Desalination and Water Treatment
www.deswater.com

51 (2013) 766–771
January

1944-3994/1944-3986
doi: 10.1080/19443994.2012.705549

Taylor & Francis
Taylor & Francis Group

Reduction of energy consumption in seawater reverse osmosis desalination pilot plant by using energy recovery devices

Youngmin Kim[a], Man Gon Kang[b], Sangho Lee[c], Sang Gyu Jeon[b], June-Seok Choi[a,*]

[a]*Korea Institute of Construction Technology, Gyeonggi-Do 411-712, Republic of Korea*
Tel. +82 31 910 0759; Fax: +82 31 910 0291; email: jschoi@kict.re.kr
[b]*Hyosung Goodsprings, Mapo-Gu, Seoul 121-804, Republic of Korea*
[c]*Kookmin University, Seongbuk-Ku, Seoul 136-702, Republic of Korea*

Received 29 February 2012; Accepted 20 June 2012

ABSTRACT

Of paramount importance, seawater desalination plants using reverse osmosis (RO) is reducing the use of energy, which is mostly required for high pressure pumps. Accordingly, energy recovery devices (ERDs) are widely used for reusing hydraulic energy in RO concentrate stream. Nevertheless, few works have been done to investigate the operation characteristics of various EDR systems in actual desalination plants. In this context, we focused on the comparison of ERDs in a pilot plant with the capacity of 1,000 m^3/day. One centrifugal ERD (turbocharger) and two different types of isobaric ERDs (pressure exchanger [PX] and pressure exchanger for energy recovery [PEER]) were installed and tested under various conditions. Operation data in the pilot plant were analyzed to estimate specific energy consumption and energy transfer efficiency. The specific energy consumption analysis results showed that the isobaric ERDs have higher efficiency than the centrifugal ERD as also expected in theoretical estimation. The energy transfer efficiencies for PX and PEER were determined to be similar in short-term tests.

Keywords: Seawater desalination; Reverse osmosis; Energy recovery; Specific energy consumption

1. Introduction

Seawater desalination has drawn attention as sustainable alternative water resources in contrast with other available water sources depleting gradually. According to Global Water Intelligence (GWI), seawater reverse osmosis (SWRO) process occupied 61% of world market share owing to its rapid technological advance [1]. Although SWRO process has lower energy consumption than conventional thermal desalination process, the energy requirements still remain the major operational cost component. The energy costs in SWRO plants could represent up to 50% of the final costs of water product, thus making highly efficient energy recovery device (ERD) of vital importance, in which they allow the energy to be recovered [2].

Two classes of ERD, centrifugal and isobaric (or positive displacement) type, are mostly used in market place. The former converts hydraulic energy into centrifugal mechanical energy and then back to hydraulic energy, the latter transfers the

*Corresponding author.

Presented at the International Conference on Desalination for the Environment, Clean Water and Energy, European Desalination Society, 23–26 April 2012, Barcelona, Spain

hydraulic energy directly. At present, large desalination plants use isobaric-chamber devices which has over 95% of energy transfer efficiecy and offer specific energy consumption (SEC) below 2.50 kWh/m^3 [3,4].

In order to localize SWRO technologies, a lot of efforts are required to develop our own in Korea. We installed a pilot plant in order to test applicability of the domestic developed technologies such as pretreatment processes, reverse osmosis (RO) membrane, vessel, and ERD. Three kinds of ERD devices, Turbocharger^{TM}, pressure exchanger (PX) (ERI), and tentatively named PEER (pressure exchanger for energy recovery, Hyosung Goodsprings), were installed in the pilot plant. Economically, the localization of energy recovering technology has an important role to spread domestically developed SWRO technologies and to commercialize the technologies. In order to test energy efficiency of the PEER system, we conducted experimental comparisons of the ERD system performances.

