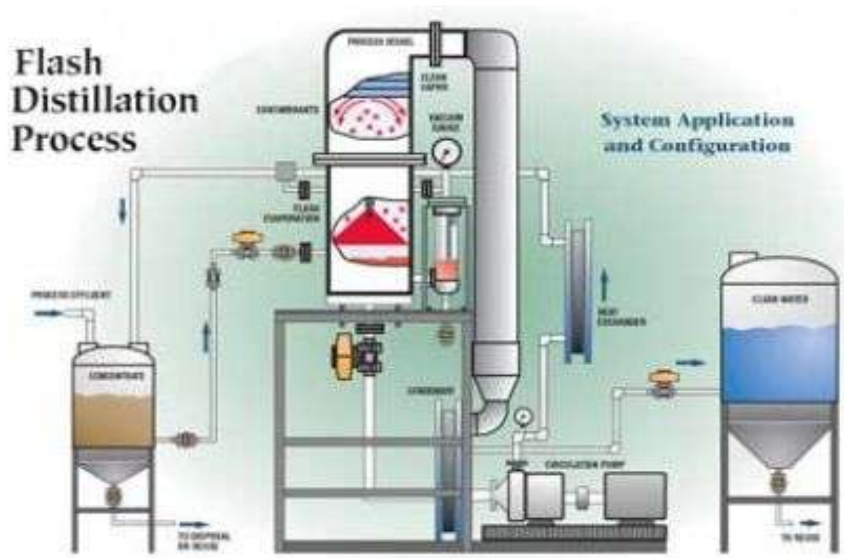
Source Guide

"Zero Liquid Discharge-Desalination"



(**Image source:** http://www.waterworld.com/etc/medialib/platform-7/iww/2010/issue-2.Par.0138.Image.400.277.1.gif)

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Content

Introduction

Achieving strict wastewater treatment regulations and “reducing water usage have become one of the most critical considerations in industry today. Numerous environmental regulations, rigorous permitting processes, and lack of water availability, among other factors, are driving many industrial facilities to implement zero liquid discharge (ZLD) systems as a solution”.[1]

Zero Liquid Discharge (ZLD) technologies help to achieve environmental compliance, reduce carbon footprint, create positive public perception, and recover high purity water for reuse.

This source guide is prepared for the Workshop on “Zero Liquid Discharge Desalination” which will be held during October 18-19, 2011 by Water Resources Division at Kuwait Institute for Scientific Research. The guide covers the latest studies conducted on the theme of the workshop. Information in the bibliographic section has been taken from Scopus database.

[1] GE Power & Water: Water & Process Technology: http://www.gewater.com/products/equipment/thermal_evaporative/index.jsp

Bibliography

Membrane Distillation

Tun, C.M., Groth, A.M.
Sustainable integrated membrane contactor process for water reclamation, sodium sulfate salt and energy recovery from industrial effluent
Desalination, . Article in Press.
Abstract
The combined global impacts of water shortage and energy provide strong impetus to use innovative combinations of technologies to supply sustainably produced high quality water. Recent innovations have focused on the integration of membrane processes with other chemical separation unit processes and various stand-alone membrane processes. Coupling well-developed pressure driven membrane processes (such as nanofiltration (NF) and reverse osmosis (RO) with low energy demand membrane processes which allow the utilization of low-grade energy, industrial waste heat or renewable energy (such as membrane distillation (MD)) brings the promise of new sustainable technical solutions. In this work, two case studies will be reviewed and discussed - 1) integrated NF and MD-Crystallizer for resource recovery; and 2) the potential application of MD-Crystallizer for the concentration of RO brine (secondary reject from industrial wastewater treatment plant) towards a zero liquid discharge (ZLD) process. In Case I, MD flux of 15-20 Lm-2 h-1 with a water recovery of 80% was achieved (at a feed temperature (TF) of 60 °C and permeate temperature (TP) of 20 °C). In Case II, average MD flux of 4 Lm-2 h-1 with overall water recovery of 95% was achieved when operating with RO brine (TF = 45 °C; TP = 25 °C).

Nikonenko, V.V.[a] , Pismenskaya, N.D.[a] , Belova, E.I.[a] , Sistat, P.[b] , Huguet, P.[b] , Pourcelly, G.[b] , Larchet, C.[c]
Intensive current transfer in membrane systems: Modelling, mechanisms and application in electrodialysis
(2010) *Advances in Colloid and Interface Science*, 160 (1-2), pp. 101-123. Cited 2 times.
Abstract
Usually in electrochemical systems, the direct current densities not exceeding the limiting current density are applied. However, the recent practice of electrodialysis evidences the interest of other current modes where either the imposed direct current is over the limiting one or a non-constant asymmetrical (such as pulsed) current is used. The paper is devoted to make the mechanisms of mass transfer under these current regimes more clear. The theoretical background for mathematical modelling of mass transfer at overlimiting currents is described. Four effects providing overlimiting current conductance are examined. Two of them are related to water splitting: the appearance of additional charge carriers (H+ and OH- ions) and exaltation effect. Two others are due to coupled convection partially destroying the diffusion boundary layer: gravitational convection and electroconvection. These effects result from formation of concentration gradients (known as concentration polarization) caused by the current flowing under conditions where ionic transport numbers are different in the membrane and solution. Similar effects take place not only in electrodialysis membrane systems, but in electrode ones, in electrophoresis and electrokinetic micro- and nanofluidic devices such as micropumps. The relation of these effects to the properties of the membrane surface (the chemical nature of the fixed groups, the degree of heterogeneity and hydrophobicity, and the geometrical shape of the surface) is analyzed. The interaction between the coupled effects is studied, and the conditions under which one or another effect becomes dominant are discussed. The application of intensive current modes in electrodialysis, the state-of-the-art and perspectives, are considered. It is shown that the intensive current modes are compatible with new trends in water treatment oriented towards Zero Liquid Discharge (ZLD) technologies. The main idea of these hybrid schemes including pressure- and electro-driven processes as well as conventional methods is to provide the precipitation of hardness salts before the membrane modules and that of well dissolved salts after.

