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Reverse osmosis applications: Prospect and challenges

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HIGHLIGHTS

- Applications of reverse osmosis (RO) membrane are reviewed.
- Advantages and limitations of the applications are discussed.
- Challenges and perspective are pointed out.

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ABSTRACT

Reverse osmosis (RO) is a pressure driven membrane process which has been widely applied and recognized as the leading technology of desalination process. Improvement in RO technology including advanced membrane material, module and process design, and energy recovery has led to cost reduction which in turn gaining interest to its commercial applications. RO is now being used in various applications including selective separation, purification, and concentration processes. In food industry, RO is applied for concentration of fruits and vegetable juices, pre-concentration of milk and whey, and dealcoholization of alcoholic beverage. For area which has large source of natural humic water or peat water, RO can be applied to produce clean water for community water supply. RO was also investigated for organic mixture separation and CO_2 regeneration from essential oil extraction using supercritical fluid. The application of RO as a final step of wastewater treatment for water reuse and valuable component recovery seems to be promising in wastewater reclamation. In this paper, the applications of RO, its advantages, and limitations are discussed. In addition, challenges and perspective of RO membranes are pointed out.

1. Introduction

Rapid growth in membrane technology development is primarily based on consciousness on the potential of this technology. Membrane processes have many advantages allowing various applications in almost every industrial sector. The major breakthrough in the development of membrane technology was recorded in the late 1950s, when Sartorius Werke GmbH, Germany manufactured industrial scale membranes and microfiltration membranes, for the first time. However, industrial application was just started ten years later, when Loeb and Sourirajan discovered very thin membrane for reverse osmosis (RO), the asymmetric membranes for seawater desalination.

RO system separates dissolved solutes (includes single charged ions, such as Na^+, Cl^-) from water via a semipermeable membrane that passes water in preference to the solute. RO can be described as a diffusion-controlled process in which the mass transfer of permeant through RO membranes is controlled by diffusion known as solution–diffusion mechanism. In the solution–diffusion mechanism, permeants dissolve in membrane material and then diffuse through the membrane [1]. RO membrane is very hydrophilic; therefore water will be able to readily diffuse into and out of the membrane polymer structure.

RO systems can be found today in a wide range of facilities: kitchens, hospitals, refineries, power plants, pulp and paper industries, crude palm oil milling, semiconductor manufacturing facilities, manned spacecraft, sailboats, etc. RO is used as a concentration step particularly in food industry, galvanic industry, and dairy industry [2]. Improvement in RO technology such as membrane material, module and process design, pre-treatment, and energy recovery has led to cost reduction that drives the interest in its commercial applications [3]. RO is now being used for various applications both for purification and concentration and becomes a leading technology for brackish and seawater desalination. In this paper, the applications of RO are pointed out including water treatment, wastewater treatment, food and beverage processing, organic mixture separation, and other applications. In the last part, challenges and perspectives in RO process are discussed.

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2. Water treatment

2.1. Desalination

Application of RO in desalination of various water sources to produce drinking water, process water, and demineralized water is presented in Table 1. The production of potable water from seawater and brackish water sources is presently the largest application of RO. Since the end of the 1970s, energy consumption of seawater reverse osmosis (SWRO) has been reduced significantly due to process improvement [4]. Nowadays, RO membranes in desalination plants are represented by 60% of the total number of worldwide plants [5]. Typical example of the largest SWRO desalination plant was commissioned in 2013 in Sorek, Israel, with production capacity of 624,000 m^3/day potable water as reported by IDE technologies [6]. The system incorporates a 16 inch RO element which is arranged in vertical and uses 100,000 m^2 of land area. The energy consumption is minimized by IDE's Proprietary 3-Center Design (pumping center, membrane center and energy recovery system) and double line intake. The plant is expected to produce water with maximum energy consumption of 4 kWh/m^3 and <0.3 mg/L of boron. Every element of the plants was customized to minimize investment costs and environmental impacts. The lower investment cost is achieved by several strategies, such as decreasing the number of pressure vessels, piping headers, control and instrumentation equipment, and reduction of footprint.

In producing high quality water, such as high pressure boiler feed water or ultrapure water, RO system requires more deionization process as the polishing step to achieve complete removal of ions, silica, and boron. Conventional ion-exchange and electrodeionization (EDI) processes are generally used as the polishing step. Nowadays, EDI is more preferable over conventional ion-exchange process due to its advantages which include technological and economical point of view [7].

