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"RECENT TRENDS IN DESALINATION OF SEA WATER"

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ABSTRACT

Desalination, desalinization, desalinisation or desalting refers to any of several processes that remove some amount of salt and other minerals from saline water. More generally, desalination may also refer to the removal of salts and minerals, as in soil desalination. Salt water isdesalinated to produce fresh water suitable for human consumption or irrigation. One potential byproduct ofdesalination is salt. Desalination is used on many seagoing ships and submarines. Most of the modern interest in desalination is focused on developing cost-effective ways of providingfresh water for human use. Along with recycled wastewater, this is one of the few rainfall-independent water sources. Sea water is a very common substance, covering more than 70 % of the Earthsurface.

OBJECTIVE

Essentially focused on the process of reverse osmosis, Veolia Environnement's research aims to optimize the operation of desalination plants utilizing membrane processes.

The research is focused on two main aspects:

■ Pretreatment of the seawater to limit membrane clogging further down in the treatment process;

■ Reducing the energy expenditure to cut the cost of desalination and improve the environmental outcomes.

1. INTRODUCTION

It is reported that 96.5% of the earth's water is located in seas and oceans, 1.7% in the ice caps, 0.8% is considered to be fresh water with the rest being brackish water. Since water shortage has been a problem for many communities and humans have been searching for the solution for a long time, desalination, turning salty water into fresh water, is not necessarily a new concept. Today the shortage of drinking water is a serious world-wide concern due to population growth and the increased demand for drinking water that exceeds readily available water resources. Over 1 billion people are without clean drinking water and approximately 2.3 billion people (41% of the world population) are living in water scarce regions (Greenlee et al, 2009). As a result, people have started to search for solutions with water reuse and seawater desalination as the keys for the sustainable growth of human activities. Water reuse is basically for the production of water for uses such as irrigation, power plant cooling water, industrial process water and ground water recharge. It has also been accepted as a method for the MEMBRANE PROCESSES - Vol. II - *Recent Advances in Membrane Science and Technology in Seawater Desalination – withTechnology Development in the Middle East and Singapore* - Takeshi Matsuura and Dipak Rana, Mohamed Rasool Qtaishat,Gurdev Singh© *Ecyclopedia of Desalination and Water Resources* (DESWARE)production of drinking water in Singapore (Newater). Alternatively, desalination hasbecome a primary source of the drinking water production. Current desalination technology consists of two methods. One is a thermal desalination method that has been developed over the past 60 years, while the other is membrane processes that have been developed over the past 40 years.Desalination is a general term for methods to remove salt from salty water to producefresh water. Notably, the definition of fresh water depends on the country. For example,the US Environmental Protection Agency (EPA) has non-enforceable standards of 250 mg/L chloride and 500 mg/L total dissolved salts (TDS) for fresh water (EPA, 2002).The World Health Organization (WHO) and the Gulf Drinking Water standardsrecommended a drinking water standard of 1000 mg/L TDS (Fritzmann et al, 2007). Incomparison to the government standards, most desalination facilities are designed to achieve a TDS of 500 mg/L or less (Greenlee et al, 2009).When the desalinated water is used for other purposes, e.g. crop irrigation, the TDSconcentration may be higher. The feed water salinity for desalination facilities ranges from 1000 mg/L to 60,000 mg/L. Most of the seawater resources contain 30,000 to45,000 mg/L TDS, while the brackish water within a range of 1,000 to 10,000 mg/L is treated by Reverse Osmosis (RO) (Greenlee et al, 2009). As mentioned above,desalination processes fall into the following two categories, i.e. thermal processes andmembrane processes.The thermal process has been used for many years since the prehistoric era but the operation of the large scale distillation plant for drinking water production began in1950s (Greenlee et al, 2009). In the beginning a process called multi-effect distillation (MED) was used but later a process called multi-stage flush (MSF) distillation was developed. The Middle East as a whole holds about 50% of the world desalination capacity and primarily uses MSF technology. However, facilities based on the membrane process have rapidly been installed since the 1960s and now surpass the thermal process in new plant installations. Outside of the Middle East, new RO plant installations have been continuing steadily. In 2001, 51% of the new installations were based on RO process, while in 2003, RO process accounted for 75% of the new production capacity.RO, nanofiltration (NF) and electro-dialysis (ED) are the typical membrane processes available for desalination. RO and NF are called pressure-driven membrane processes since the transmembrane pressure difference is the driving force for the mass transport,while for ED the electrical potential difference is the driving force for the mass (ions) transport. ED is an older membrane desalination process than RO and NF. NF is a relatively new membrane separation process developed in 1980s. While NF can not desalinate seawater to produce drinking water in one step, it can be used successfully to treat the mildly brackish water (Greenlee et al, 2009). It is hence desirable to use NF in combination with RO for seawater desalination. The most important feature of NF is its capacity to remove divalent ions such as calcium and magnesium that contribute to hardness of water. However, RO membrane can remove monovalent ions such as sodium and chloride and hence has become the mainstream of membrane desalination technology. Salt rejection as high as 99.7 and 99.8%, can be achieved by RO MEMBRANE PROCESSES - Vol. II - *Recent Advances in Membrane Science and Technology in Seawater Desalination – withTechnology Development in the Middle East and Singapore* - Takeshi Matsuura and Dipak Rana, Mohamed Rasool Qtaishat,Gurdev Singh© *Ecyclopedia of Desalination and Water Resources* (DESWARE) (Hydranautics, 2007; Greenlee et al, 2009; Reverberi and Gorenflo, 2007). RO membrane technology is also applicable for both seawater and brackish water desalination.As mentioned earlier, the first countries that used the desalination process on a large scale for drinking water production were in the Middle East. Seawater desalination plants began to be developed in the 1950s, and the first industrial desalination plant was opened in Kuwait in 1960s. The first successful RO plant used brackish water as feed in the late 1960s (Amjad, 1993). In the following decades, membrane permeability was much improved and RO membranes were then applied for seawater desalination (Vander Bruggen and Vandecasteele, 2002). From the early 1960s to the end of the 1990s, the membrane productivity (flux) and salt rejection have much improved as shown in Figure 1. Table 1 also shows similar advancement made for the Dow RO membranes.Figure 1. Progress in membrane performance during the past forty years.Reverse osmosis conditions: feed NaCl concentration, 1500-3000 ppm; operating pressure, 0.5-3.0 MPa; temperature, 25◦C; pH, 6.5. I, II, III and IV are fully aromatic polyamide TFC membranes (adapted from Kurihara and Fusaoka, 1999).

