively small. So far the RO units operated on UF/MF effluent are designed in a similar way as the RO system operating with conventional pretreatment. a limited number of medium size plants that utilize membrane filtration as the pretreatment step are being built and some are operational already (Table 1)

Location	Addur, Bahrain	Valdaliga Sud – Italy - Enel	Fukuoka, Japan	Kindasa, Saudi Arabia	Yu-Han, China
Membrane filtration capacity, m3/day	140,000	1,250	96,000	90,000	70,000
Operational status	Operational since May 2000	Operational since May 2004	Operational since May 2005	Start-up mid-2006	Start-up Early 2006
Membrane technology	Pressure driven UF backwashable spiral	Pressure driven UF capillary	Pressure driven UF backwashable spiral	Pressure driven UF capillary	Submersible UF capillary
Pretreatment Membrane module manufacturer	Nitto Denko	Hydranautics	Nitto Denko	Hydranautics	Zenon

The Ad Dur plant is probably one of the first seawater plants where the concept of integrated membrane solution (IMS) has been implemented. The UF filtration equipment used is unique as it is based on spiral wound elements that are backwashed by reversing the direction of the filtrate flow, so called reversible spiral (RS). At the time of implementation (year 2000) the RS technology was at the early stages of commercial development and a number of operational and performance problems were encountered. Subsequently, the problems were solved by product modifications and improvement of operating conditions. Presently, the performance of the UF filtration unit is according to specifications.

Conclusion

There continues to be a trend toward the use of membrane pretreatment in RO-based systems. When difficult feedwaters are encountered, such as wastewater or difficult surface water, UF/MF pretreatment can effectively reduce membrane fouling rates. The reduced fouling rates lead to lower energy consumption, lower chemical usage, longer membrane life, less maintenance and greater system online time. Additionally, the improved water quality may allow the RO to run at higher flux. This will result in a smaller RO system and further capital cost savings.

An experiment with different pretreatment methods

Desalination, *Volume 156, Issues 1-3*, *1 August 2003*, *Pages 51-58*

C. K. Teng, M. N. A. Hawlader and A. Malek

Abstract

The use of reverse osmosis (RO) method for the desalination of seawater to produce fresh water is gaining momentum over the last decade. Although there have been considerable improvements in membrane materials, the fouling of membrane creates a significant problem yet to be overcome. Performance of systems employing different pretreatment methods used in the RO desalination process was investigated experimentally. Field tests included advanced membrane filtration techniques: ultrafiltration (UF) and microfiltration (MF). During the pilot testing, silt density index (SDI) of the filtrate samples were regularly measured to quantify the performance of pretreatment systems. Measurements of other important parameters included filtrate flux, transmembrane pressure (TMP), total suspended solids, colloidal silica, total organic carbon, etc. Test results showed that membrane pretreatment consistently produced filtrate of a good quality. SD1 of the filtrate produced by membrane pretreatment method was consistently below 3.0, a prerequisite for proper operation of a RO desalination plant. Improved maintenance procedures, such as filtrate backwashing and air scouting coupled with periodic use of chemicals, resulted in significant flux and pressure recoveries during the pilot tests. Ease of operation of the membrane pretreatment systems was also noted by the authors.

Keywords: Reverse osmosis; Fouling; Pretreatment; Ultrafiltration; Microfiltration; Silt Density Index

Conclusions

There was a significant difference between the operating fluxes of the MF and UF pretreatment systems. The higher operating flux of the MF pilot system was achieved at the expense of increasing TMP, which had to be kept constant by a more elaborate maintenance system comprising of air scouring and filtrate backwashing. However, SDI of the filtrate produced by the UF pilot system was superior to that produced by the MF pilot system. It should be noted that while filtrate quality of the MF system was inferior to that of the UF pilot system, it is still of considerably good quality. Filtrate SDI of the MF pilot system was consistently less than 3.0 in the experiment. During the pilot tests, ease of operation of the membrane pretreatment systems was noted by the author. Moreover, membrane pretreatment systems generally require less space and chemicals compared to the conventional pretreatment system. Together with improved maintenance procedures, such as filtrate backwashing and air scouring significant flux and pressure recoveries are achievable with minimal use of chemicals. Using membrane methods of pretreatment will also go in tandem with the recent trend of increasing packing density of spiral wound RO elements.

With an increasing packing density, propensity to fouling and pore blockage for the new RO spiral element will definitely be higher and greater emphasis will be placed on pretreatment in producing better quality feed. Therefore, there is an economic incentive to the usage, and continual improvement and research in the area of membrane pretreatment. Current research also emphasized the importance of pilot testing as measured performance is the combined effect of the membrane, system configuration and the dynamic cake layer that formed on surface of the membrane during filtration.

Study of seawater alkalization as a promising RO pretreatment method
Desalination, *Volume 153, Issues 1-3*, *10 February 2003*, *Pages 109-120*
Samir El-Manharawy and Azza Hafez

Abstract
Inorganic fouling is a major challenge in seawater RO desalination due to its relatively high SO_4/HCO_3, molar ratios. In most of the recorded cases, if not all, calcium sulfate scale is dominating (>90% wt/wt) other scale types such as $CaCO_3$, $MgSO_4$, $MgCO_3$, $MgSiO_3$, SiO_2, and $CaPO_4$. However, the standard pretreatment practice in RO plants depends on the acidification of seawater in order to remove the minor carbonate and bicarbonate. Meanwhile, solubility of the major sulfate species decreases considerably because of acidification. The present study investigated the application of NaOH alkalization on the Red Sea surface water instead. It was found that the method has many technical and economical advantages, such as removal of hard chemical species (i.e. hard carbonate, bicarbonate, sulfate, silicate, phosphate and iron), removal of suspended solids and colloids, bacterial disinfection, cleaning and wetting of a membrane surface, increasing permeate recovery, lower sludge volume of environmentally chemical nature, and the possibility of instant preparation of NaOH in-line by seawater electrolysis. The alkalization method is fast, clean and economic. The proposed model as well as chemical equations are presented in detail.
Keywords: Seawater alkalization; RO pretreatment; Seawater softening; Seawater electrolysis

Conclusions and recommendations
The alkalization of the Red Sea water by sodium hydroxide to pH 10 was found to be a valuable substitution of the acidification process used for RO pretreatment. The method has many technical and economical advantages in a single process, such as removal of hard chemical species (i.e. hard carbonate, bicarbonate, sulfate, silicate, phosphate and iron), removal of suspended solids and colloid, bacterial disinfection, cleaning and wetting of the membrane surface, increasing permeate recovery easily, decreasing corrosion rate, low sludge volume of environmentally chemical nature, and the possibility of instant preparation of NaOH in-line by seawater electrolysis. The alkalization method is fast, clean and economic. It is recommended to upgrade the present laboratory study to a pilot-scale in order to update the obtained results on a larger scale, evaluate the technoeconomic pre-feasibility, and determine the detailed engineering parameters required for the full-scale design. It is also recommended installing the pilot plant on the Red Sea side to avoid the rapid interaction of atmospheric CO_2 that will cut the cost effectively. A more detailed laboratory investigation may be needed for better understanding of the proposed model and associated chemical equations, which is basically different from other chemical softening models.

Intake of seawater for desalination plants

Content:

- Improved seawater intake and pre-treatment system based on Neodren technology
- Reverse osmosis on open intake seawater: pre-treatment strategy
- Water type and guidelines for RO system design

Improved seawater intake and pre-treatment system based on Neodren technology

Desalination, *Volume 203, Issues 1-3*, *5 February 2007*, *Pages 134-140*

Thomas Peters, Domènec Pintó and Esteve Pintó

Abstract

Consistent high quality pre-treatment of the feed water is one of the most important prerequisites for long-term successful operation of seawater desalination plants. A first step to fulfil this requirement is the use of directed drilled horizontal drains below the sea bed, a technology that has been developed by drilling experts based on experiences with dredge-less pipeline installations starting 1996. With the use of these horizontal drains the raw and fine screening, as well as conventional filtration of seawater will not be necessary due to the fact, that the sand of the sea bed will act as a "natural" pre-filter, separating all kind of solids and particles down to the micron range from the seawater to be fed to the desalination plant. This system, introduced as Neodren, can be operated in sandy and karstic sea beds as ecological and economical alternative for conventional open seawater intake systems and has even advantages in comparison with beach well installations. This technology for seawater intake and pretreatment can also be adapted successfully in areas with high contaminated seawater. It minimizes the environmental impact and is safe against the destroying forces of waves in the coast line. It is applicable for desalination plants for the production of drinking water from seawater on any scale between several 100 m³/d to several 100,000 m³/d. In combination with micro-bubble flotation and ultrafiltration the process minimizes drastically the need for chemicals that are necessary usually for the pre-treatment of seawater in order to reduce the scaling and fouling potential and to prevent biofouling before feeding it for example to blocking-sensitive membrane elements of a reverse osmosis plant. Reduction of the costs related with infrastructure, logistics and operation can be achieved.