Ji, X.[a] , Curcio, E.[a b] , Al Obaidani, S.[c] , Di Profio, G.[a b] , Fontananova, E.[a b] , Drioli, E.[a b]
Membrane distillation-crystallization of seawater reverse osmosis brines
(2010) *Separation and Purification Technology*, 71 (1), pp. 76-82. Cited 3 times.
Abstract
This work aims at investigating the performance, in terms of water recovery and NaCl crystallization kinetics, of a membrane distillation-crystallization (MDC) bench-scale plant operated on brines discharged from a seawater reverse osmosis (RO) unit. Experimental tests carried out on artificial RO concentrates resulted in

the production of 21 kg/m3 of NaCl crystals, exhibiting substantially a ordinary cubic shape with size between 20 and 200 μm; the final water recovery factor increased up to 90%. Analogous investigations carried out on RO brines from natural seawater were affected by the presence of dissolved organic matter, showing a 20% reduction of the amount of salt crystallized, and a 8% decrease of the transmembrane flux. Growth rate of sodium chloride crystals generated from natural RO brines varied between 0.8 × 10-8 and 2.8 × 10-8 m/s; these values were 15-23% lower than those measured for NaCl crystals grown form artificial concentrates. In general, the NaCl crystal size distribution was characterized by a narrow dispersion (coefficient of variation within 35-40%). MDC operations were stable over 100 h as a result of a careful control of supersaturation, polarization phenomena, nucleation process and hydrodynamics.

Neilly, A., Jegatheesan, V., Shu, L.

Evaluating the potential for zero discharge from reverse osmosis desalination using integrated processes - A review

(2009) *Desalination and Water Treatment*, 11 (1-3), pp. 58-65. Cited 1 time.

Abstract

Desalination processes used worldwide produce a large amount of waste concentrate, the disposal of which can have significant environmental impacts. As such, there has been research carried out into the development of zero liquid discharge technologies which recognise that the waste concentrate streams contain valuable salts, minerals and water. These technologies include the proprietary SAL-PROC systems, as well as other integrated systems that use a variety of different technologies for the extraction of salts and minerals from waste concentrates. Research has also been conducted on using forward osmosis as a means of treating the waste concentrate in order to produce additional product water and thus reduce the volume of waste concentrate. This article provides a review of these technologies and evaluates the potential for achieving zero liquid discharge by combining these technologies with conventional desalination technologies into integrated processes.

Al Obaidani, S.[a b] , Curcio, E.[b c] , di Profio, G.[c] , Drioli, E.[b c]

The role of membrane distillation/crystallization technologies in the integrated membrane system for seawater desalination

(2009) *Desalination and Water Treatment*, 10 (1-3), pp. 210-219. Cited 2 times.

Abstract

Membrane desalination technology has emerged in recent years as the most viable solution to water shortage. However, despite the enormous improvement in membrane desalination technology, some critical developments are still necessary in order to accomplish possible improvements in the process efficiency (increase recovery), operational stability (reduce fouling and scaling problems), environmental impact (reduce brine disposal), water quality (remove harmful substances) and costs. In particular, cost effective and environmentally sensitive concentrate management is today recognized as a significant obstacle to extensive implementation of desalination technologies. As a result of the significant impact of desalination plants on the environment, the requirements for concentrate management tight up: brine disposal minimization and zero liquid discharge (ZLD) are the demanding targets for several applications. In this concept, conventional pressure-driven membranes such as MF, NF and RO were integrated with the innovative units of membrane contactors such as Membrane Distillation/Crystallization (MD/MC). The integration of different membrane units represents an interesting way for achieving the ZLD goal due to the possibility of overcoming the limits of the single units and, thus, to improve the performance of the overall operation. The present research study is focusing on the evaluation of the integrated membrane system which merges the membrane contactor technology with the conventional pressure-driven membrane operations for seawater desalination. Sensitivity studies were performed for several configurations of the integrated system to obtain the most sensitive parameter in the total water cost and the optimal design of the system. The results revealed that the pressure-driven membrane operations were very sensitive to the feed concentration and the cost of electricity consumption. On the other hand, MD processes were not sensitive to the variation on the feed concentration or the electricity costs. The most sensitive parameter in the total water cost of the MD plant was the cost of steam which contributed to values as high as high as 11.4% in the case of MD without heat recovery system. The best tolerance to the variation of these parameters was obtained when using the integrated membrane system of pressure-driven membranes and MC processes.

Martinetti, C.R.[a] , Childress, A.E.[a] , Cath, T.Y.[b]
High recovery of concentrated RO brines using forward osmosis and membrane distillation
(2009) *Journal of Membrane Science*, 331 (1-2), pp. 31-39. Cited 16 times.
Abstract
Vacuum-enhanced direct contact membrane distillation (VEDCMD) and forward osmosis (FO) were investigated for water recovery enhancement in desalination of brackish water. Past studies have demonstrated that both VEDCMD and FO can be effectively utilized in the treatment of a wide range of highly concentrated feed solutions. In the current study, two reverse osmosis (RO) brine streams with total dissolved solids concentrations averaging 7500 and 17,500 mg/L were further desalinated by VEDCMD and by FO. In both processes, high water recoveries were achieved; however, recoveries were limited by precipitation of inorganic salts on the membrane surface. Various cleaning techniques were able to remove the scale layer from the membrane and restore water flux to almost initial levels. FO achieved water recoveries up to 90% from the brines and VEDCMD achieved water recoveries up to 81% from the brines. Addition of a scale inhibitor during both processes was effective at maintaining high water flux for extended time. When considering the total water recovery (the recovery from the RO processes combined with the batch recovery from the VEDCMD or FO process), greater than 96 and 98% total recoveries were achieved for the two different brine streams. © 2009 Elsevier B.V. All rights reserved.

Integrated Membrane Systems

Mohammadesmaeili, F.[a] , Badr, M.K.[b] , Abbaszadegan, M.[a] , Fox, P.[a]
Byproduct recovery from reclaimed water reverse osmosis concentrate using lime and soda-ash treatment
(2010) *Water Environment Research*, 82 (4), pp. 342-350. Cited 1 time.
Abstract
Lime and soda-ash softening of reclaimed water reverse osmosis concentrates as a pretreatment step for concentration by seawater reverse osmosis was the focus of this study. The objectives were removal of the potential fouling minerals of calcium, magnesium, and silica by selective precipitation, while producing byproducts with potential resale value. Three different bench-scale lime-soda processes were evaluated. The traditional method produced low-quality magnesium hydroxide [Mg(OH)2] and calcium carbonate (CaCO 3) byproducts. A modified process with pre-acidification to eliminate carbonate removed 98 to 99% of calcium and magnesium and produced CaCO 3 that was >94% pure. To prevent the contamination of byproducts with calcium sulfate (CaSO4) in high-sulfate concentrates, a CaSO4 crystallization step was added successfully to the modified process to precipitate CaSO4 before Mg(OH)2 precipitation and produce gypsum that was 92% pure. The modified limesoda process also removed 94 to 97% silica, 72 to 77% barium, and 95 to 96% strontium, which are known as reverse osmosis membrane foulants.