2. Materials and methods

2.1. The SWRO pilot plant

As stated above, this pilot plant was constructed to test the applicability of self-developed technologies. Fig. 1 shows a schematic diagram of the plant. The main components of the plant are dissolved air floatation (DAF), dual media filter (DMF), two series of crossover 16 inches RO systems, and ERDs. In the first RO series, a foreign-made vessel (ROPV) and domestic RO modules (Woong-Jin) were installed. A domestic vessel (FiberTech) and foreign-made RO modules (Toray) were mounted in the other series. This plant has production capacity of 1,000 m^3 of fresh water per day.

The operation data (i.e. flow, pressure, and water quality values) were automatically detected from the sensor equipments and stored in a central server system. We analyzed the operation data and compared the energy transfer efficiency and reduction rates required to permeate production with the ERD systems.

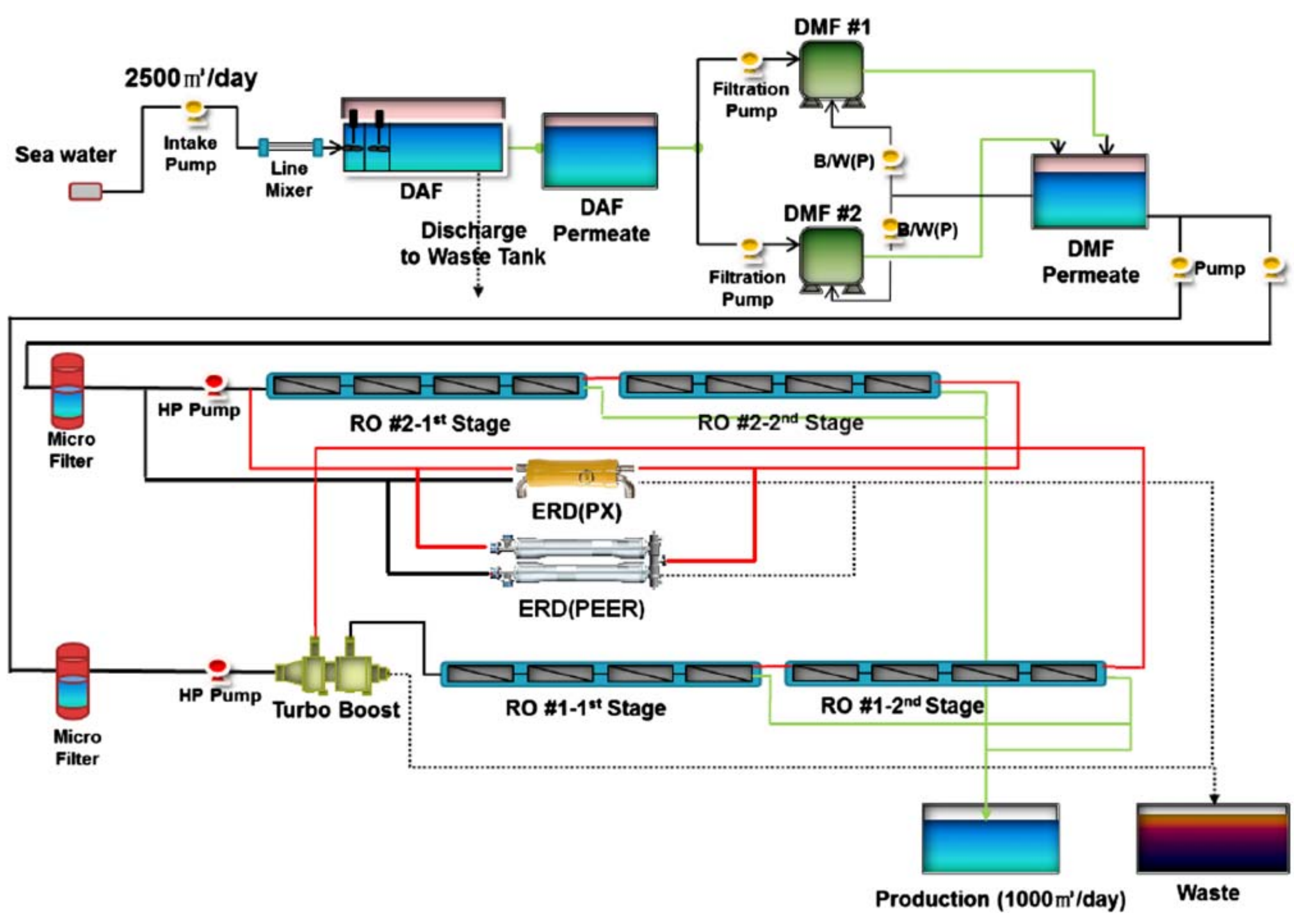

Fig. 1. A schematic diagram of the pilot plant for seawater desalination.

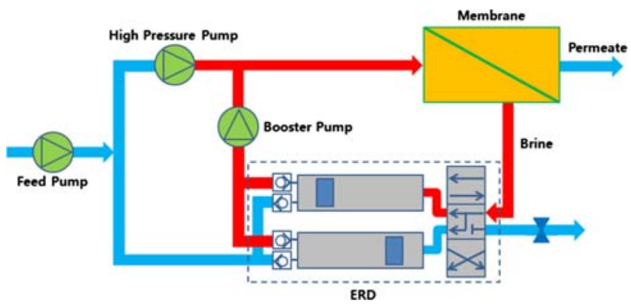

Fig. 2. A conceptual diagram of PEER system.

2.2. The ERDs

Two classes of ERD, centrifugal and isobaric (or positive displacement) type, were installed. Isobaric PX and PEER systems were equipped in the first series of RO process. Turbocharger was equipped as a centrifugal type in the second series. Turbocharger transfers high pressure energy to the RO pump discharge via the pump side impeller. PX and PEER exchange hydraulic pressure in their chamber space.

As a domestic developed device, PEER system was designed to minimize losses of pressure and flow leakage by fabrication. Fig. 2 shows a schematic diagram of the system. It has two reciprocating pistons, without central rods, and two chambers, which can be used to exchange hydraulic pressure. A control valve is used to decide movement directions of the pistons by hydraulic cylinders.