Keywords: Seawater intake; Seawater pretreatment; Seawater desalination; Reverse osmosis

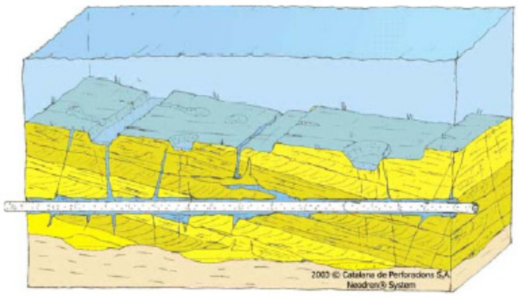


Fig. 1. Horizontal drain in the sea bed.

Conclusions

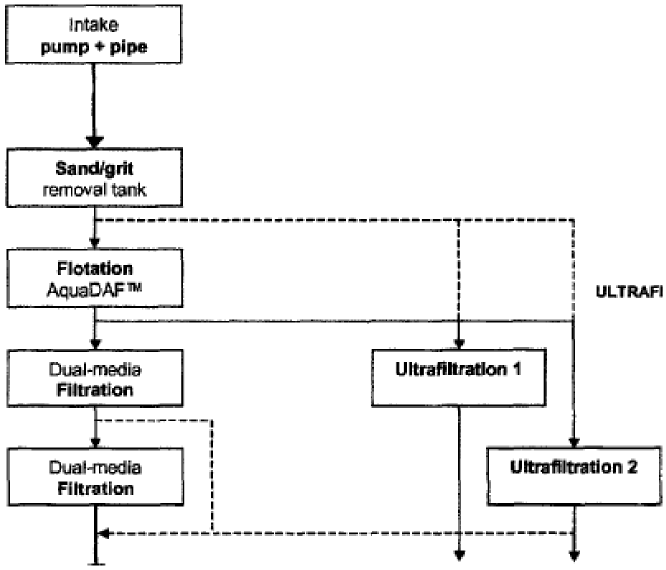
Aspects concerning the Neodren technology for seawater intake and pre-treatment:
Effective:

• Obtaining water with the same quality as sea's.
• No effect of dynamic action in the sea on the drain, due to its subterranean positioning.

• Elimination of turbidity from the seawater.
• Homogeneous temperature of the harnessed water.
• Constant recharge of the submarine aquifer.
Ecological:
• No changes in the coastline. No effect to the sea habitat.
• No dig excavation necessary in the seabed.
• No changes of the physical and biological sea environment.
• It does not affect the freshwater aquifers.
• Fixation of the sandy spots and submerged beaches in the seabed as side effect.
Quick:
• Superficial location of the drilling equipment, with no need of any ground disturbance.
• Positioning of the intake point in a reduced space
• Two reduced working areas, one on land, and one offshore
• No blasting, breakwaters construction or seabed dredging.
Regarding desalination of seawater the use of the Neodren technology will help to
• simplify the pre-treatment in seawater desalination plants reduce the use of chemicals for seawater pretreatment
• reduce the frequency of chemical cleaning that has an important influence to the lifetime of the membranes
• reduce the costs for membrane replacement
• reduce the costs associated with cleaning like handling, rinsing water, waste water discharge
• reduce the environmental impact correlated with the installation and operation of desalination plants with conventional seawater intake and pre-treatment
• improve the overall efficiency of desalination plants
• reduce the cost of ownership.

Reverse osmosis on open intake seawater: pre-treatment strategy
Desalination, *Volume 167*, *15 August 2004*, *Pages 191-200*
Véronique Bonnelye, Miguel Angel Sanz, Jean-Pierre Durand, Ludovic Plasse, Frédéric Gueguen and Pierre Mazounie

Abstract
Pre-treatment of seawater feeding reverse osmosis (RO) membranes is a key step in designing desalination plants. The pre-treatment process must be adapted to the seawater quality to be treated (wells, open intake, etc.), especially when treating surface seawater with highly variable quality. After a general presentation of different pretreatment options in relation to the seawater quality, this paper is focusing on two case studies, two open intake seawater pre-treatment upstream reverse osmosis desalination. The first site is located in the Gulf of Oman (Indian Ocean), the second in the Persian Gulf. The pre-treatment uses different technology strategies, conventional pretreatment (coagulation and direct filtration on dual media filters) and innovative technologies (high rate dissolved air flotation, ultrafiltration and microfiltration) according to the water quality. The parameters taken into account for the water quality characterization are the suspended solids, turbidity, fouling tendency, organic matters and algae content. This paper presents the pre-treated water quality achieved by the two types of pre-treatment and discusses potential impacts on RO hydraulic performances.
Keywords: Seawater reverse osmosis; Open intake; Pre-treatment



Conclusion
The pilot testing during 9 months on the Gulf of Oman, which was paramount to optimise the pre-treatment stage and the chemical regime in relation to the seawater quality, improves the optimisation of the process. The results were used for the commissioning of the full industrial plant, a 37.5 MGD open seawater intake desalination plant located in Fujairah. Preliminary full-scale plant results demonstrate that the foreseen performance and water quality are being achieved. In the Persian Gulf, on a rather bad surface seawater intake, the pre-treatment including dissolved air flotation, direct filtration or ultrafiltration, gives good results in terms of turbidity, algae and hydrocarbon removal, leading to a reliable SDI far below 3 value. These pilot tests improve the knowledge of surface seawater treatment upstream RO and demonstrate the reliability and robustness of such treatment facing variable surface seawater.

Water type and guidelines for RO system design
Desalination, *Volume 139*, 27 *January 2001*, *Pages 97-113*
Samir El-Manharawy, Azza Hafez

Abstract

Water type is the cornerstone in reverse osmosis system designing. However, the systematic differentiation and identification of different natural waters are almost missing. In the RO industry all natural waters are usually grouped under two types: brackish (1000-15000 mg/l) and seawater (> 15,000 mg/l) as based on their total salinity. Only two RO membrane types are commercially available (i.e., B WRO and SWRO), which are currently used for all waters regardless of the wide variation in their chemical nature, even those of similar salinity. Most of the recommended pretreatment methods given by the membrane manufacturers are normally based on a single water type, either brackish or seawater. In addition, the current use of the misleading saturation indices (LSI, S&DSI, etc.) that developed originally for heating boilers and exchangers, led to serious inorganic scaling problems. These generalized approaches have serious impact on the performance and economics of RO desalination. The cost of $2-3 per lm 3 of desalinated water is not surprising anymore, especially in the case of small-capacity plants.

The present work concerns the critical importance of differentiation of natural waters in a systematic chemical classification that may provide assistance in RO system design, selection of membrane and proper pretreatment as well. From the experience gained in hydrochemistry and water analysis along the last 30 years, besides the extensive literature survey and the statistical analysis of more than 200 water analyses, the present authors were able to conclude a systematic water classification. The proposed classification is based on the earlier work of El-Manharawy and Hafez as well as the real molar-concentration of the dissolved ion associations of the investigated water samples which covered a wide range of natural surface and ground water types. It was possible to identify four major water classes (<10, 150, 400 and >600 mM chloride ion), including 10 subclasses of different water types [<0.1, 0.2, 0.5, 1.0, 2.0, 5.0, 10, 15, 20, >20 (SO/riCO3) molar ratio]. These classes and types cover the whole spectrum from salinity of-200 mg/1 up to -60,000 mg/l. More detailed subdivisions could be derived when necessary. In light of the obtained water molar classification, it was possible to set guidelines for inorganic scale prediction and the suitable chemical pretreatment for specifically each of the proposed water types. Technical recommendations for RO system design and membrane selection are also provided in detail.

Keywords: Water classification; Water type; RO system design; Molar ratio; Membrane fouling

Conclusions

The current study has shown that natural waters could be chemically differentiated and classified into four major chemical classes and ten water types as based on their ion molar concentrations and ratios. The proposed "Water Molar Classification" is useful in understanding the chemical nature of the investigated water type and its possible behaviour under the pressure dehydration process that characterizes desalination by RO membrane technology. Inorganic scaling potential, as well as scale chemical nature, could be easily predicted in light of the present classification. It was possible to determine guidelines for the RO system design, membrane selection, pretreatment and chemical cleaning methods that are suitable for a specific water type.