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Jeppesen, T., Shu, L., Keir, G., Jegatheesan, V.
Metal recovery from reverse osmosis concentrate
(2009) *Journal of Cleaner Production*, 17 (7), pp. 703-707. Cited 9 times.
Abstract
The use of reverse osmosis (RO) membranes is becoming increasingly common in desalination plants, though disposal of the highly concentrated brines poses significant environmental risks. The targeted extraction of some metals from the concentrate can have multiple environmental and economic benefits. This is particularly apparent with recent developments in the development of zero liquid discharge desalination systems. This study has shown that recovery of sodium chloride from RO concentrate can significantly lower the cost of potable water production if employed in conjunction with thermal processing systems. Additionally, the recovery of rubidium from seawater may be a potential source of revenue, however further work is needed to characterise the economics of the rubidium extraction process. Finally, removal of phosphorus from RO concentrate provides little economic benefit, but may become increasingly necessary as environmental restrictions increase in the future.

Martinetti, C.R.[a] , Childress, A.E.[a] , Cath, T.Y.[b]
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(2009) *Journal of Membrane Science*, 331 (1-2), pp. 31-39. Cited 16 times.
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Heijman, S.G.J.[a b] , Guo, H.[a] , Li, S.[a] , van Dijk, J.C.[a] , Wessels, L.P.[b]
Zero liquid discharge: Heading for 99% recovery in nanofiltration and reverse osmosis
(2009) *Desalination*, 236 (1-3), pp. 357-362. Cited 4 times.
Abstract
Concentrate of nanofiltration and reverse osmosis installations is an increasing problem, especially for inland membrane installations. Introduction of membrane filtration in The Netherlands is severely hindered by the concentrate problem. Two approaches are viable for solving or reducing the concentrate problem: (1) low recovery NF/RO without anti-scalant dosing, (2) Zero liquid discharge. This research focuses on the second option: Zero liquid discharge NF/RO. First and main problem to be solved with zero liquid discharge is to increase the recovery of the membrane installation to its limits, without increasing the costs of water produced. A high recovery (>99%) is necessary to reduce energy consumption and costs for evaporation of the remaining waste stream (<1%). The only possibility to achieve a very high recovery in NF/RO, is removing the scaling components from the feed water. A very important advantage of removing the scaling components is that the nanofiltration or RO can be operated at high fluxes. In this paper the results of two pilot experiments are reported. One treatment concept was developed for surface water treatment and one for groundwater treatment. The surface water treatment concept consisted of fluidized ion exchange to remove positive multivalent cations, and then followed by ultrafiltration, nanofiltration and granular activated carbon filtration. With this setup a recovery of 97% was achieved. To achieve an even higher recovery it is also important to remove silica from the feed water because silica can limit the recovery. Silica can be removed at high pH during co-precipitation with magnesium hydroxide. The groundwater concept consisted of: precipitation at high pH, then followed by sedimentation, weak acid cation exchange and nanofiltration. With this setup a recovery of 99% was achieved. © 2008 Elsevier B.V. All rights reserved.

Badruzzaman, M.[a] , Oppenheimer, J.[a] , Adham, S.[b] , Kumar, M.[c]
Innovative beneficial reuse of reverse osmosis concentrate using bipolar membrane electrodialysis and electrochlorination processes
(2009) *Journal of Membrane Science*, 326 (2), pp. 392-399. Cited 6 times.
Abstract
Reverse osmosis (RO) is a widely used and rapidly growing desalination technology. A major disadvantage of this process is that the concentrate from the RO process, which could be as much as 25% of the feed stream, represents a polluting stream. This waste stream could pose a significant challenge to the implementation of this process, particularly for inland communities which do not have the option of ocean disposal. An excellent environmentally benign approach to disposal could be beneficial reuse of the waste stream. This study presents two innovative beneficial reuse strategies for RO concentrate produced by an integrated membrane system (IMS) from a wastewater reclamation facility. The technologies evaluated in this study included bipolar membrane electrodialysis (BMED) for conversion of RO concentrate into mixed acid and mixed base streams, and electrochlorination (EC) for onsite chlorine generation. Bench-scale studies conducted with BMED demonstrated that RO concentrate could be desalted while producing mixed acids and mixed bases with concentrations as high as 0.2N. Similarly, the EC process was capable of producing a 0.6% hypochlorite solution from RO concentrate. The acids and bases as well as the hypochlorite produced could be directly applied to the RO process as well as upstream pre-treatment processes. A preliminary economic evaluation of the viability of these two approaches was conducted by conducting rough order of magnitude cost estimates based on the bench-scale performance of these processes on RO concentrate. A comparison of the overall costs of an Integrated Membrane System utilizing these innovative reuse strategies with conventional disposal options and thermal zero liquid discharge treatment is presented. This comparison indicates that a reuse approach might be economically viable for inland wastewater reuse facilities that utilize RO membranes and have limited options for concentrate disposal. © 2008 Elsevier B.V. All rights reserved.

Durham, B.[a b] , Mierzejewski, M.[c]
Water reuse and zero liquid discharge: A sustainable water resource solution
(2003) *Water Science and Technology: Water Supply*, 3 (4), pp. 97-103. Cited 1 time.
Abstract
Increased water demand from population and economic growth, environmental needs, change in rainfall, flood contamination of good quality water and over abstraction of groundwater are all factors that will continue to create water shortage problems. This paper considers alternative solutions, which conform to sustainable solution premises whilst being economically beneficial to the community. The importance of pilot studies is reviewed and the surprises they can uncover. Case studies describe the benefits of long-term operating experience of zero discharge systems reusing the wastewater produced by car manufacture and secondary sewage reuse for a large coal fired power plant. Applications of reuse on large islands such as Hawaii and desert communities are discussed including the production of cash crops with high efficiency irrigation systems by reusing brackish municipal wastewater. Large municipal zero discharge potable water production is also described with an economic comparison of the alternatives.

Thöming, J.[a b]
Optimal design of zero-water discharge rinsing systems
(2002) *Environmental Science and Technology*, 36 (5), pp. 1107-1112. Cited 10 times.
Abstract
This paper is about zero liquid discharge in processes that use water for rinsing. Emphasis was given to those systems that contaminate process water with valuable process liquor and compounds. The approach involved the synthesis of optimal rinsing and recycling networks (RRN) that had a priori excluded water discharge. The total annualized costs of the RRN were minimized by the use of a mixed-integer nonlinear program (MINLP). This MINLP was based on a hyperstructure of the RRN and contained eight counterflow rinsing stages and three regenerator units: electrodialysis, reverse osmosis, and ion exchange columns. A "large-scale nickel plating process" case study showed that by means of zero-water discharge and optimized rinsing the total waste could be reduced by 90.4% at a revenue of $448 000/yr. Furthermore, with the optimized RRN, the rinsing performance can be improved significantly at a low-cost increase. In all the cases, the amount of valuable compounds reclaimed was above 99%.