2.3. ERD efficiency

The ERD performance is quantified in terms of energy transfer efficiency and the degree of mixing [5]. The energy transfer efficiency is calculated by using the following equation:

$$\text{Energy transfer efficiency} = \frac{\sum(\text{Pressure} \times \text{Flow})_{\text{out}}}{\sum(\text{Pressure} \times \text{Flow})_{\text{in}}} \times 100\% \quad (1)$$

The energy required to desalinate with SWRO system can be expressed in terms of the SEC. The SEC is defined as the energy needed to produce a cubic meter of permeate of a desired salt concentration [6]. Accordingly, the SEC for the desalination plant is given by:

$$\text{SEC} = \frac{\dot{W}_{\text{pump}}}{\epsilon_{\text{p}} Q_{\text{p}}} \quad (2)$$

where $\dot{W}_{\text{pump}}$ is the rate of pump work, ϵ_{p} is the pump efficiency, and Q_{p} is the permeate flow rate. The Eq. (2) can be expressed by the total water recovery for the RO process, Y_{t}, as:

$$\text{SEC} = \frac{\Delta P}{\epsilon_{\text{p}} Y_{\text{t}}} \quad (3)$$

3. Results and discussion

The ERD efficiencies were estimated from the data analysis using above equations on the pilot plant operation. This analysis was used for evaluating the domestic PEER system.

3.1. Water recovery

We have monitored desalination facilities from November 2010 to date. Fig. 3 compares water recovery rates of the RO processes in February 2012. The first and second RO systems showed 33.3 and 34.4% of average values, respectively, in these periods. These are a little lower than conventional SWRO desalination plants, which have 40–45% of water recovery rate. This is because we faced a lot of temporary interrupts of permeate production by breakdowns, repairs, and renovations of pretreatment and RO facilities.