Reports from Desalination plants

Content:

- Membranes as pretreatment to desalination in wastewater reuse: operating experience in the municipal and industrial sectors
- Pretreatment of seawater: Results of pilot trials in Singapore
- Pilot plant study at the Dhekelia seawater desalination plant: a review of the performance and operating data of the Koch Membrane Systems spiral-wound TFC® 2832SS-540 Magnum® seawater elements and study and interpretation of the normalized data using the NormPro® software
- Performance characteristics of a cyclically operated seawater desalination plant in Tajoura, Libya
- Fifteen years of R&D program in seawater desalination at KISR part I. Pretreatment technologies for RO systems

Pretreatment of seawater: Results of pilot trials in Singapore

Desalination, *Volume 159, Issue 3*, *5 November 2003*, *Pages 225-243*

K. T. Chua, M. N. A. Hawlader and A. Malek

Abstract
In this paper, performance of different pretreatment systems used in the seawater reverse osmosis desalination process is presented. The different pretreatment techniques analyzed included conventional media-filtration technique and nonconventional membrane filtration techniques. For the membrane filtration techniques, two ultrafiltration and one microfiltration pilot plants were used in the experimental study. During the experiments, the silt density index (SDI) of the filtrate samples was regularly measured to quantify the performance of pretreatment systems in rejecting colloidal particles. Measurements of other important parameters included filtrate flux, transmembrane pressure, total suspended solids, colloidal silica, total organic carbon, etc. According to the experimental findings, the quality of the filtrate produced by the conventional media-filtration technique was inferior and highly inconsistent. SD1 of filtrate varied from 2.8 to 3.8 and spikes as high as 6.3 were frequently observed Membrane pretreatment produced filtrate of a better quality, SD1 of the filtrate produced was consistently below 3.0, a prerequisite for proper operation of a RO desalination plant. The ease of operation of the membrane pretreatment processes was also noted. Together with improved maintenance procedures such as filtrate backwashing and air scouring, complete flux and pressure recoveries were achievable with minimal use of chemicals during the experiments.
Keyword: Pretreatment; Reverse osmosis; Microfiltration; Silt Density Index; Ultrafiltration

Comparison of membrane pretreatment techniques

Description	UF pilot system 1	UF pilot system 2	MF pilot system
Feed source	Sand-filtered filtrate	Seawater	Seawater
Membrane process	Direct-flow	Cross-flow with recovery of 80%	Direct-flow
Availability, %	92.7	74.4	92.4
Filtrate flux, $l/m^2.h$	47	57.6	100
SDI	2.5–3.0	0.9–1.2	2.5–3.0
Chemical costs, $US\$/m^3$	0.01390	0.00027	0.00218

Conclusions
According to the experimental findings, the quality of the filtrate produced by conventional media-filtration techniques is inferior and highly inconsistent. Unlike a media-filtration technique, membrane pretreatment consistently produces filtrate of a better quality. The ease of operation of the membrane pretreatment processes was also noted. Moreover, membrane pretreatment systems generally require less space and fewer chemicals compared to a conventional pretreatment system. Together with improved maintenance procedures such as filtrate backwashing and air scouring, complete flux and pressure recoveries are achievable with minimal use of chemicals. Successful application of membrane technology was also reported by Taniguchi [18].Using membrane methods of pretreatment will also go in tandem with the recent trend of increasing packing density of spiral-wound RO elements. With an increasing packing density, the propensity to fouling and pore blockage for the new RO spiral element will definitely be higher and greater emphasis will be placed on pretreatment in producing better quality feed. Therefore, there is an economic incentive to the use and continual improvement and research in the area of membrane pretreatment. The current research also emphasized the importance of pilot testing as measured performance is the combined effect of the membrane, system configuration and the dynamic cake layer that formed on surface of the membrane during filtration.

Pilot plant study at the Dhekelia seawater desalination plant: a review of the performance and operating data of the Koch Membrane Systems spiral-wound TFC® 2832SS-540 Magnum® seawater elements and study and interpretation of the normalized data using the NormPro® software

Desalination, *Volume 139, Issues 1-3*, *20 September 2001*, *Pages 125-129*

Olga Sallangos and Peter Moss

Abstract

The need for good-quality water in Cyprus continues to be the driving force for the use of reverse osmosis to desalinate brackish water and seawater for irrigation and potable use. Much work continues both to optimize the process designs for new plants and to refine the operation of existing ones. The pilot plant has been operated successfully for over 2 years. It uses four TFC ® 2832SS-540 Magnum ® elements in one tube operating at 50% recovery. It has been monitored using the NormPro ® normalization software to assess the performance of the elements during this time. The normalized data are reviewed and an interpretation of the results given. The effect of the pretreatment on fouling is assessed and the results of the cleaning reviewed. The study shows the importance of monitoring in order to ensure satisfactory long-term stable system performance.

Keywords: Reverse osmosis; Seawater; Pilot plant; Normalization; Pretreatment; Cleaning; Cyprus

Conclusions

The pilot plant has operated successfully for over 2 years and demonstrates that the spiralwound element, TFC ® 2832SS-540 Magnum ®, can operate reliably under these site conditions. The permeate flow, salt passage and pressure drop are stable. The performance follows the projected results and gives a high level of confidence in the prediction values used for design purposes. The quality of the seawater and pretreatment is good and minimizes fouling, requiring cleaning only everly 9 to 12 months. Boron rejection is much higher than anticipated.

Performance characteristics of a cyclically operated seawater desalination plant in Tajoura, Libya

Desalination, *Volume 139, Issues 1-3*, *20 September 2001*, *Pages 131-132*

A. A. Abufayed

Abstract

The Tajoura seawater reverse osmosis desalination plant had to be operated cyclically because the conveyance works from the plant to the town were not completed at the time of the plant's start-up. The objective of this paper was to evaluate the plants performance characteristics through analysis of data collected during its first year of cyclic operation. Although it was difficult to assess the plant performance relative to similar continuous flow plants, it was clearly demonstrated that the TSWRO plant performed satisfactorily in terms of its design objectives. Normalized product flows were better than the design ones and permeate concentrations were well below the WHO drinking water standards. Moreover, variations in performance indicators were quite similar to non-cyclic "normal" systems indicating that membranes were not sensitive to cyclic fatiguing effects. Chemicals and power costs were also not impacted notably by the cyclic mode of operation as they were by design shortcomings. Membrane replacement was warranted after over 4 years of cyclic operation.

As expected, the frequency of membrane preservation operations and of repairs were higher than "normal" operating conditions. Unit product costs were high as a result of the low availability of 20%. The results can be applied to similar situations or for the prediction or optimization of design and operation of reverse osmosis desalination plants under cyclic operational conditions.
Keywords: desalination; Reverse osmosis; Cyclic operation; Libya

Conclusions
The TSWRO plant has been operating cyclically for several years. Based on this plant's performance throughout its first one year of operation, the following conclusions were made:
1. The holistic approach to water supply and conveyance/distribution proved invaluable with special stress on contracting and project management;
2. Utilization of actual field data was essential to the proper design of desalination plants and to minimizing water production costs;
3. Cyclic operation with variable length operate/ shut-down periods had no discernable quantitative adverse effects on plant efficiency; normalized product flows were consistently equal to or better than design and reference flows;
4. Normalized product concentrations increased gradually with time exceeding the reference concentrations, but remaining well below the design values;
5. Overall product unit costs were higher than projected due mostly to underutilization of resources resulting from the very low plant availability.

Fifteen years of R&D program in seawater desalination at KISR part I. Pretreatment technologies for RO systems
Desalination, *Volume 135, Issues 1-3*, *20 April 2001*, *Pages 141-153*
S. Ebrahim, M. Abdel-Jawad, S. Bou-Hamad and M. Safar

Abstract
Reverse osmosis (RO) has been established as a reliable process for seawater desalination. The reliability of the RO technique depends upon the extent of the pretreatment that must be designed to reduce the suspended and colloidal materials in the feedwater. During the last 15 years of research and development work at the Doha Research Plant (DRP), the Kuwait Institute for Scientific Research (KISR) has evaluated various types of pretreatment technologies for RO systems. These included: conventional pretreatment (CP), microfiltration (MF) and the beachwell (BW) intake systems. This paper gives brief description of these pretreatment technologies which were implemented at DRP and discusses their performances
Keywords: Reverse osmosis; Seawater desalination; Pretreatment technologies

Conclusions
- Proper pretreatment is the most critical factor for successful long-term performance of a SWRO.
- Since 1984, KISR has carried out an intensive R&D program to assess the technical viability and economic feasibility of desalting SWRO technology with special emphasis on pretreatment of the seawater feed.
- The program included evaluation of three pretreatment techniques: conventional, microfiltration and beachwell.