Thermal Distillation

Alnaizy, R., Aidan, A.A.
Development of a renewable energy-based solution for saline waters desalination
(2010) *AIChE Annual Meeting, Conference Proceedings*, .
Abstract
It is vital to identify and develop diverse and sustainable energy alternatives to overcome the current and future energy shortage. Energy costs can be greatly reduced by utilizing a natural and "free" source of energy. In this work, we present the findings of using renewable energy sources (solar) as a potential solution to meet the potable water needs. The project addresses these issues by examining a multi-effect, multi-stage (MEMS) flash distillation system for desalination using solar heating and the sensible heat that can be extracted from a Salinity Gradient Solar Pond (SGSP). The project involved a comprehensive testing and analysis over a broad range of operational conditions, with the thermal energy derived from a SGSP. The relationship between system performance and operating conditions was analyzed to determine the economic and technical viability of the system. Mathematical and computer models were developed to describe the physical behavior of the system and to predict its performance. The proposed desalination process is expected to meet all imposed criteria and conditions, i.e. zero discharge with a very high recovery ratio of 82%. In addition, all the thermal energy needed for the MEMS, which represents more than 90% of the total energy, will be derived from a solar pond. The close-to-saturation brine will be sent to a shallow man-made pond to evaporate all the water and collect the remaining salts as crystals and guarantee the zero-liquid discharge process. The process is far less costly than the other processes, as the site conditions are favorable for salinity-gradient solar ponds.

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Pfromm, P.[a] , Hussain, M.[b]

Reducing water demand by increasing energy efficiency for bio-ethanol

(2009) *Conference Proceedings - 2009 AIChE Annual Meeting, 09AIChE*, 1 p.

Abstract

The U.S. has a significant commitment to bio ethanol production and other countries like Brazil will continue to produce large amounts of this bio fuel via fermentation. Although the advantages and disadvantages of bio ethanol by fermentation are debatable it is clear that fermentation-based ethanol will be produced on a very large scale for some time to come and therefore merits efforts to clarify and improve any technological and environmental aspect of it. The water consumption for fermentation-based bio ethanol has recently begun to attract the attention of the public, legislators, engineers, and scientists in the U.S. and elsewhere. Widely varying water needs ranging from zero to perhaps more than 10 gallons of water per gallon of ethanol are reported, excluding the water needs to grow the needed plants. We first show a minimum non-recyclable consumption of about 2.85 gal water/gal of ethanol produced (for processing of corn to fuel grade ethanol, gate-to-storage) assuming zero liquid discharge from the process and otherwise current industrial practice data for yeast fermentation-based bio ethanol. Reduction of the thermal energy input to the process is vital to reduce this irretrievable water consumption. The direct relation of the minimum water demand of bio-ethanol production to the energy used in the process will be shown based on the well established chemical engineering concepts of unit operations and mass and energy balances. We will then discuss a possible reduction of the energy demand and thereby the water consumption for water/ethanol separation by salt extractive distillation and electrodialysis.

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(2009) *Journal of Membrane Science*, 331 (1-2), pp. 31-39. Cited 16 times.

Abstract

Vacuum-enhanced direct contact membrane distillation (VEDCMD) and forward osmosis (FO) were investigated for water recovery enhancement in desalination of brackish water. Past studies have demonstrated that both VEDCMD and FO can be effectively utilized in the treatment of a wide range of highly concentrated feed solutions. In the current study, two reverse osmosis (RO) brine streams with total dissolved solids concentrations averaging 7500 and 17,500 mg/L were further desalinated by VEDCMD and by FO. In both processes, high water recoveries were achieved; however, recoveries were limited by precipitation of inorganic salts on the membrane surface. Various cleaning techniques were able to remove the scale layer from the membrane and restore water flux to almost initial levels. FO achieved water recoveries up to 90% from the brines and VEDCMD achieved water recoveries up to 81% from the brines. Addition of a scale inhibitor during both processes was effective at maintaining high water flux for extended time. When considering the total water recovery (the recovery from the RO processes combined with the batch recovery from the VEDCMD or FO process), greater than 96 and 98% total recoveries were achieved for the two different brine streams.

Freeze Crystallization

Stanford, B.D.[a] , Leising, J.F.[a] , Bond, R.G.[b] , Snyder, S.A.[a]

Chapter 11 Inland Desalination: Current Practices, Environmental Implications, and Case Studies in Las Vegas, NV

(2010) *Sustainability Science and Engineering*, 2 (C), pp. 327-350.

Abstract

Water utilities around the world are facing increasing demands being placed on the limited water resources available and, as such, are turning to new strategies to ensure a sustainable, safe, reliable drinking water supply. Included within the portfolio of strategies available to utilities to stretch drinking water supplies are potable reuse, indirect potable reuse (IPR), ocean desalination, and inland desalination. This chapter will touch upon issues surrounding IPR and ocean desalination, but will devote most of the text to examining inland desalination practices including environmental effects, energy costs, infrastructure costs and challenges, and several practices that have been investigated to increase water recovery while reducing the impact of the system. The chapter will highlight two studies carried out in connection with the Southern Nevada Water Authority and Black and Veatch in order to compare strategies investigated for zero-liquid discharge (ZLD) for the desalination of saline shallow groundwater.

Nikonenko, V.V.[a] , Pismenskaya, N.D.[a] , Belova, E.I.[a] , Sistat, P.[b] , Huguet, P.[b] , Pourcelly, G.[b] , Larchet, C.[c]

Intensive current transfer in membrane systems: Modelling, mechanisms and application in electrodialysis

(2010) *Advances in Colloid and Interface Science*, 160 (1-2), pp. 101-123. Cited 2 times.

Abstract

Usually in electrochemical systems, the direct current densities not exceeding the limiting current density are applied. However, the recent practice of electrodialysis evidences the interest of other current modes where either the imposed direct current is over the limiting one or a non-constant asymmetrical (such as pulsed) current is used. The paper is devoted to make the mechanisms of mass transfer under these current regimes more clear. The theoretical background for mathematical modelling of mass transfer at overlimiting currents is described. Four effects providing overlimiting current conductance are examined. Two of them are related to water splitting: the appearance of additional charge carriers (H^+ and OH^- ions) and exaltation effect. Two others are due to coupled convection partially destroying the diffusion boundary layer: gravitational convection and electroconvection. These effects result from formation of concentration gradients (known as concentration polarization) caused by the current flowing under conditions where ionic transport numbers are different in the membrane and solution. Similar effects take place not only in electrodialysis membrane systems, but in electrode ones, in electrophoresis and electrokinetic micro- and nanofluidic devices such as micropumps. The relation of these effects to the properties of the membrane surface (the chemical nature of the fixed groups, the degree of heterogeneity and hydrophobicity, and the geometrical shape of the surface) is analyzed. The interaction between the coupled effects is studied, and the conditions under which one or another effect becomes dominant are discussed. The application of intensive current modes in electrodialysis, the state-of-the-art and perspectives, are considered. It is shown that the intensive current modes are compatible with new trends in water treatment oriented towards Zero Liquid Discharge (ZLD) technologies. The main idea of these hybrid schemes including pressure- and electro-driven processes as well as conventional methods is to provide the precipitation of hardness salts before the membrane modules and that of well dissolved salts after. © 2010 Elsevier B.V.

