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Energy recovery by PRO in sea water desalination plant

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HIGHLIGHTS

- Our PRO system was used concentrated brine and treated wastewater.
- Hollow fiber membrane module examined in our PRO prototype plant.
- UF membrane treatment and the chemical dosing made the operation available.
- Energy reduction for sea water reverse osmosis is possible by our PRO system.

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ABSTRACT

Sea water reverse osmosis (SWRO) would face some problems like energy saving and management of concentrated brine. To solve these problems at the same time, the energy recovery by Pressure Retarded Osmosis (PRO) was proposed in the Mega-ton Water System project. Prototype plant test was conducted using concentrated brine from SWRO plant and fresh water from regional waste water treatment facility. Hollow-fiber membrane module were examined in the prototype plant and the test operation was carried out for more than one year. We have reached the maximum membrane power density, 13.5 W/m^2, using 10-in. module. Followings were still existing obstacles for further effective PRO. It was also challenging how to get clean fresh water from waste or river water without additional cost. Innovative new technologies were also required to address these concerns. We have also estimated plant cost and surveyed financial impacts on the energy saving of SWRO operation, based on the situation of currently operated SWRO plants worldwide, especially about the Mega-ton scale ones. Those studies indicated that potential market of PRO was 1–2 GW, and 10% energy saving was possible on the Megaton scale SWRO plants. Those results indicate that the commercialization plant would be available very near future.

1. Introduction

Sea water reverse osmosis (SWRO) is one of the promising processes to solve the water shortage problem, because it claims lower cost and less energy. However, because the electricity cost accounts for about half of the product water cost, the reduction of electricity cost has been important. On the other hand, the concentrated brine emitted from SWRO plant is causing environmental problems.

In this article, Pressure Retarded Osmosis (PRO) is focused on as a process that could recover energy from the osmotic pressure difference between the concentrated brine and fresh water and, simultaneously, as a candidate to solve the environmental problem caused by the SWRO brine released back into the sea.

PRO was proposed by Loeb et al. some 40 years ago [1–4]. They conducted experiments of the PRO process at the Dead Sea in Israel [3] and the Great Salt Lake in the USA [4], where both concentrated saline and fresh water were available. Their results were not so good because these experiments employed semi-permeable membranes that were not for forward osmosis, but for SWRO. Dr. Takeo Honda of National Institute of Advanced Industrial Science and Technology (AIST) showed that net output power from PRO, generated power minus consumed power, would be positive if membrane module is properly modified [5]. Recently, some research teams, especially from Europe like WETSUS in the Netherlands [6], are studying the process to recover salinity gradient power. In Japan at 2011, FIRST (Funding Program for World-Leading Innovative R&D on Science and Technology) program

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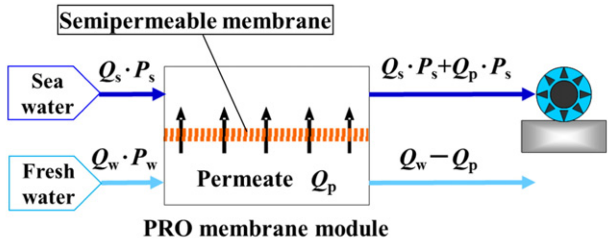

Fig. 1. Basic principle of PRO.

"Mega-ton Water System", supervised by Dr. Masaru KURIHARA (Toray Fellow), Senior Scientific Director, started and our PRO included the project. The project aims to develop much larger SWRO with the selling points, including "Energy Saving", "Low Cost" and "Low Environmental Load". In the project, PRO has been positioned for energy saving. We have reached the maximum membrane power density per surface area, 13.5 W/m^2, using a 10-inch module at our prototype PRO plant in Fukuoka. In this article, feasibilities of PRO plants are discussed based on the data and experiences obtained from our test operations at our prototype PRO plant. Besides, PRO's market scale and impact of its introduction to SWRO system was studied.

2. Theory

2.1. Principle of PRO

PRO is a hydraulic power generation using the osmotic pressure difference between high osmotic pressure liquid such as sea water and low osmotic pressure liquid such as fresh water. Fig. 1 shows the principle of the PRO. PRO membrane module is separated by a semipermeable membrane (that allows only water molecules pass through). The sea water of higher osmotic pressure (P_s) is put into one side at the flow rate (Q_s). The fresh water of lower osmotic pressure (P_w) is put into another side at the flow rate (Q_w). Then the fresh water permeates into the sea water of higher pressure at the flow rate (Q_p) because of the osmotic pressure difference. Thus, the higher osmotic side obtained excess hydraulic power, with which the PRO works [1].

The relation between the water flux (J_w) and the applied pressure is described by Eq. (1).

$$J_w = A(\Delta\Pi - \Delta P) \tag{1}$$

where A is the water permeation coefficient of the membrane, ΔΠ is the osmotic pressure difference between the sea water and fresh water, and ΔP is the hydraulic pressure difference between the sea water and fresh water.

The power density (PD = output energy per membrane surface area) is calculated using Eq. (2).

$$PD = J_w \Delta P = A(\Delta\Pi - \Delta P)\Delta P \tag{2}$$

Eq. (2) is a quadratic function of the ΔP, and the power density becomes maximum when the hydraulic pressure difference is half as much as the osmotic pressure difference.

In PRO system using sea water, the power density becomes maximum when the sea water supply pressure is 1.5 MPa under the assumption that the salt concentration is 3.5% and the osmotic pressure is about 3 MPa. When PRO system uses concentrated brine emitted from SWRO plant, the power density becomes maximum when the concentrated brine supply pressure is 3 MPa assumed the salt concentration is 7%, the osmotic pressure is about 6 MPa.

3. Results and discussion

3.1. Test operation at a prototype plant

A PRO prototype plant was constructed near Fukuoka SWRO plant (Fig. 2). The PRO unit has cellulose triacetate (CTA) hollow fiber membrane modules of 10-in. and 4-orifices. Purchased from TOYOBO Co. Ltd., three kinds of hollow fiber membrane modules were fabricated and installed to the plant, named PRO1, PRO2 and PRO3. Approximate dimension of hollow-fiber membrane was outer diameter (OD) 0.2 mm, inner diameter (ID) 0.1 mm and length 1.3 m.

Brine from the SWRO facility was used as draw solution (DS), and was applied to the shell side of the membrane. Low salinity water, from the regional waste water treatment facility, was used as feed solution (FS) after removing any potential foulants of the membranes, using on-site UF unit and chemical, before introducing into the PRO unit. The prototype PRO plant has shown 13.5 W/m^2 as the maximum membrane power density per surface area using 10-in. PRO3 module.

3.2. Continuous test

At the PRO prototype plant, installed with PRO1, long term test operation was carried out over one year as shown in Fig. 3. The osmotic flow through membrane was found to depend on the temperature, which seasonally varied, as traditional reverse osmosis (RO) membranes. Also found was little decline in osmosis flow rate between the beginning and one year after the test launch, even though continuing the same membrane modules. In this test, treated waste water was pretreated with the on-site UF and the low pressure RO method. The high water quality was obtained by the pretreatment using the low pressure RO membrane. Therefore, there was no fouling inside the membrane and the PRO performance was kept for more than a year. However, the

Fig. 2. Prototype PRO plant [7,8].