Desalination of geothermal water using RO for water supply is also reported in literatures [8–11]. Geothermal water is considered as a valuable water source. For this purpose, RO can be applied to treat the geothermal water for high quality water production. However, according to those reports, more treatment of RO permeate is needed to achieve more removal of boron since the geothermal water contains a relatively high concentration of boron.

Surface water may be contaminated with pollutants such as pesticides from the irrigation system. In order to be used as the source of drinking water, those pollutants contained in surface water should be removed. RO not only removes dissolved solids in surface water but also removes pollutants to meet the standard of drinking water. Low pressure RO (LPRO) membranes have been studied by several research on this purpose [12–15]. The studies indicated the efficacy of LPRO on removing the pesticides from water. For example, up to 99.8% removal efficiency can be achieved by using commercial RO membrane [13]. Meanwhile, in a recirculation aquaculture system (RAS), the presence of ammonia should be controlled due to its toxicity to fish. RO membrane could achieve a complete removal of ammonia and about 50.2 $L \cdot m^{-2} \cdot h^{-1}$ of flux from 9.60 mg/L ammonia containing solution at 2.45 MPa of pressure which is desirable for RAS [16].

2.2. Peat water treatment

Peat water or natural brown water is an acidic brown water commonly found in peat land area which has high content of natural organic matter (NOM) [23]. Meanwhile, the peat water contains a small concentration of total dissolved solid (TDS). Due to its availability, an appropriate peat water treatment could be a potential source of water supply. However, peat water usage as clean water source is inhibited by its high dissolved organic matter, especially humic acids and humic substances. Humic substance is the major fraction of NOM that endowed with aromatic and aliphatic characteristic which contributes to surface charge and reactivity mainly by the phenolic and carboxyclic groups [24]. The reactions between the water clarifying antiseptics and dissolved humic substance or phenolic molecules can produce some carcinogenic substances, which are known as disinfectant by-products (DBPs) that have negative effects on the human health in long-term period [25]. Trihalomethanes (THMs) are formed due to chlorination of water containing organic compounds, principally humic and fulvic acids. The DBP formation could be reduced by minimizing the number of THM precursors in water prior to chlorination process.

Removal of humic acid from natural water has been already studied by using membrane filtration. Ødegaard and Koottatep [26] reported an investigation of humic substance removal from natural water using several RO membranes in order to remove color and haloform precursors. Results of the study showed that the removal of humic substances amounted to 80–100% in terms of color removal for selected membrane. In similar study, Agui et al. [27] investigated separation characteristics of humic substances on RO membranes. They found that the rejection of humic substances was around 75% and could be improved up to 90% by adjusting pH level. Flux decline of RO membranes due to humic acid fouling is a major drawback in the treatment of humic containing

Table 1
Typical example of RO application in desalination process.

Cost ($/$m^3$)	Seawater RO (SWRO)	Brackish water RO (BWRO)	Low-pressure RO (LPRO)	RO–EDI	RO-DM
Feed water	Seawater	Brackish water[a]	Surface water[b]	Well water[c]	Seawater
Target quality	Drinking water	Drinking water	Drinking water	Boiler feed water	Boiler feed water
Fixed charge	0.311[d]	0.180[e]	0.046[f]	0.118[g]	–
Energy	0.134[h]	0.056	0.032	0.102	–
Chemical	0.021	0.022	0.015[i]	0.005	–
Membrane replacement	0.028	0.020	0.179	0.179	–
Filters	0.005	–	–	–	–
Others	0.017	0.066[j]	0.018	0.012	–
Water cost	0.525	0.344	0.129	0.53	1.56
Ref.	[17,18]	[19]	[20]	[21]	[22]

DM — demineralizer; EDI — electrodeionization
[a] Total dissolved solid (TDS): 1600 mg/L.
[b] TDS: 500 mg/L.
[c] TDS: 30 mg/L.
[d] Capacity 330,000 m^3/d.
[e] Capacity 45,455 m^3/d.
[f] Capacity 700,000 m^3/d.
[g] Capacity 2880 m^3/d.
[h] Electrical energy < 3.9 kWh/m^3 (using energy recovery device).
[i] Membrane module: 16″ × 60″.
[j] Operating labor and maintenance.