Ning, R.Y.[a] , Tarquin, A.J.[b]

Crystallization of salts from super-concentrate produced by tandem RO process

(2010) *Desalination and Water Treatment*, 16 (1-3), pp. 238-242.

Abstract

We continue to address the challenge of improving concentrate disposal for the large 15 mgd (2370 m3/h) inland reverse osmosis (RO) plant in El Paso, Texas. For the first time on a pilot scale, the feasibility of using two RO systems in tandem and using appropriate antiscalants and pH control, continuous production of permeate to limiting osmotic pressure of about 1000 psi (69 Bars) is possible [1,2,12]. Recovery is simply limited by the highest pump pressure available to overcome the resulting osmotic pressure [2]. Tandem RO without interstage treatment is being demonstrated. We envision that such a continuously operated tandem RO process can recover all the water possible to be produced from brackish ground waters at the highest possible pump pressures. At the maximum system pressure of 1000 psi, the highest total dissolved solids attainable in the concentrate are about 8-9% by weight. Anticipating the universal application of the continuous tandem RO process to generate super RO concentrates, an alternate path is now open for fractional crystallization of salts before thermal evaporation of water. Pursuing the development of an economical zero-liquid-discharge process applicable to inland municipal water treatment plants, we wish to explore the feasibility of fractionating the less soluble divalent calcium and magnesium salts from the monovalent sodium and potassium salts. In relatively large amounts, even in mixtures, these fractionated salts may have economic values such as in soil and dust control and for softening and deicing applications. Further more, 8-9% brine softened by the removal of multivalent salts and silica may have utility in cooling towers while being thermally concentrated for the ultimate recovery of the soluble sodium and potassium salts. In this paper, we present our initial investigation into a super-concentrate depleted of bicarbonates due to acidification needed for silica control. The concentrate at maximum recovery with a secondary RO in tandem in the demonstration plant was treated for calcium sulfate, magnesium, iron and silica precipitation. This paper describes the laboratory conditions used and observations made on the use of lime in preparation for scale-up.

Mohammadesmaeili, F.[a] , Badr, M.K.[b] , Abbaszadegan, M.[a] , Fox, P.[a]

Byproduct recovery from reclaimed water reverse osmosis concentrate using lime and soda-ash treatment

(2010) *Water Environment Research*, 82 (4), pp. 342-350. Cited 1 time.

Abstract

Lime and soda-ash softening of reclaimed water reverse osmosis concentrates as a pretreatment step for concentration by seawater reverse osmosis was the focus of this study. The objectives were removal of the potential fouling minerals of calcium, magnesium, and silica by selective precipitation, while producing byproducts with potential resale value. Three different bench-scale lime-soda processes were evaluated. The traditional method produced low-quality magnesium hydroxide [Mg(OH)2] and calcium carbonate (CaCO 3) byproducts. A modified process with pre-acidification to eliminate carbonate removed 98 to 99% of calcium and magnesium and produced CaCO 3 that was >94% pure. To prevent the contamination of byproducts with calcium sulfate (CaSO4) in high-sulfate concentrates, a CaSO4 crystallization step was added successfully to the modified process to precipitate CaSO4 before Mg(OH)2 precipitation and produce gypsum that was 92% pure. The modified limesoda process also removed 94 to 97% silica, 72 to 77% barium, and 95 to 96% strontium, which are known as reverse osmosis membrane foulants.

Ji, X.[a] , Curcio, E.[a b] , Al Obaidani, S.[c] , Di Profio, G.[a b] , Fontananova, E.[a b] , Drioli, E.[a b]
Membrane distillation-crystallization of seawater reverse osmosis brines
(2010) *Separation and Purification Technology*, 71 (1), pp. 76-82. Cited 3 times.
Abstract
This work aims at investigating the performance, in terms of water recovery and NaCl crystallization kinetics, of a membrane distillation-crystallization (MDC) bench-scale plant operated on brines discharged from a seawater reverse osmosis (RO) unit. Experimental tests carried out on artificial RO concentrates resulted in the production of 21 kg/m3 of NaCl crystals, exhibiting substantially a ordinary cubic shape with size between 20 and 200 μm; the final water recovery factor increased up to 90%. Analogous investigations carried out on RO brines from natural seawater were affected by the presence of dissolved organic matter, showing a 20% reduction of the amount of salt crystallized, and a 8% decrease of the transmembrane flux. Growth rate of sodium chloride crystals generated from natural RO brines varied between 0.8 × 10-8 and 2.8 × 10-8 m/s; these values were 15-23% lower than those measured for NaCl crystals grown form artificial concentrates. In general, the NaCl crystal size distribution was characterized by a narrow dispersion (coefficient of variation within 35-40%). MDC operations were stable over 100 h as a result of a careful control of supersaturation, polarization phenomena, nucleation process and hydrodynamics.

Al Obaidani, S.[a b] , Curcio, E.[b c] , di Profio, G.[c] , Drioli, E.[b c]
The role of membrane distillation/crystallization technologies in the integrated membrane system for seawater desalination
(2009) *Desalination and Water Treatment*, 10 (1-3), pp. 210-219. Cited 2 times.
Abstract
Membrane desalination technology has emerged in recent years as the most viable solution to water shortage. However, despite the enormous improvement in membrane desalination technology, some critical developments are still necessary in order to accomplish possible improvements in the process efficiency (increase recovery), operational stability (reduce fouling and scaling problems), environmental impact (reduce brine disposal), water quality (remove harmful substances) and costs. In particular, cost effective and environmentally sensitive concentrate management is today recognized as a significant obstacle to extensive implementation of desalination technologies. As a result of the significant impact of desalination plants on the environment, the requirements for concentrate management tight up: brine disposal minimization and zero liquid discharge (ZLD) are the demanding targets for several applications. In this concept, conventional pressure-driven membranes such as MF, NF and RO were integrated with the innovative units of membrane contactors such as Membrane Distillation/Crystallization (MD/MC). The integration of different membrane units represents an interesting way for achieving the ZLD goal due to the possibility of overcoming the limits of the single units and, thus, to improve the performance of the overall operation. The present research study is focusing on the evaluation of the integrated membrane system which merges the membrane contactor technology with the conventional pressure-driven membrane operations for seawater desalination. Sensitivity studies were performed for several configurations of the integrated system to obtain the most sensitive parameter in the total water cost and the optimal design of the system. The results revealed that the pressure-driven membrane operations were very sensitive to the feed concentration and the cost of electricity consumption. On the other hand, MD processes were not sensitive to the variation on the feed concentration or the electricity costs. The most sensitive parameter in the total water cost of the MD plant was the cost of steam which contributed to values as high as high as 11.4% in the case of MD without heat recovery system. The best tolerance to the variation of these parameters was obtained when using the integrated membrane system of pressure-driven membranes and MC processes.