3.2. Energy transfer efficiency

Using the Eq. (1), energy transfer efficiency of ERDs was determined from the operation data on pressure and flow rate. Fig. 4 compares the measured results obtained in 2 February 2012. Turbocharger system was continuously operated in the period and

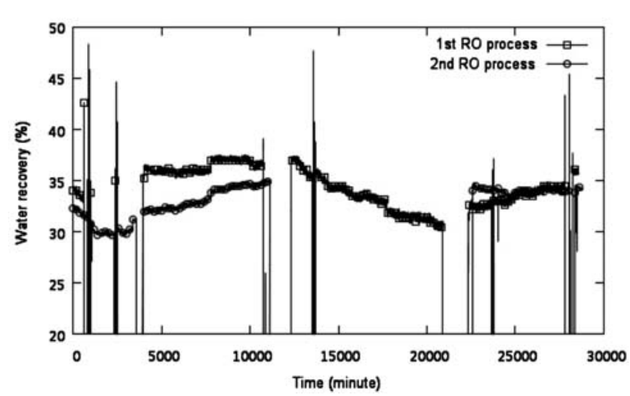

Fig. 3. Identification of operation status on the RO processes by water recovery.

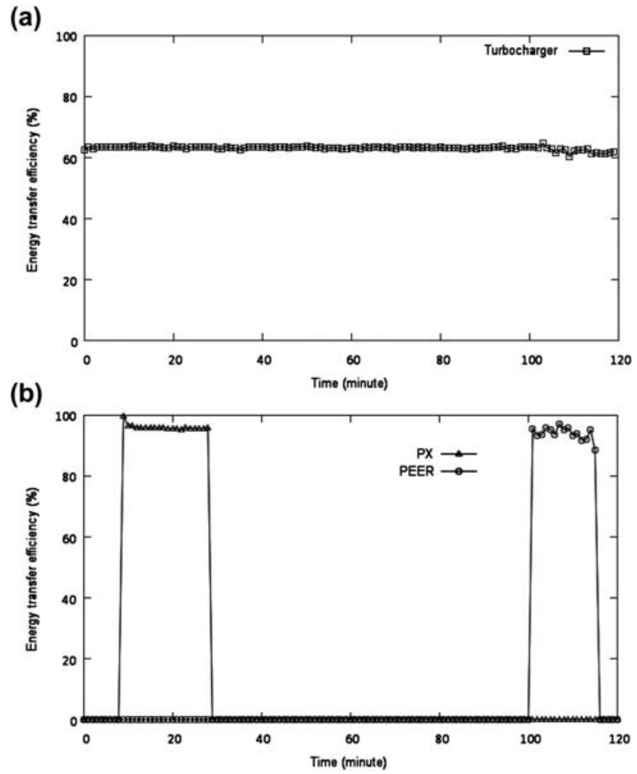

Fig. 4. Comparision of ERD energy transfer efficiency per class of RO in 2 February 2012: (a) ERD operation data of the second RO process and (b) ERD operation data of the first RO process.

