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Hollow fiber type PRO module and its characteristics

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HIGHLIGHTS

- CTA hollow fiber type PRO modules have been developed.
- The characteristics of PRO module are shown.
- The PRO module performance was investigated and analyzed.
- The simple solution–diffusion model was applicable to the PRO module.

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ABSTRACT

Seawater desalination reverse osmosis, SWRO, is expected to be a promising process to solve the problem of water scarcity. However, higher cost-effectiveness and less energy consumption are required for SWRO plants. Forward osmosis, FO processes using the comparable permselective membranes same as RO have gained renewed interest in recent years, and they might become a solution for the most challenging problem of water and energy scarcity. This FO process is expected to have capability of applying energy-saving seawater desalination and power generation by Pressure Retarded Osmosis, PRO. Especially, the PRO technology has drawn attention as a process that could recover energy from the salinity difference between the concentrated brine from SWRO plant and pure water and reduce energy consumption of SWRO plant.

A Cellulose triacetate (CTA) hollow fiber type PRO module has been developed and PRO probabilities have been investigated by operating at a prototype PRO plant. The PRO module has characteristics similar to RO module such as high selectivity, chlorine resistance and sufficient pressure resistance. A CTA hollow fiber type PRO membrane module can be expected to have superior fouling resistance compared to a polyamide PRO membrane module from the viewpoint of chemical property such as chlorine resistance.

The performance of the PRO module was investigated and analyzed by a hollow fiber type FO module analytical model. The investigation has found that this analytical model based on solution–diffusion model was applicable to the CTA hollow fiber type PRO module.

The PRO module configuration and operating condition are expected to be optimized more effectively by this analytical model in the future.

1. Introduction

In the water treatment technology for desalination process, reverse osmosis (RO) process with long-term reliability has been the mainstream especially for seawater desalination. [1–3] Seawater desalination reverse osmosis, SWRO, is expected to be a promising process to solve the problem of water scarcity because the SWRO has capability of reducing the cost and energy consumption more than the other types of desalination process. However, higher cost-effectiveness and less energy consumption are required for SWRO plants.

Forward osmosis, FO processes using the comparable permselective membranes same as RO have gained renewed interest in recent years, and they might become a potential solution for the most challenging problem of water and energy scarcity. This FO process is expected to realize energy saving seawater desalination and power generation by Pressure Retarded Osmosis, PRO. Especially, the PRO technology has drawn attention as a process that can recover energy from the salinity difference between the concentrated brine from SWRO plant and pure water and reduce energy consumption of SWRO plant. [4].

By utilizing the PRO technology, various types of PRO membranes were developed. In the nature of flow configuration, a hollow fiber type PRO membrane has several advantages over a flat sheet membrane. [5].

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Table 1
Dimension and characteristics of CTA hollow fiber membranes for PRO and RO.

Application	Dimension (diameter)	RO performance	Pressure resistance	Chlorine resistance
	Inner Outer (mm) (mm)	Salt rejection (%)	Maximum pressure (MPa)	Maximum residual chlorine* (mg/L)
PRO	0.085–0.135 0.175–0.240	>99.0*2	2.9	1
RO (for brackish water)	0.08 0.16	>99.0*2	2.9	1
RO (for seawater desalination)	0.07 0.16	>99.8*3	6.9	1

*1: Residual chlorine is limited by the quality and the temperature of feed water.
*2: Feed pressure 2.9 MPa, Feed conc. NaCl 0.15 g/L, Temperature 25 deg.C.
*3: Feed pressure 5.4 MPa, Feed conc. NaCl 3.5 g/L, Temperature 25 deg.C.

The CTA hollow fiber type PRO modules were developed by Toyobo Co., Ltd. and PRO probabilities were investigated by operating at a prototype PRO plant using practical size hollow fiber type PRO modules. [4] A long-term test operation was carried out over one year and its results of operation by concentrated brine from SWRO plant and treated sewage as pure water from regional waste water treatment facility were reported. The results also show the plant cost estimation. Also the financial impacts of the energy saving of SWRO operation were surveyed. [6].

In this paper, the hollow fiber type PRO module configuration and its characteristics are described. In addition, the PRO module performance was analyzed by using a simple analytical model based on a solution–diffusion model. [7].

2. Material and methods

A hollow fiber membrane was made from Cellulose Triacetate (CTA). The hollow fiber membranes and PRO module were produced by the method similar to that of producing hollow fiber type reverse osmosis membranes and modules.[7)]

3. Characteristics of CTA hollow fiber type PRO module

3.1. PRO membranes

Toyobo's hollow fiber type PRO membrane is made from CTA which is the raw material of the Toyobo's RO membrane. The CTA hollow fiber type membranes show superior chlorine resistance compared with polyamide membranes. Toyobo's hollow fiber type RO membranes have been used widely in the Middle East seawater desalination plants because of its excellent performance and reliability of operation of large-scale plants [8].

Sterilization of biologically active seawater by chlorine is considered a very effective way to prevent biological fouling in PRO process. The material properties of CTA are expected to maintain CTA hollow fiber type PRO easily by chlorine injection, since hollow fiber type RO membrane has demonstrated stable production and easy maintenance by eliminating biological fouling in seawater desalination.

PRO membrane requires high selectivity and pressure resistance as RO membrane. The CTA hollow fiber type PRO membrane has sufficiently high selectivity for salt contents and pressure resistance since it is similar in property to the hollow fiber type RO membrane. Therefore, the CTA hollow fiber type RO membrane is one of the suitable membranes for PRO application.

The dimension and characteristics of CTA hollow fiber membrane for PRO and RO are shown in Table 1.

3.2. Structure advantage

The CTA hollow fiber type PRO module shows excellent pressure resistance and retention for PRO application as shown before. This outstanding pressure resistance is achieved by the hollow fiber design and selection of suitable dimensions. The bundles of hollow fiber membranes are wound into an element with layers by a cross arrangement technique as shown in Fig. 1. A hollow fiber membrane manufactured by a multi-filament spinning process is assembled into an element with multiple layers of crossly wound hollow fibers. A bundle of more than several thousands of hollow fibers is arranged in a cross-wound configuration without any type of support materials between the hollow fiber layers and this unique fabrication leaves regular spaces between the hollow fibers. This cross-winding arrangement can achieve a minimum pressure loss and allow a uniform flow resulting in minimizing the concentration polarization in the shell side of the module. In addition, this structure reduces the blockage by fouling matters in the PRO module. These structural features enable the prevention of rapid increase in differential pressure in PRO process and allow an easy operation and maintenance of PRO plants.

3.3. Large surface area

Continuous flux (permeability or flow per membrane surface area) across membranes can cause performance difficulties in a water treatment process due to deposition of fouling matters on the membrane surface. Generally, the higher the flux is, the sooner the membrane surface will become coated with fouling matters. Spiral wound membrane elements offer relatively small membrane surface area, thus the maximum flow must be more restricted to prevent fouling.

Millions of hollow fibers are wound into an element configuration by the cross winding technology. Compared to a spiral wound membrane element, a hollow fiber type membrane element has approximately 10 times larger surface area in the case of an RO module. Much larger surface area of hollow fiber type membrane element is subjected to much less surface fouling (as shown in Fig. 2). This property is expected to be the same for PRO module.

4. Module configuration

Toyobo's hollow fiber type module in practical size is composed of several hundred thousands of fine hollow fibers which are crossly

Fig. 1. Cross winding arrangement of the fiber.