Bond, P.[a] , Veerapaneni, S.[b]
Zeroing in on ZLD technologies for inland desalination
(2008) *Journal / American Water Works Association*, 100 (9), pp. 76-89+10. Cited 2 times.
Abstract
Many communities need affordable inland desalination to meet increasing water demands by making brackish water sources available for use in supplementing existing water supplies or to control the salinity of current sources. Most desalination technologies generate two streams - a desalinated product water stream and the saline by-product referred to as concentrate. Management of the concentrate stream, typically 15-30% of the feed flow, presents the greatest challenge to implementing desalination. This research demonstrated the novel use of existing technologies to reduce the cost and energy consumption for desalination with zero liquid discharge (ZLD) of concentrate. Test results indicated treatment of the concentrate for further recovery by a second application of reverse osmosis could lead to significant reductions in desalination costs and energy consumption to achieve ZLD. The approach described here

could cut ZLD costs by 50-70% and reduce energy consumption by 60-75% compared with established methods currently in use.

Prato, T., Muller, R., Alvarez, F.
EDI application in polishing evaporator product water at a Texas power plant
(2001) *Ultrapure Water*, 18 (9), pp. 48-51.
Abstract
A new feedwater source for electrodeionization technology (EDI) in the water treatment system of the gas-powered Guadalupe Power Plant in Texas, USA is described. The system is designed for zero liquid discharge. Cooling tower blowdown is treated in an evaporator, followed by crystallization, EDI and ion-exchange polishing. The principles of EDI are outlined and the performance of the Panda EDI system is discussed. EDI brine blowdown and electrode steam waste are recycled back to softening clarifiers, increasing the EDI percent recovery from 95 to 100%.

Dalan, J.A.
Things to know about zero liquid discharge
(2000) *Chemical Engineering Progress*, 96 (11), pp. 71-76. Cited 3 times.
Abstract
Zero-liquid-discharge systems are installed for reasons of environmental compliance, siting economics, and corporate citizenship. This article provides an overview of several points that will assist the engineer in performing feasibility studies of different types of systems, preparing specifications for purchase, understanding how existing zero-liquid-discharge system work with a view toward operational improvements, and intelligent purchasing of systems or components.

Lancaster, Richard L., Sanderson, William G., Mordecai, Davis E.
Staged cooling at Orange Cogen zero wastewater discharge operations at a peaking plant
(1998) *International Exhibition & Conference for the Power Generation Industries - Power-Gen*, p. 166.
Abstract
The Orange Cogen plant is a zero liquid discharge facility and liquid discharge is not permitted either within or beyond plant boundaries. The plant incorporates a highly automated 'Staged' cooling zero wastewater discharge process that minimizes operator attention while optimizing water reuse and recycle for lowest ZDS costs. This article describes the design and control features of the 'Staged' cooling zero wastewater discharge system. Startup and operating experience and some of the unique challenges of minimum manpower zero wastewater discharge plant operations are also discussed.

Seigworth, A.[a] , Ludlum, R.[b] , Reahl, E.[c]
Case study: Integrating membrane processes with evaporation to achieve economical zero liquid discharge at the Doswell Combined Cycle Facility
(1995) *Desalination*, 102 (1-3), pp. 81-86. Cited 4 times.
Abstract
New restrictive permitting, operating and environmental requirements placed on independent power producers, utility power plants, chemical processing plants, refineries and other industrial installations are mandating zero liquid discharge of wastewater to sewers, rivers, deep wells and the like. Economic reclamation and reuse of wastewater is becoming essential. Since the mid-70's, vapor compression evaporation has been the preferred means to achieve zero liquid discharge. Evaporation recovers about 95% of a wastewater as distillate for reuse. Waste brine can be reduced to solids in a crystallizer/dewatering device. However, evaporation alone can be an expensive option when flow rates are large or when wastewater is not extremely high in total dissolved solids (TDS). As a result, grassroots power plants and other industrial facilities often find it difficult to economically justify a zero liquid discharge system. One way to solve this problem is to integrate membrane processes with evaporation. By combining membrane processes such as electrodialysis reversal (EDR) and/or reverse osmosis (RO) with evaporation, the synergism makes zero liquid discharge a much easier goal to meet. An example of this hybrid approach for economical zero liquid discharge is the installation of EDR plus RO along with evaporation and crystallization at the Doswell Combined Cycle Power Plant in Hanover County, Virginia. Use of membrane processes to preconcentrate and reclaim plant wastewaters has significantly reduced the evaporator feed volume, resulting in a 62% downsizing of the evaporator system. Without the EDR and RO system, the evaporator/crystallizer system would have treated 250 gallons per minute (gpm) of wastewater at a total dissolved solids concentration of 2900 parts per million (ppm). Using the combined EDR and RO systems to pretreat wastewater helped reduce the evaporator feed volume to about 90 gpm with a higher TDS concentration of 9700 ppm. Compared to straight evaporation/crystallization, the hybrid approach reduced overall capital costs by $900,000 and saves energy and operating costs by $680 per operating day. © 1995.

Van Wyk, James E., Hall, Ray
Improvements to zero discharge systems
(1995) *Proceedings of the American Power Conference*, 57-2, pp. 1380-1383.
Abstract
State regulatory agencies favor zero liquid discharge systems. Previous studies have addressed waste water minimization and zero liquid discharge options. In the present work, improvement to the staged evaporation system which utilizes all the benefits of the staged evaporation system while incorporating features are presented. The system is referred to as Improved Zero Discharge (IZD). In general, the improvements in the system take advantage of the lower capital and operating costs inherent in the system.