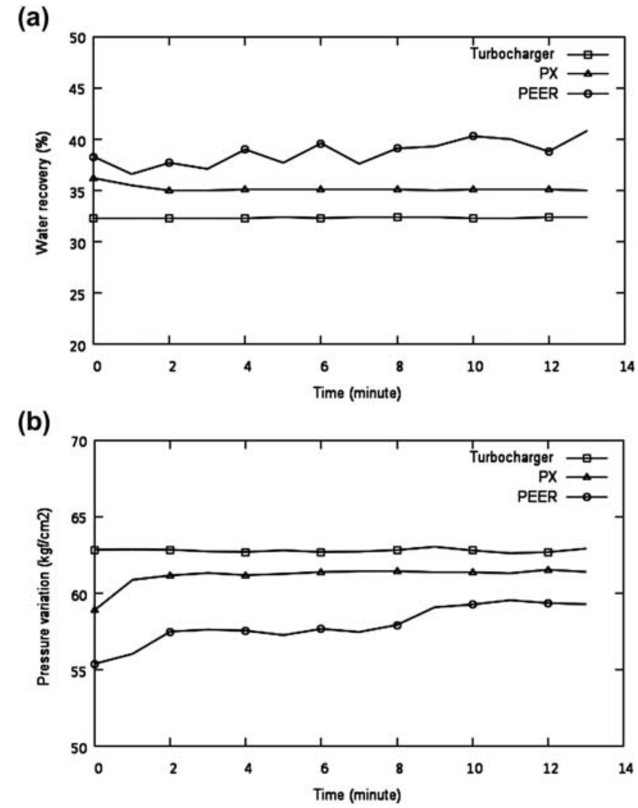

Fig. 5. Effect of the ERD mode on the performances of RO processes in 2 February 2012: (a) water recovery variations and (b) pressure variations between raw water and pressurized feed water.

showed about 63% of average value of energy transfer efficiency (Fig. 4(a)). On the other hand, isobaric PX and PEER system was operated in rotation and showed similar high energy transfer efficiencies of about 95% (Fig. 4(b)). This represents that energy loss could be occurred in centrifugal type during the conversion process via the pump side impeller. Comparison suggests that isobaric type is more efficient in the energy transfer of SWRO process. Meanwhile, the turbocharger system has an advantage of easy maintenance and operation.

3.3. The SEC

The SEC is useful as a metric to quantify RO desalination system energy use. Within the SEC framework, the issues of unit cost optimization have relevance to water recovery, energy recovery, system efficiency, feed/permeate flow rates, and membrane module topology [6–8].

Fig. 5 shows that water recovery and pressure differential of the ERD systems were arranged as a same time scale. Fig. 5(a) shows water recovery rates. The PEER system showed the highest recovery ratio, which was found to be worst for Turbocharger and found to occupy an intermediate position for PX. This is because each system has different leakage properties of brine as well as differences in structure and operation methodology. In general, PX was informed that it has about 1% of lubrication flow [5]. In PEER system, 0.1% of flow leakage was suggested from experiment results of the manufacturer. Fig. 5(b) shows pressure differentials between raw water and pressurized feed water. Turbocharger and PX showed over 60 kgf/cm^2 of pressure differential, but PEER showed less than 58 kgf/cm^2.

Using the Eq. (3), the SECs were estimated by ERD modes in 2 February 2012. Turbocharger, PX, and PEER systems showed the average values of SEC of 5.6, 5.0, and 4.3 kWh/m^3, respectively (Fig. 6). As a result of the comparison, isobaric PX and PEER systems have excellent energy transfer efficiency and less pressure losses than centrifugal turbocharger system.

This SEC analysis has a limitation to judge ERD energy performance directly due to the different operation conditions. Two isobaric systems (i.e. PX and PEER) have different pressurized conditions as shown

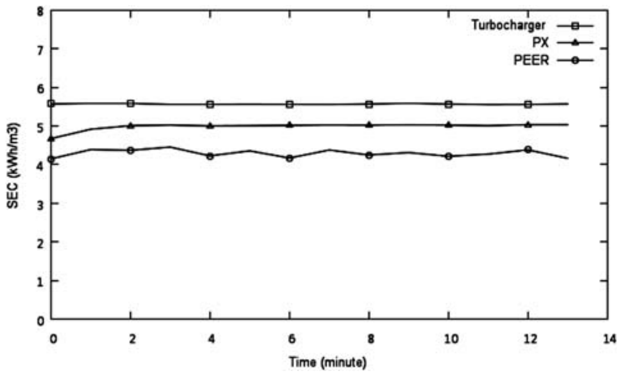

Fig. 6. The SEC of the RO processes by ERD mode in 2 February 2012.

in Fig. 5(b). It was likely that the PEER system was estimated in the midst of applying pressure. Moreover, the turbocharger system was operated in different RO processes with two isobaric systems.