- In designing new commercial seawater RO desalination plants, a beachwell intake system should be considered as a first priority for small to medium size plants. If this system is technically not feasible, a MF system should be considered as an alternative pretreatment method.
- A conventional surface pretreatment system is not recommended due to its economics and operating drawbacks. It can be considered as a pretreatment for a seawater RO plant only if beachwell and MF systems are not feasible.
- In selecting a seawater pretreatment system for RO, MF or beachwell should be evaluated for biological content prior to the final selection of the system.

Comparison of unit cost of seawater pretreatment by alternative systems for 1995 (plant capacity 27,276 m³/d)

Cost component	Unit cost, fils/m³		
	Conventional surface	Beachwell	Microfiltration
A Capital cost (depreciation)	10.365	2.917	3.537
Feed pumps	0.119	—	0.119
Chlorine dosing plant	0.015	—	—
Structure – intake	0.387	0.387	0.387
Structure – outfall	0.387	—	0.387
Pretreatment plant	9.457	2.530	—
Beachwell	—	—	—
Microfiltration plant	—	—	2.644
B Operating cost	17.788	8.165	8.727
Electricity	9.648	6.426	7.090
Chemicals	4.662	—	1.637
Filters	3.478	1.739	—
Total unit cost (A+B), fils/m³*	28.153	11.082	12.264

*1000 fils = US$3.33

Comparative performance analysis of two seawater reverse osmosis plants: Twin hollow fine fiber and spiral wound membranes

Desalination, *Volume 120, Issues 1-2*, *15 December 1998*, *Pages 95-106*

Sameer Bou-Hamad, Mahmoud Abdel-Jawad, Mohammad Al-Tabtabaei and Saud Al-Shammari

Abstract

In spite of the great advances in increasing the reliability, and technical and economic viability of seawater desalination by reverse osmosis (RO) made over the past decade, its commercial application is still limited. Unit design is highly dependent on the quality of the feedwater and pretreatment method used to safeguard membrane performance. Work is in progress at Doha Research Plant (DRP), in Kuwait, to determine the performance of two seawater RO units under the prevalent seawater conditions. The RO units have a total capacity of 300 x 2 m3/d and are fed with beachwell seawater with a silt density index (SDI) of around 2, without any further pretreatment. The two RO plants are identical in all operational aspects, but differ in membrane configuration, i.e., twin hollow fine fiber and spiral wound. This paper

discusses the analytical performance of the two types of membranes using a single-stage system.

The paper covers one year of performance data and discusses the technical parameters of water productivity and permeate quality. It also covers the evaluation of membrane performance, system availability and operational problems encountered.
Keywords: Availability; Salt rejection; Productivity; Permeate quality; Operational problems

Conclusion
Arabian Gulf seawater is some of the most saline seawater in the world. Present RO technology has proved to be suitable for desalting this highly saline water through a single-stage configuration. Excellent availability, salt rejection and permeate productivity were demonstrated the more than 6,000 h of operation under comparable conditions of two RO plants. Spiral wound RO modules proved to be superior to twin hollow fine fiber RO modules in resisting slime that accumulated downstream of the chemical dosing points. During the one year of operation, the spiral wound modules was cleaned one time, whereas the twin hollow fine fiber was cleaned four times. Investigating the source of slime indicated that the added chemicals (i.e., antiscalant, sulphuric acid and sodium hydrogen sulfite) could be the reason for slime formation. Work to determine its exact cause will continue. Work to evaluate the performance of the RO modules will also continue for another year.

Economical Aspects

- Economic evaluation of a new ultrafiltration membrane for pretreatment of seawater reverse osmosis
- Thermoeconomic analysis of a seawater reverse osmosis plant
- Exergy analysis of a seawater reverse osmosis plant
- Wind and solar powered seawater desalination applied solutions for the Mediterranean, the Middle East and the Gulf countries
- An investigation into the economic feasibility of unsteady incompressible duct flow (waterhammer) to create hydrostatic pressure for seawater desalination using reverse osmosis
- Design and economics of RO seawater desalination

Economic evaluation of a new ultrafiltration membrane for pretreatment of seawater reverse osmosis
Desalination, *Volume 203, Issues 1-3*, *5 February 2007*, *Pages 300-306*
Frans Knops, Stephan van Hoof, Harry Futselaar and Lute Broens

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Thermoeconomic analysis of a seawater reverse osmosis plant
Desalination, *Volume 181, Issues 1-3*, *5 September 2005*, *Pages 43-59*
Vicente Romero-Ternero, Lourdes García-Rodríguez and Carlos Gómez-Camacho
Desalination, *Volume 203, Issues 1-3*, *5 February 2007*, *Pages 300-306*
Frans Knops, Stephan van Hoof, Harry Futselaar and Lute Broens

Abstract
Thermoeconomy is a useful and powerful tool that combines thermodynamics and economics. It can evaluate how irreversibility and costs of any process affect the exergoeconomic cost of the product flows.

The thermo-economic analysis of a seawater reverse osmosis desalination plant with a 21,000 m3/d nominal capacity located in Tenerife (Canary Islands, Spain) is given. This analysis extends the exergy analysis performed in a previous paper where further details about features of desalination facility, flow diagram, equipment purposes and flows of the process are widely provided. The main result indicates that economics predominates over the thermodynamics aspect; thus the influence of the operational parameters on the unit cost of the final product is significantly limited. Reverse osmosis skid is the most influential equipment on both the thermodynamic and economic aspects. As well, pretreatment has a large influence on the unit cost of the final product, essentially due to O&M costs. The unit cost of external consumption and the annual real discount rate are the most influential parameters on the sensitivity analysis of the final product and the high-pressure pump efficiency the most important of the operational ones; conversely, membrane replacement is the least important among the parameters analysed.
Keywords: Thermoeconomic analysis; Reverse osmosis plant

Conclusions

1. Fixed costs

1. When distribution is not considered, investment costs and discounted O&M costs including replacement as well along the lifetime of the desalination plant with an annual discount rate of 5% and a lifetime of 20 years, contribute equally to fixed costs. A reduction of the annual discount rate or an increase of the lifetime would increase the contribution due to discounted O&M costs. Additionally, it is important to point out that half of the fixed costs without distribution are shared costs, thus representing a noteworthy contribution.

2. The highest fixed costs are located in the reverse osmosis skid and pretreatment equipment with a contribution slightly greater than one-third of the total fixed costs (about half for each one). The first represents the highest investment cost and the second the highest O&M costs for equipment. This is the first evidence where major improvements on fixed costs may be made, and therefore, any line of work designed to the reduction of fixed costs relating to the pretreatment and membrane cost is a suitable and realistic option. In this way, for example, it would be advisable to fit the pretreatment design to the intake seawater quality to avoid unnecessary over-scale.

3. Core stages contribute only to 40% of the total fixed costs, in contrast to the 80% of the total exergy destruction [10]; therefore, it discloses a significant influence of the no-core stages on the fixed costs. While this happens, it seems reasonable to operate with high-performance mechanical equipment in the core stages, even though it represents an increase of their fixed costs.

2. Exergoeconomic analysis

1. High-pressure feed mass flow has the highest exergoeconomic cost, about half of which is due to energy recovery by the Pelton turbine. Consequently, as a universal result, energy recovery always increases the exergoeconomic cost of the high-pressure feed, but conversely, it decreases the exergoeconomic cost of the product in the final

stages. However, as a consequence of its high specific exergy, the exergoeconomic unit cost of the high-pressure feed mass flow is relatively low.