Selected Web Sites

Aquatech International Corporation
Aquatech International Corporation is a global leader in water purification technology for industrial and infrastructure markets with a focus on desalination, water reuse, and zero liquid discharge.
www.aquatech.com

Desalination & Water Reuse (D&WR)
DD&WR covers the engineering aspects of desalination and water reuse from municipal water supplies through to industrial needs. It delivers practical information and news on projects, materials and equipment and research with sections devoted to the International Desalination Association and IDA affiliates, worldwide. D&WR also publishes an annual Desalination Sources Directory which lists, comprehensively, details of suppliers of equipment, products and services for the desalination industry.
http://www.desalination.biz/about.asp?channel=0

The International Desalination Association (IDA)
IDA is the leading global organization dedicated to desalination, desalination technology and water reuse. The hub of expertise, news and information, and professional development for the worldwide desalination industry, IDA serves more than 2,400 core members from 60 countries and reaches an additional 4,000 members from its worldwide network of Affiliate organizations.
http://www.idadesal.org/t-about.aspx

Global Water Intelligence (GWI)
Track major global water projects from conception to contract award. Discover emerging trends in the global water industry. Formulate strategy in a rapidly changing world.
http://www.globalwaterintel.com/home/

HPD
HPD is a global leader in evaporation and crystallization technology and a part of the Veolia Water Solutions & Technologies family of companies. Our focus is the development of unique process designs and technology for our industrial clients in a broad range of markets. http://www.hpdsystems.com/en/

Water Sciences and Technology Association (WSTA)
The WSTA is a non-government organization and its WSTA membership is open to all water professionals in the GCC, water-related national and international organizations, educational institutes, consultants, and companies.
http://www.wstagcc.org/about.php

Zero Liquid Discharge Desalination For Treatment of Saline Water Waste Streams-JCCP
Essam E.F. El-Sayed, Third SQU-JCCP Joint Symposium, 19-21.December 20101. Presented in Environmental Challenges and Mitigation approaches for sustainable development in oil and gas industry.

Frequently Asked Questions[A1]

Source: http://www.sidem-desalination.com/en/process/FAQ/

What happens to the salt?

The desalination plant typically uses three kilograms of seawater to produce 1 kilogram of fresh water. The extracted salt dissolves in the excess sea water used in the process to form so-called brine. The brine is returned to the sea where it is diluted again in its natural medium.

Can salt be recovered?

The usual desalination processes do not provide for such recovery. Whereas they concentrate seawater 1.5 times, recovery of salt would require seawater to be concentrated ten times. Under such conditions the first crystals would appear in the brine. This would require a lot of energy and cannot be justified on an economic standpoint. Today whenever a large surface area is available close to a sunny seashore, salt pans, which make use of solar energy, are still the best method of salt production.

Do desalination plants pollute?

Desalination plants reject slightly concentrated seawater called brine to the sea. The salt content of the brine is roughly 60g/l for seawater at 40g/l. The temperature of the brine reject is slightly higher than that of the seawater - a few degrees Celsius. This excess salt concentration and temperature quickly vanish in the vicinity of the rejection point.

Seawater is chlorinated at the plant inlet to avoid the growth of seaweed and seashells inside the piping. Chlorine is accurately dosed so as to avoid active chlorine remaining at the outlet of the plant.

Antiscale and antifoam additives are also dosed in seawater entering the plant, dose levels being in the range of a few grams per ton. Once they have reacted inside the plant and due to their huge dilution, they present no risk of pollution at the plant outlet.
Desalination units are often set in environmentally protected areas with no particular problem raised.

As such, a desalination plant has no other reject to the environment. However it can be coupled with a boiler or a power plant. The rejects of such plants are controlled by environmental standards.
These combined plants provide the best efficiency and minimise the overall impact of power and water production on the environment.

Is desalinated water drinkable?

Thermal desalination processes produce distilled water, which is quite pure. Whereas seawater contains some 40 kilos of salt per ton, distilled water has only a few grams of salt per ton. In this sense it does not comply with WHO recommendations. However having a glass of it would not be a problem for most of us. The problem is preservation of such water since it will acidify, become corrosive and can easily be contaminated.
Therefore water desalinated for human consumption is mineralised and chlorinated before dispatch.

Who buys desalination plants?
The largest clients are located in the Middle East. This region is home to more than half of the world wide installed capacity, considering all processes, whereas the USA have 15%, Europe and Asia 10% each and Africa around 6%.
Beside these major clients the largest petroleum or chemical companies are clients of desalination in order to provide reliable water sources to their plants.

Desalination, what for?
Desalination is used for industrial, human consumption or agricultural purposes. Petroleum or chemical industries always need large quantities of pure water for boilers or process requirements. Wherever local supply cannot meet their own requirements they will go to desalination to free themselves from local constraints. This particular industrial use represents one third of the world wide installed capacity. 60% of desalination is devoted to human consumption: thus a reliable water resource is created and enables sustainable development of a population in a region.
Agricultural use is mainly a second hand use: in many Middle East countries, desalinated water is first devoted to human consumption, then after treatment it is re-used in irrigation.
A few percent of desalination capacity is for military, navy, tourism uses ...etc...

How much does desalinated water cost?
The cost of desalinated water taken at the outlet of a plant may vary widely from one site to the other. It mainly depends on the cost of energy, the plant total capacity, the depreciation period, and on the production pattern (whether it is used seasonally only or throughout the year). As a rule of thumb a large plant located in Europe with a continuous production pattern will produce water at a cost of 1 Euro per cubic meter. The water produced in a smaller plant (a few thousand cubic meters per day) would cost 3 to 5 times higher.

Seawater or brackish water?
Salted water is not always the same. Depending on whether they come from warm or cold oceans, closed or open seas, their salt content will vary. This is a short comparison between samples:

- Brackish water:0,5 à 3 g/l
- Northern Sea close to estuaries :21 g/l
- Atlantic Ocean :35 g/l
- Mediterranean Sea :38 g/l
- Arabian Sea :45 g/l
- Dead Sea :300 g/l

Open seawaters always contain the same proportion of different salts; they can be desalinated without problem. For brackish waters, whether from underground or surface, a particular study is often required since they often contain very low solubility salts. These salts will impede concentration as they will immediately precipitate and disturb process operation.

Combined power and desalination plants
Thermal desalination is even more efficient when combined with a power plant. Considering the low overall efficiency of power generation whatever the process used, it

will reject large quantities of low temperature heat to the environment. Since desalination processes work at low temperatures they can be efficiently supplied with heat recovered from power plant rejects. These particular arrangements provide the lowest water costs.

How much water comes from desalination?

According to the International Desalination Association the total worldwide installed desalination capacity represents 50 million m3/day, of which 46% is obtained by thermal distillation.