Year	Production capacity (gpd)	Salt rejection (%)
Brackish water		
1990	8,000	98
1998	10,000	99.2
2007	11,000	99.8
Seawater		
1990	4,000	99.4
1998	5,500	99.5
2007	7,500-8,000	99.8

Advances in Dow RO membrane

From 1996 to 2007 the rejection of typical seawater desalination membrane increased from 99.6 to 99.8% and the flux increases from 43 to 69 L/m2 day bar (Mickols et al, 2005). As of 2009, over 15,000 desalination plants were in operation world-wide, and approximately 50% of those are RO plants. A new recent trend is to construct large seawater desalination plants with a production capacity of 100,000 m3/day or more (Greenlee et al, 2009).Saudi Arabia is currently the world leader in desalination with approximately 26% of global production capacity, followed by the United States (17%). In Saudi Arabia most of the desalination plants are based on the thermal process (newly constructed plants are different) and the source water is seawater. In contrast, in the United States 69% of the desalination plants are based on RO and only 7% is seawater desalination plants. While only 20% of the total number of the desalination plants world-wide use thermal process, 50% of the total production capacity is based on the thermal processes. Israel has opened the world's largest seawater RO desalination plant with a production capacity of 330,000 m3/day, or 100 million m3/year. The United Arab Emirates (UAE) opened its Fujairah desalination plant in 2005 with a combined MSF and RO production capacity of 454,000 m3/day.

Membrane Processes for Desalination: Overview

Reverse Osmosis History

As mentioned, RO is currently dominant in membrane separation processes for desalination. Interestingly, the early development of RO membrane for seawater desalination began with the following fundamental equation called the Gibbs Adsorption Isotherm (Sourirajan, 1970).

NaCl concentration in molality (mol kg-1) Pure water layer thickness (nm)

0 0.56

0.747 0.38

1.603 0.34

2.435 0.24

Asymmetric Structure of the Membrane

Most of membranes that are used in industrial separation processes have an asymmetric structure and so are called asymmetric membranes. Figure 3 shows schematically a typical cross-sectional view of an asymmetric membrane (Matsuura, 1994). As shown in the figure, an asymmetric membrane consists of two layers; i.e. one very thin dense layer at the top of the membrane and a porous sublayer underneath the top dense layer (also called top skin layer). While the top dense layer governs the permeation properties of the membrane, the porous sub-layer only provides the membrane with mechanical strength. When the material of the top skin layer and the porous sublayer are the same, the membrane is called integrally skinned asymmetric membrane. This type of membrane is made by the dry-wet phase inversion technique. When the polymer for the top skin layer is different from the polymer for the porous sub-layer, the membrane is called composite membrane. The advantage of the composite membrane over the integrally skinned asymmetric membrane is that the material for the top skin layer and for the porous sublayer can be chosen separately to optimize the overall performance. This type of membrane is made by coating a thin layer on top of the surface of a porous substrate. Various coating techniques are available but the interfacial in-situ polymerization method has been proven to be commercially most successful.Figure 3. Asymmetric structure of the membrane.

Phase Inversion Technique-Preparation of Integrally Skinned Asymmetric Membranes

Phase inversion is a process in which a polymer is transformed from a liquid to a solid state. There are a number of methods to achieve phase inversion. Among others, the dry-wet phase inversion technique and the temperature induced phase separation (TIPS) are most commonly used in the industrial membrane manufacturing. The dry-wet phase inversion technique was applied by Loeb and Sourirajan in their development of the first CA membrane for seawater desalination (Loeb and Sourirajan, 1961, 1963, 1964). Therefore, this method is often called the Loeb-Sourirajan method.

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