2. Mass flows for previous stages present the highest fuel-product increases of the exergoeconomic unit cost, with an influence of the fixed costs greater than 90%. Like this, the product from previous stages (feed) exhibits the highest unit cost--a significant influence of fixed costs and low gain of exergy (while feed exergy represents only 11% of the core fuel, feed exergoeconomic cost means 51% of the core fuel exergoeconomic cost). In summary, previous stages have a significant influence on the exergoeconomic analysis (supporting conclusion 1.2) but is weak on an exergetic one [10] with respect to the final product.
3. Core stages as a whole are characterised by a more balanced contribution between thermodynamic performance and fixed costs (contribution of fixed costs is slightly lesser than 60%) on the fuel-product increases of their exergoeconomic unit costs. Similarly, reverse osmosis skid presents the lowest influence of fixed costs (35%) and a significant influence of exergy destruction (53%); the remaining 11% is due to losses (blowdown). Hence, given that pressure drop in membranes has a negligible effect on exergy destruction [10], any thermodynamic improvement on the membrane performance (e.g., development of membranes with similar permeate mass flow rate but operating with a lesser pressure), have an appreciable influence on the unit cost of the final product. Since the theoretical minimum of specific consumption is about 1 kWh/m 3 for the actual recovery factor of a seawater desalination plant (40-45%) and the actual specific consumption range is close to 3 kWh/m3, it seems reasonable to expect future advancement in this way, even though other factors like mechanical equipment performance are involved in this specific consumption decrease.
4. Final stages without distribution present an influence of fixed costs near to 70% and lower fuel-product increases of the exergoeconomic unit cost than previous stages. In view of this result and conclusion 2.2, it can be stated that the previous stages are a greater influence on thermoeconomic analysis and particularly on unit exergoeconomic cost of the final product.
5. There is a strong predominance of fixed costs (79%) on the fuel-product increase of the exergoeconomic unit cost of the final product with respect to global fuel (external consumption). Thus, improvements of the thermodynamic performance of the process are clearly limited by fixed costs. In order to reach a reasonable influence of thermodynamic performance, it is necessary to reach a notable reduction of these fixed costs.
6. When influence of equipment on the fuelproduct increase of the exergoeconomic unit cost of the final product with respect to global fuel is considered, reverse osmosis skid contributes approximately one-fourth of this increase; pretreatment, the high-pressure pump, the Pelton turbine and distribution contribute about a half (in an individual range of 12-15%); and the remainder is due to seawater and product pumping, regulation valve and posttreatment.
7. Core and previous stages contribute 55% and 27% (the latter almost exclusively due to fixed costs), respectively, on the fuel-product increase of the exergoeconomic unit cost of the final product when distribution is not considered.
8. Results for the fuel-product increase of the exergoeconomic unit cost with respect to global fuel are similar in magnitude when distribution is not taken into account, and thus the main conclusions can be applied to pumped product as well.
9. Energy recovery is economically suitable only when the external consumption unit cost from the grid is higher than 8.6 c/MJ (2.4 c/kWh), far enough from the actual 6 c/kWh.

10. Exergoeconomic unit cost of the final product is 12.1 c/MJ, 30% due to external consumption 23% high-pressure pump and 7% seawater and product pumping (half each one) 68% to fixed costs and 4% to losses (blowdown). Finally, the cost per cubic meter is 76.7 c/m 3.

3. Sensitivity analysis

1. The exergoeconomic unit cost of the final product presents the highest sensitivity with respect to external unit consumption cost and the annual real discount rate, parameters whose influence is determined by market considerations.
2. The next greatest influences are due to availability, high-pressure pump performance and chemical costs for pretreatment. The latter supports some previous conclusions, but it can be limited by a possible drop in availability. The second one indicates the possible advantages of choosing a high-performance pump even though it were more expensive.
3. From among the parameters analysed, the lower sensitivity corresponds to the Pelton turbine's performance and membrane replacement costs; and thus intensification of the pretreatment does not seem beneficial for reducing only membrane replacement costs.

Wind and solar powered seawater desalination applied solutions for the Mediterranean, the Middle East and the Gulf countries

Desalination, *Volume 168*, *15 August 2004*, *Pages 73-80*

Johannes H. Lindemann

Abstract

A seawater desalination plant with an average daily drinking water production of 1.000 m3/d is planned by imb+frings watersystems and Synlift for an island in the Arabian Gulf. The plant is supplied by a stand alone 750 kW wind energy plant as on grid. The water treatment plant with open intake is planned with ultrafiltration as pretreatment and reverse osmosis. The water will be stored in an 1.500 m 3 storage tank for drinking water. For a successful introduction of wind energy in ADE it is therefore suggested, to implement projects in 2004-2005. The 750 kW wind energy plant will be started up in August 2004. SYNWATER -- wind powered ground- or seawater treatment will present a sustainable state-of-the-art technology with example character for the entire Gulf region. A reverse osmosis (RO) plant with an average daily drinking water production of 0.8-3 m3/d was installed on Gran Canaria Island. The plant is supplied by a stand alone 4.8 kWp photovoltaic (PV) system with an additional battery storage of 60 kWh. The installation constitutes the smallest PV supplied seawater desalination plant currently in operation. On behalf of this prototype the feasibility of small PV-RO systems (I-5 ma/d) is being investigated. The technical details of the RO plant and the energy supply are presented briefly and the operation strategies of the system are presented. Three different regulation strategies for the energy management of the plant are compared and recommendations for an optimised operation are given.

Keywords: Wind powered desalination; Open intake; Reverse osmosis; Pretreatment

Conclusions

RO plants for the desalination of brackish water and seawater are becoming more and more important to cover the increasing drinking water demand in semiarid regions in the Near East, North-western Africa and on small islands. The feasibility of these plants supplied by own power stations or the electric grid is indisputable.

Within this paper, three different operation strategies for a better adaptation of RO plants to a renewable energy supply have been presented. Further modifications of the operation scheme are currently being worked out in order to optimise plant operation: Additionally, experiments for the operation of the plant at varying feed pressures following the actual irradiation will be realised. With this, a more direct use of the renewable energy will be realised and the costs for a battery storage could be reduced. To lower the investment costs for renewable energy RO plants energy recovery systems seem to be very interesting. At the moment energy recovery systems as the pressure-exchange system (PES) and Pelton turbines are only in use for larger RO seawater desalination plants with capacities of more than 5,000 m3/d. These energy recovery systems are working with high efficiencies of up to 98% and could lower the energy consumption of the high pressure pumps [6]. Cheap energy recovery systems could be useful to reduce the specific energy consumption of small PV-RO plants. Additionally the heating of the feed water up to 45°C would increase the drinking water production about 50% of the actual rate. These possibilities will be investigated in a following phase of the project.

An investigation into the economic feasibility of unsteady incompressible duct flow (waterhammer) to create hydrostatic pressure for seawater desalination using reverse osmosis
Desalination, *Volume 138, Issues 1-3*, *20 September 2001*, *Pages 307-317*
R. A. Sawyer and D. F. Maratos

Abstract
It has been suggested that wavepower can be used for seawater desalination using unsteady incompressible duct flow to create the hydrostatic pressure for reverse osmosis [1]. This approach requires further investigation in a number of areas: the non-linear relationship between reverse osmosis recovery rate and output of fresh water for the proposed system; determination of the optimum recovery rate; pretreatment costs for the optimum recovery rate; and operating costs in comparison to conventional desalination plants of varying sizes, recovery rates, seawater types and intake. The reason for the non-linear relationship between recovery rate and output is explained, and the optimum recovery rate for Mediterranean seawater is determined. Pretreatment costs for this recovery rate and operating pressure are determined. Operating costs for the proposed system are estimated and compared with those for open sea intake and seawell intake desalination plants in the Red Sea, the Arabian Gulf, the Mediterranean Sea, oceanic seawater and the Caribbean Sea.
Keywords: Wavepower; Seawater desalination; Hydro-ram; Water hammer; Renewable resource

Conclusions and further work
It is concluded that the proposed system can offer operational cost savings in comparison to conventional RO plants, irrespective of size, recovery rate, seawater types and seawater intake system. An investigation into the technical aspects of the proposed system is required, including flow pressure losses, drive pipe configuration, ram pump design and configuration.

Design and economics of RO seawater desalination
Desalination, *Volume 105, Issue 3*, *July 1996*, *Pages 245-261*
A. Malek, M. N. A. Hawlader and J. C. Ho

Abstract
Large-scale seawater desalination is an attractive and viable alternative for the production of potable water in the absence of natural fresh water resources. Over the past two decades, the reverse osmosis (RO) process has allowed a tremendous reduction in the cost of potable water from seawater desalination. Indeed, cost studies conducted by various researchers have indicated that it is possible to obtain product water cost of about US$ 0.80/m 3. This paper introduces a comprehensive, but tractable, means of modelling large-scale seawater RO desalination plants that can accommodate various flow configurations. The two most important considerations in RO plant modelling are the permeator performance characteristics and the permeator replacement scheme. In particular, the flux degradation of the permeator with operational age has to be accounted for. The RO model introduced here was used for extensive plant cost analysis. The cost studies indicate that the permeator cost makes up a large percentage (-37%) of the total plant capital cost. This means that large-sized permeators, which offer smaller cost per unit membrane area, should be utilized in order to appreciate economies of scale. In terms of operating cost, the annual permeator replacement cost also forms the major portion. Interestingly, with the use of hydraulic energy recovery systems, the product water cost is relatively insensitive to energy price fluctuations. Also, cost comparisons conducted for a brine-stage RO plant configuration indicated that it is more costly than single-stage plants, especially for high concentration seawater.
Keywords: Desalination; Reverse osmosis; Design methodology and economics

Conclusions
A comprehensive mathematical model of a large-scale seawater RO desalination plant was utilized in performing extensive RO cost studies. This model allows accurate predictions of the DuPont B10 RO permeator performance, the permeator flux degradation, as well as the annual permeator replacement scheme. The model also allows for various RO plant configurations. Costs studies conducted for single-stage RO plant showed that the permeator cost constitutes a significant percentage (~37%) of the total capital cost. It is imperative, thus, to use a permeator which offers the smallest cost per unit membrane area. This generally entails the use of larger-sized permeators. Furthermore, the annual cost of permeator flux degradation also makes up the largest component of the operating costs. It is also shown here that the product water cost is relatively insensitive to energy cost fluctuations, since energy cost forms only small percentage of total operating costs. For the purpose of comparison, the costs of a brine-stage RO plant were also studied. In this regard it was found that the product water cost is higher than a single-stage plant. Thus, this scheme is not attractive, particularly if the feed concentration is high.