Roughly 70% of desalination is devoted to human consumption. Considering an average water daily consumption of 150 litres per capita, it means that some 230 million people rely on this process for their daily water usage.

For how long has seawater been desalinated?

The sun has done it forever ... by evaporation to provide rain. Steam powered ships were first equipped with evaporators for the production of boilers make-up water (1900). Desalination units were first used on board ships and were then widely developed with the growth of OPEC countries (1970). The capacity of the plants has grown drastically over that perod, from a few hundreds cubic meters per day in the 1960's to hundreds of thousands cubic meters per day for the largest desalination plants nowadays.

What are the main desalination processes?

The market is split into two major families: reverse osmosis and distillation.

Osmosis is a natural phenomenon that occurs when two solutions with different salt concentrations are separated by a semi-permeable membrane: fresh water migrates through the membrane from the lower concentration side to the higher concentration one. When putting pressure on the high concentration side, this natural flow will decrease. It will stop at a pressure so called the osmotic pressure. If the pressure increases beyond this point then the flow turns opposite: from higher concentration to lower. This is reverse osmosis.

This phenomenon is used for desalination. After a thorough pre-treatment aiming at full destruction of all biological life and material, and also at controlling scaling within the system, water is passed through osmotic membranes, which will let fresh water through and retain salt.

Distillation or thermal desalination reproduces the natural cycle of rain within an evaporator. There are two main types of seawater distillation processes: Multi Stage Flash (MSF) and Multiple Effect Distillation (MED). The latter has two alternate configurations: MED with thermal vapour compression (MED-TVC) and MED with mechanical vapour compression (MED-MVC).

In a MSF unit seawater is significantly heated and pressurised. Then it is introduced into different cells where pressure and temperature are lower and lower. In each cell a phenomenon occurs that can be compared to what would happen when opening a pressure cooker filled up with hot water under pressure: it would violently boil out (it is not advisable to try it!), it would flash. Vapour released by this boiling in each cell is condensed into fresh water.

In each cell of a MED unit seawater flows down by gravity in a thin film around horizontal tubes heated by an internal steam flow. Seawater partly evaporates and the vapour raised condenses inside the horizontal tubes of the next cell, thus turning to fresh water.

This principle is repeated in multiple cells: the vapour raised in one cell heats up the tubes of the next one.

How much energy is required to retrieve the salt from the seawater?
In theory, calculation shows that 1 kWh is enough to produce one ton of fresh water from seawater. However this assumes a perfect thermodynamic and mechanical system which is not possible to build. In practical terms a desalination system will require 7 to 18 kWh/m3 depending on the corresponding investment.

Desalination systems vapour consumption is usually measured by giving how many kilos of fresh water are produced from one single kilo of steam entering the system. This number, the so-called Gain Output Ratio (GOR), will vary from 6 to 7 for classical plants up to 16 and more for plants equipped with the latest technology.
This figure however does not show properly how steam quality will impact on plant design: the higher the steam supply pressure the more velocity it will provide by expansion, the more suction it will generate and the bigger recovery it will enable thus enhancing overall efficiency. This is why the higher the steam pressure the lower the investment cost for a given GOR. A GOR 8 unit fed with 3 bar steam will cost some 20% more than the same GOR with 20 bar steam.
In addition to steam consumption one has to consider electrical power for pumps. The MSF process requires a large flow of seawater or brine to be circulated in condensers. This results in a specific electrical consumption of 3 to 4 kWh/m3 for MSF plants. This is to be compared to specific consumption of MED plants where no such circulation is required: 1,5 kWh/m3. This is the particular point for which MED now supersedes MSF. By going for MED an Independent Power and Water Company will save some 3 kWh per cubic meter produced: this additional power will be delivered to the network and will generate additional income. This will result in reduced cost of power and water produced by the plant when compared to MSF.

Are desalination plants vulnerable to oil spills?
Oil in seawater can foul the piping, reduce exchange surfaces performance and even pollute fresh water if part of it distils with seawater. For a thermal plant this damage can be corrected by circulation of adequate dispersing agents within the units: after a while normal cleanliness will be restored. Reverse osmosis membranes are not so tolerant and must be kept away from oil pollution.

In the event of oil spill it is recommended to protect the sea water inlet system - with floating dams for example - and to reduce the load in accordance with the filtration capacity of such dams.

What is water-steam equilibrium?
Under atmospheric pressure (1000 hPa or 1 bar), pure water boils at 100°C and changes into steam. On top of the Mont-Blanc (Alt. 4807 m) where atmospheric pressure is 530 hPa it will boil at 83°C only. On the other hand in a sealed pressure cooker water must be heated to 120°C to start boiling, at that time internal pressure will be around 2000 hPa. For each pressure there is one boiling water temperature: when water is at the temperature corresponding to the pressure there is an equilibrium between water and steam.
An evaporator consists of several cells each working at different temperatures. Each of them is in an equilibrium state between steam and water. The lower the temperature, the

lower the pressure. The coldest cells have a temperature in the range of 45°C and therefore a pressure of 100 hPa (which means a vacuum of -0,9 bar).

Solar desalination

It is the main process for water production in the world, due to ocean evaporation. There are simple ways to reproduce this phenomenon such as for example having a small salted pond under a plastic cover heated up by the sun. Condensation droplets can be recovered from the cover. However this method is not very productive.

Distillation requires a heat source and a cold source. Heat may come from oil, gas, sun or nuclear. Each time distillation can adapt to the proposed energy source.

Today the economic advantage of solar desalination has not yet been proven. The main problem of solar energy is its high investment cost and uneven sunlight distribution. The lowest cost for water from the sea is still achieved by fossil fuel power plant combined with thermal desalination plants.

Has seawater quality any impact on desalinated water quality?

Distillation processes are not sensitive to seawater quality. A 0.5mm filtration, chlorination and a suitable anti-scale and anti-foam treatment will be sufficient to guarantee a steady water quality versus time, particularly with the low temperature MED process. Bacteria and pathogenic organisms are generally destroyed by these processes. Distilling pollutants are the only ones to create a problem when mixing with condensed vapour, if a seawater screening solution is not set up in due time. (see pollution by oil spills)

Membrane processes are more sensitive to seawater quality. Depending on seasonal conditions water quality may be affected by the weather or by biological activity. In such case the installed pre-treatment system may well no longer be fitted for such conditions. Bio-fouling which is the clogging of membranes by bacteria is a permanent threat for membranes. It generally results in a loss of production together with an increase of the produced water salinity. In such a case fresh water is contaminated with chloride and it will corrode the water distribution network: water is rusty at the consumer's tap. To enhance the reliability of such pre-treatment, the reverse osmosis systems involve more and more frequently additional ultra or nano filtration membranes, although this results in a price increase.