Membrane technologies

Membrane R&D, Key to Evolution & Use of Membranes by IIan Wilf

Technology makes the world go round. This statement is not only valid in general, but is also a true representation of the future of membranes in the field of the water treatment. Since their introduction in the late 1950 s, reverse osmosis, nanofiltration, ultrafiltration and microfiltration membranes have been increasingly used for a multiple of different applications in the field of water treatment. From the early development work of Sourirajan and Loeb on the spiral wound cellulose acetate membrane and the invention of capillary technology, to the introduction of a low fouling composite (LFC) spiral RO membrane and the backwashable capillary ultrafiltration membrane in the late 1990 s, membrane research and development has proven key to the evolution and continuation of the use of membranes in all aspects of life.

Within the past 40 years, the evolution of membrane development has improved performance, reliability and contributed to lower operating costs, making membranes the preferred technology in the water treatment industry. The evolution of membrane technology can be categorized in two specific avenues; the first being spiral wound reverse osmosis and nanofiltration technology and the second capillary ultrafiltration and microfiltration technology. Both technology categories have evolved through the years and are equally important in understanding what has been achieved up to this point and what the future may hold. The treatment of fluids with membrane technology is about to take on a new meaning as technology charges forward and reshapes the use of membranes, as we know them today. Recapping the technological advancements of the 20th century, with respect to the treatment of fluids with membranes, one can see a significant shift from the traditional aspects of membrane treatment, to a more technologically refined process, where one can maximize ones resources and achieve higher quality and performance, all at less cost than what could have been previously achieved. The research and development efforts put forth in the 20th century have paved the way to a new family of future products and applications. This article will concentrate on three distinct developments in the field of membrane technology, and how each development will contribute and redefine the use and application diversity of membranes in water and waste water industries.

Content:

- Low Fouling Technology
- Hydranautics Announces The New CPA3-LD - Low Fouling *And* High Flow
- Seaguard is a genuine breakthrough
- Electrodeionization: technology and applications
- Comparison of three pilot studies using Microza® membranes for Mediterranean seawater pre-treatment
- High advanced open channel membrane desalination (disc tube module)
- Experiences with the pretreatment of raw water with high fouling potential for reverse osmosis plant using FILMTEC membranes
- A new immersed membrane for pretreatment to reverse osmosis

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Low Fouling Technology

Source: http://www.hydranautics.com/docs/papers/05_new_membrane.pdf

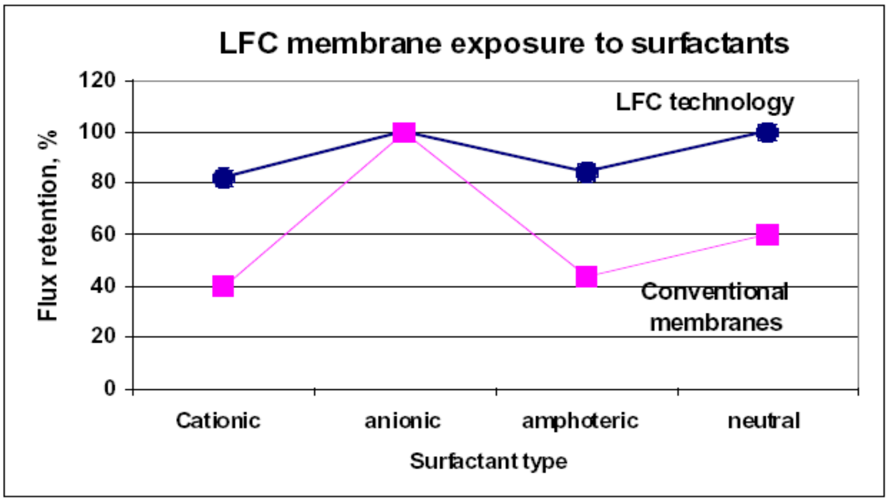
To significantly reduce this fouling tendency, an LFC membrane was developed. The LFC is characterized by a low surface charge and a hydrophilic membrane surface characteristic. *Figure 1* presents the difference between the surface charge potential of a conventional composite polyamide RO membrane and the new LFC membrane, both as a function of pH.

The surface charge of the LFC membrane is significantly less negative (more neutral) as compared to the surface charge of conventional composite membranes. This characteristic can be directly translated to the affinity of the LFC membrane to dissolved organic constituents.

Figure below demonstrates this quite effectively. When subjected to a wide range of surfactants, the LFC retained its flux significantly better than conventional RO membranes.
The surface charge of the LFC membrane is significantly less negative (more neutral) as compared to the surface charge of conventional composite membranes. This characteristic can be directly translated to the affinity of the LFC membrane to dissolved organic constituents.

Figure below demonstrates this quite effectively. When subjected to a wide range of surfactants, the LFC retained its flux significantly better than conventional RO membranes.

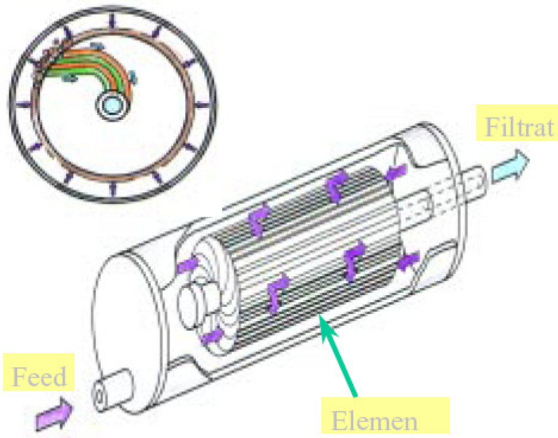
Figure 1



To confirm this observation, the LFC membrane was operated opposite a conventional low pressure composite polyamide membrane. Both membranes were subjected to municipal effluents treated by ultrafiltration capillary membrane technology at Water Factory 21, CA.

Reversible Spiral Technology

The second significant advancement is the introduction of the low pressure Reversible Spiral (RS) membrane. This innovative and unique product is truly a revolution in the membrane industry with significant bearing on the design of pretreatment systems in the future. The RS was developed to either act as pretreatment to spiral wound RO membrane elements or as the primary treatment for surface water and waste water applications. This element type is based on the unsurpassed reliability of the spiral wound design, but constructed in such a way that utilizes a filtrate backwash mechanism that allows the membrane to operate at a dead end mode, rather than the traditional cross flow configuration. This quality provides extraordinary benefits with respect to operating efficiency, membrane stability and overall improved system performance.
Spiral wound membrane elements have traditionally utilized cross-flow operational mode. Under this mode of operation the highest single element recovery achievable is 15%, with system recovery at 90%. Limitations are governed by hydraulic considerations, economics and spiral wound RO element configuration. Operating an RO system outside these limits contributes to an increase in membrane fouling, by the formation of a boundary layer on the membrane surface, and potentially completely plugging the element flow channels. Currently, the only method to attempt and either reduce or remove the colloidal fouling layer in a membrane element is by cleaning using chemicals and traditional cross flow methods. A cleaning solution is pumped from the feed channel, to concentrate and permeate channels.



Conclusions

The RS and capillary membranes are the technologies of the future for meeting SWTR guidelines. The following are the extraordinary benefits realized with the use of either technology as compared to conventional pretreatment:

1. Significantly better Filtrate Quality — through the use of ultrafiltration membrane technology with respect to membrane chemistry and module design, the quality of the filtrate achieved is significantly better as compared to conventional pretreatment. The reasons for this difference can be attributed to the fact that:

a) All colloidal particles are removed using ultrafiltration membrane technology. Due to the presence of the ultrafiltration membrane, as a filtration barrier, the membrane, producing colloidal free filtrate will reject all colloidal matter.

b) Filtrate quality produced is independent of the raw feed water conditions. Therefore, any variations in raw water quality posses a reduced impact on the overall plant operation.

c) Due to the ability to consistently produce good filtrate quality, raw feedwater conditions do not affect the RO membrane system availability.

d) Good quality filtrate is produced immediately upon startup, thereby increasing the operational efficiency of the overall plant.

e) The ability to eliminate or significantly reduce the use of floculants and flocculation aids. The advantage translates to reduced chemical consumption, handling and the elimination of the auxiliary equipment necessary to support this process.

f) Disposal of backwash is much less problematic. With the elimination or significant reduction in floculant consumption, backwash disposal becomes a less significant issue.

2. Increased efficiency of RO system design and membrane operation. RO membrane operation is dependent on the quality of the filtrate produced by the pretreatment system. The better the filtrate quality from the pretreatment, the better the RO membranes will operate. Since the filtrate quality is significantly improved using ultrafiltration membrane technology, one will realize the following operational improvements:

a) Increased membrane stability. Using ultrafiltration as pretreatment, the fouling rate of the RO membranes is reduced significantly. As a consequence, the cleaning frequency is reduced

as well. Both of these factors lend themselves to prolonging membrane stability and life over time.
b) Reducing capital and operational costs. Ultrafiltration technology provides the ability to operate the RO membranes at optimal design conditions. Depending on the required operating conditions, one may choose to design the RO system at a higher flux rate, therefore reducing the number of membranes, pressure vessels and piping required initially.

All of the technological advancements described above are important in their own right. However, when one integrates one technology with the next, then one can significantly maximize the efficiency of a treatment process, expanding the possibilities and achieving the greatest return on investment. This process is termed Integrated Membrane Solutions (IMS TM) and will become an industry standard in the near future. The first rule of a successful technology company understands the implications and application of a specific technology. Through IMSTM one can do just that. IMSTM can be a powerful tool in the treatment of a variety of feedwaters. Where in the past one had to utilize a combination of conventional treatment and membrane technologies to treat a certain feedwater characteristic, already today and even more so in the future, we have the ability to completely utilize membranes for this same process. The advantages of this concept can be realized in performance and process improvement, cost savings, systems reliability, and ultimately the ability to treat more applications than ever before.

Hydranautics Announces The New CPA3-LD - Low Fouling *And* High Flow.
Source: http://www.membranes.com/press/CPA3%20LD.6.25.07.pdf

Low differential pressure element meets the challenge of high purity industries with high fouling feed water.
Oceanside, CA Hydranautics/Nitto Denko, the global leader in membrane technology, announces their new Composite Polyamide CPA3-LD (Low Differential pressure) spiral wound reverse osmosis element. Industries requiring high purity water, particularly those in developing countries with limited access to municipally treated feedwater, reap the benefits of this hard to foul yet high performing element. The unique CPA3-LD has a 31 mil brine spacer – low fouling and easy to clean and maintain. This thicker spacer lowers the Delta P, making it a perfect fit for scenarios that demand a lower fouling /low maintenance membrane while maintaining high permeate flow. The 31 mil spacer also enhances the flux distribution in the RO system; efficiency is heightened because there is less flux loss in the pressure vessel from membrane to membrane. Hydranautics' innovative CPA3-LD provides 11,000 gallons per day (41.6 m3/d) of flow at 99.7% nominal salt rejection.

Seaguard is a genuine breakthrough
KnowHow Volume 9/2006 no. 2 page 4-5 by Norit NV

The process of producing fresh water from seawater is a cost-intensive process. X-Flow is the first in the world to launch a membrane that is specially designed to pretreat seawater; the treatment that takes place before the actual desalination process (reverse osmosis). The SEAGUARD is a membrane for pretreating seawater highly efficiently, producing significant cost benefits throughout the entire process. One of the main objectives of the Norit/X-Flow engineers was to keep the total costs down. Only if a significant cost reduction could be achieved compared to existing technologies would the water treatment companies be willing to change over to this new revolutionary technology. This has proved to be a highly successful approach. Throughout the world, the SEAGUARD is now being considered for the pretreatment of seawater. An extensive test programme preceded the ultimate launch. X-Flow tested the SEAGUARD around the world under a wide range of conditions. Extensive practical tests have shown that this new pretreatment method solves the disadvantages of the technologies that have been available up to now.

The continually recurring problem was the quality of the pretreatment. The conventional systems found it difficult to cope with the differing compositions of the seawater, which can vary markedly in different conditions. The result was water of varying quality, which was detrimental to the ultimate desalination treatment (reverse osmosis). The SEAGUARD has made this problem a thing of the past.

Quality

The ultrafiltration technology of the SEAGUARD guarantees consistent water quality. It can cope with all water types and allows for far-reaching automation. In addition, the SEAGUARD removes the maximum amount of particles, bacteria and microbiological contamination. Parallel with the aim to improve quality, a reduction in the total costs has also been achieved. Since the market introduction, X-Flow has clearly seen that it has been pursuing the right course. Throughout the world the SEAGUARD has been received enthusiastically and has brought about a breakthrough in the pretreatment of seawater.

Membrane features

Element Size	8 inch diameter & 60 inch long
Installation	In standard low pressure membrane housings
Permeate SDI	100% < 3
Clean Water Permeability	> 1000 LMH/bar
Surface area	40 m2
Average TMP	0,2 bar
Average Energy	<< 0,1 KWH/m3
Burst & Collapse Pressure	>> 7 bar
Capacity	3 – 5 m3/hr per element

Retrieved from http://www.norit.com/?RubriekID=2740

X-Flow has managed to achieve comprehensive cost savings with the development of the SEAGUARD by keeping the following parameters in mind:

- Pressure level:

Less pressure required, less energy. The SEAGUARD membrane must operate under a stable average pressure of 0.2 bar with a maximum of 0.5 bar in order to function optimally.

- Chemicals for maintenance and pretreatment:

It must be possible to clean the membrane with readily available chemicals, such as acids or sodium chloride.

- Quality of seawater:

The membrane must be able to process not only pure seawater, but also seawater that is used for cooling purposes, in the event that a purification plant is combined with a power station. The membrane must be able to deal with all types of seawater as well as water with a different composition due to natural forces such as storms, floods or water discharges, whether or not of natural origin. This makes it possible to build a purification plant close to where people live, reducing the costs of transporting the fresh (drinking) water.

- Water quality follow-up treatment:

In order to guarantee the life of membranes, the membrane manufacturers impose requirements for reverse osmosis on turbidity and the amount of sludge in the water. From a microbiological point of view, bacteria, algae and viruses should preferably be filtered as quickly as possible. The SEAGUARD membrane ensures that the water which passes through meets these parameters, which then has a positive effect on subsequent steps further along the chain.

Electrodeionization: technology and applications
The R&D notebook A publication of the Bioscience Division of Millipore
Source:http://www.millipore.com/publications.nsf/dda0cb48c91c0fb6852567430063b5d6/5ff4c5f4980dcce685257133005a147f/$FILE/RD010EN00.pdf

Abstract
In combination with reverse osmosis (RO), electrodeionization (EDI) is gaining importance in the water purification market. EDI removes ions (organic and inorganic) using semi-permeable membranes and ion exchange resins that are continuously regenerated by an electric field. Used downstream from RO, this self-regenerating module provides water with resistivity > 10 MΩ• cm and a low organic level. This paper presents technical insights and also discusses several applications in which RO-EDI water is used. In particular, the benefits of using the combination of RO and EDI water as a pretreatment system for polishing units are highlighted. Water quality in this study was characterized using a variety of analytical data.

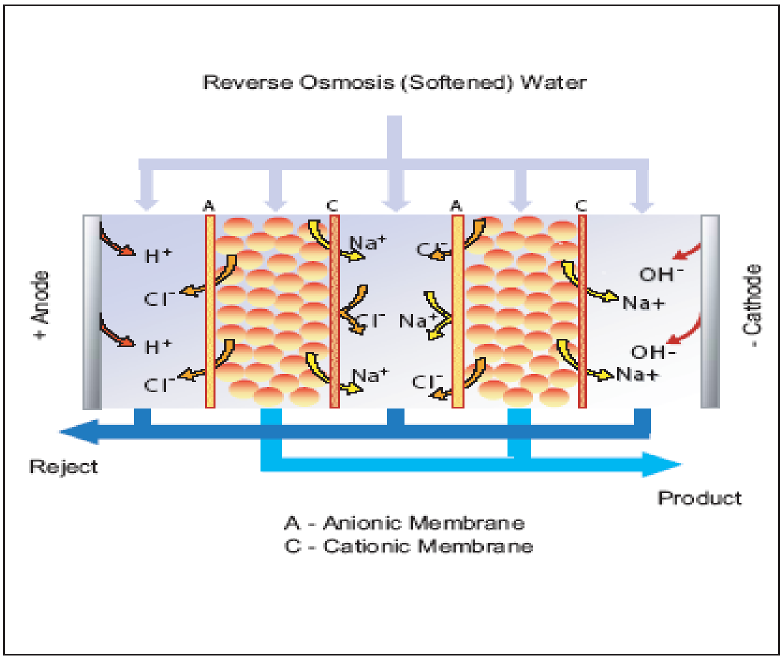


Figure 2: Schematic of the first EDI module

Conclusions
In combination with RO, EDI technology is beginning to occupy a more prominent place in both the process water treatment and laboratory-scale water purification system markets. RO removes the bulk of the contaminants and produces water suitable for EDI. The EDI technology further reduces the levels of inorganic as well as organic ions. Due to its capacity for removing a wide range of contaminants (ions, particulates and organics), the RO-EDI combination is becoming a preferred water treatment method, capable of providing good water quality both in terms of resistivity and TOC level. In addition, thanks to RO-EDI's low running cost, constant operation and minimal maintenance, this method surpasses the

distillation process for laboratory use. EDI is a sustainable technology that combines the strengths of several key purification technologies or media. Several ways to improve this technology have been identified and are currently being evaluated. Moreover, all of the steps required to assemble these EDI modules are performed at our centralized product manufacturing site and specific Quality Control tests are performed after key steps in the production process to increase product reliability.

This approach enables Millipore's EDI (Elix) technology to play a key role in instrumentation dedicated to the production of ultrapure water for laboratory applications.

Comparison of three pilot studies using Microza® membranes for Mediterranean seawater pre-treatment

Desalination, *Volume 156, Issues 1-3*, *1 August 2003*, *Pages 43-50*

D. Vial, G. Doussau and R. Galindo

Abstract

Until recently, in desalination plants seawater was pre-treated with a combination of conventional techniques such as air flotation, clarification, sand filtration and cartridge filtration prior to spiral wound reverse osmosis desalination membranes. Microfiltration or ultrafiltration membranes are now considered as an alternative solution for seawater pre-treatment. This paper describes pilot test results obtained at three different locations treating Mediterranean seawater using 0.1 urn hollow fiber membranes in Pall's Microza modules. Depending of the location, the pilots operated with or without pretreatment using ferric chloride and with or without specific flux maintenance (SFM) protocols performing daily highly chlorinated backwash. The study shows that system optimization yields stable, reproducible permeate flow and permeate SD1 of 1.8 or less, with mean SD1 of 1.43 when seawater was coagulated or SFM was performed. At these conditions, reverse osmosis system recovery is enhanced and total integrated system performance is optimized.

Keywords: Microfiltration; Ultrafiltration; Reverse osmosis; Pre-treatment; SDI; Seawater; Desalination

Conclusions

Long-term pilot testing at different locations verified that seawater filtered through 0.1 pm Microza hollow fiber membrane provided clarified water to RO having SD1 of 1.8 or less and mean SD1 of 1.43. Clarified water having such low SD1 allows RO operation at higher recovery, enhancing total system running cost. Specific flux maintenance protocols performed daily help maintain a constant and higher specific flux compared to seawater pretreatment with $FeCI_3$, and recover of specific flux after a stormy period. In addition, SFM resulted in lowest running cost, significantly below that obtained via ferric chloride addition upstream of the membranes.

High advanced open channel membrane desalination (disc tube module)
Desalination, *Volume 134, Issues 1-3*, *20 April 2001*, *Pages 213-219*
Thomas Axel Peters

Abstract
As in many regions it is no longer possible to satisfy the growing demands for water by conventional methods an increased production of potable water from saline waters is called for. One option with growing importance is the desalination of seawater with reverse osmosis using decentralised desalination plants with a fresh water capacity of few hundred to few thousand m3/d. Requested are plants that are easy to handle, able to be operated unattended under rough working conditions and require the lowest possible pretreatment. Reverse osmosis plants designed in accordance to the "plug and play" approach and equipped with the open channel disc tube module type DT using selected membranes can meet the requirements of this application niche of desalination technology. Technical details of the module and this plant concept as well as operating results are discussed.
Keywords: Reverse osmosis; Desalination of seawater; Decentralized desalination plants; Open channel RO module

The success of the disc tube module DT is due to the unique cross flow construction of its stacked membrane discs, which enhance membrane performance. It operates effectively and economically at high particulate loading, providing high recovery rates without the degree of fouling or scaling that is typically associated with other module configurations that are not based on a construction with an open channel for the feedwater.

Conclusions
Reverse osmosis has become an important instrument in the struggle to overcome water scarcity. But the increasing demand can not be satisfied only with the reverse osmosis plants with production capacities in the range of 5,000 to 20,000 or more mVd per unit. One option with growing importance is the desalination of seawater using decentralised desalination plants with a fresh water production capacity of few hundred or few thousand mVd. This application niche of desalination technology requires plants that are easy to handle, need low pretreatment, are designed for unattended operation and can be operated remote controlled. Reverse osmosis plants equipped with the disc tube module DT manufactured in accordance to the "plug and play" concept meet these requirements. The combination of open channel construction and narrow gap technology realized in this module allows in connection with a special plant design for an economic operation with high availability. As no chemicals are used for the pretreatment, this kind of desalination technology can be considered to be in accordance with guidelines for a sustainable environmentally friendly development.

Y2K generation FILMTEC* RO membranes combined with new pretreatment techniques to treat raw water with high fouling potential: summary of experience
Desalination, *Volume 136, Issues 1-3*, *May 2001*, *Pages 287-306*
J. A. Redondo and I. Lomax

Abstract
Improvements achieved by the new FILMTEC products as well as results of field experiences made with FILMTEC seawater and brackish water reverse osmosis (RO) membranes are presented as per their status as of February 2000, along with the analysis of the relationship between the achieved performance and the pretreatment used in the respective plants.

The field performances presented correspond to two commercial RO plants: one is a brackish water RO (BWRO) plant using a fouling-resistant membrane, FILMTEC BW30-365 FR, and the other is a seawater RO (SWRO) plant using the new seawater membrane, FILMTEC SW30HR-320, for higher fouling RO feeds (e.g., open intakes). Possible pretreatment steps are analyzed in relation to measured efficiency to limit the fouling incidence, and possible optimization is reviewed as well.
Keywords: RO membranes; Pretreatment techniques; Raw water

General conclusions from the experiences explained in the case histories for wastewater and high fouling seawater
It becomes apparent that the combination of new biofouling control methods with corrected pretreatment to increase efficiency can be used in conjunction with the new membrane technology of area increase and the new internal element configuration explained here on the base of the new FILMTEC RO products as a means to make feasible the use of waters with high fouling potential as adequate feed for the RO process. The part of the optimization process related to the pretreatment improvement has to be adjusted for each particular plant. The part related to the elements is more general since they are based upon lowering the fouling incidence by physical methods.

A new immersed membrane for pretreatment to reverse osmosis
Pierre Cote, Jason Cadera, John Coburna, Alistair Munro
Desalination 139 (2001) 229 - 236

Abstract
Ultrafiltration is an ideal pretreatment method for reverse osmosis because it allows removing suspended solids and colloidal materials completely and reliably without chemicals. This paper introduces the ZeeWeed ® 1000 immersed membrane and its application for seawater ultrafiltration. ZeeWeed ® 1000 is a new version of the ZeeWeed ® immersed membrane designed to minimize life cycle costs. The building blocks of a ZeeWeed ® 1000 filtration system are parallelepiped membrane elements. Cassettes are built by assembling elements in the vertical and horizontal dimensions to fill tanks of various depths and sizes. This lead to the construction of very small footprint plants. The ZeeWeed ® 1000 system is operated as a simple semi-batch process where filtration and backwash alternate in sequence. In filtration mode, permeate is drawn through the membranes as a result of the negative pressure applied to the permeate network. Filtration is direct (dead-end), without aeration. All particulate materials rejected by the membrane are left behind in the tank, and accumulate near the membrane surface. In backwash mode, the membrane is back-pulsed with permeate while air and feed water are injected to aid in dislodging the rejected particulate materials rejected by the membrane surface. This process is efficient in de-concentrating the membranes without emptying the tank. The ZeeWeed ® 1000 was evaluated in several pilot studies on different types of water. Typical results on open seawater will be presented.

Keywords: Immersed membrane; Membrane; Filtration

Conclusions

ZeeWeed ® 1000 is a new immersed membrane targeted at low suspended solids applications. It was designed to minimize lifecycle costs, including initial system, energy, civil, and membrane replacement costs.

ZeeWeed ® 1000 is based on a fine outside-in, very low-pressure ultrafiltration hollow fibre membrane capable of removing all suspended solids and colloids without chemicals. The ZeeWeed ® 1000 building block is a modular parallelepiped element that can be assembled into large cassettes to fill tanks of various depths and dimensions. ZeeWeed ® 1000 is ideally suited for the construction of new plants of any size and especially for increasing the capacity and water quality of existing plants. Piloting results were presented on a brackish water and a seawater, demonstrating the ability of the ZeeWeed ® 1000 to produce a high quality reverse osmosis feed water under low pressure and stable operating conditions.