To compare performance of isobaric types more precisely, PX and PEER systems were tested on 15 March 2012. The operation of two ERDs was tried to maintain under the same operational conditions.

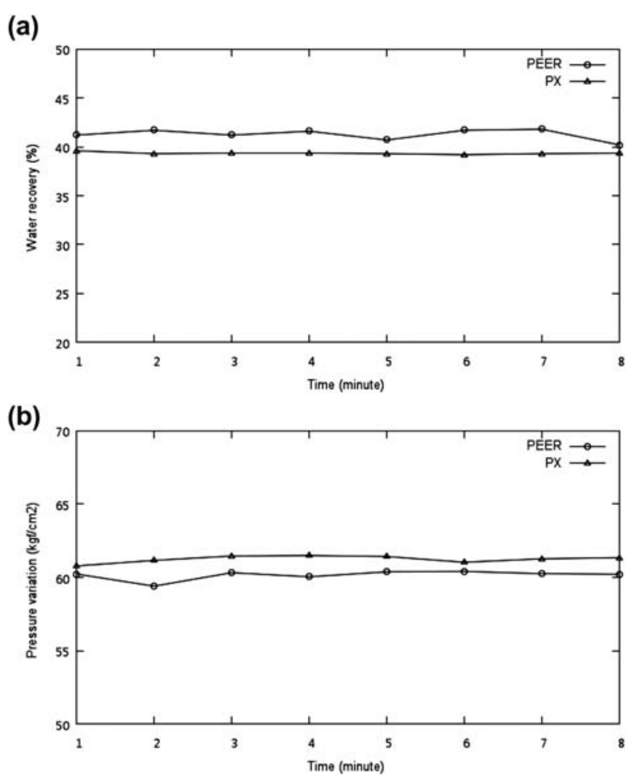

Fig. 7. Comparisons of operational performances between two isobaric systems in 5 March 2012: (a) water recovery variations and (b) pressure variations between raw water and pressurized feed water.

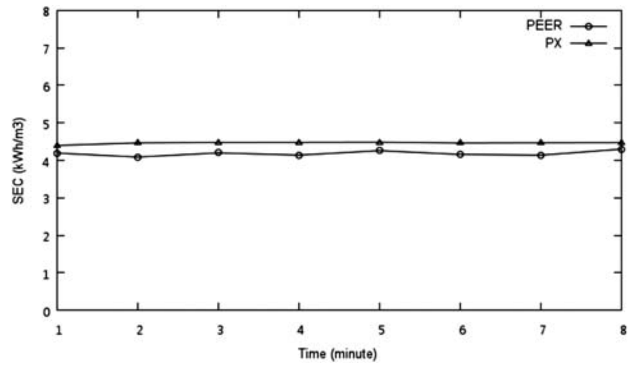

Fig. 8. The SEC of the RO processes by ERD mode in 5 March 2012.

Fig. 7(a) shows that water recovery rates were enhanced to about 40% by comparison with results obtained in 2 February 2012, which have relatively low levels of feed water and pressure compared to 15 March 2012. Moreover, the pressure variations were maintained as constant differentials above the 60 kgf/m^3 during the operation. As shown in Fig. 8, the SECs of isobaric systems were calculated at 4.4 kWh/m^3 (PX) and 4.2 kWh/m^3 (PEER) on average.

One unanticipated finding was that the SECs, which were calculated numerically only without the actual measured values of electricity, could make a calculation error with operating condition. Accordingly, the direct measurement of the amount of electricity used should be needed. As this research was based on short-term experiments to identify performance of domestic ERD system, it is necessary for the long term further research to test stability and reliability of the PEER system.

4. Conclusions

In this work, ERD energy transfer efficiency and SEC were theoretically measured to test performance from the monitoring results. The following conclusions can be drawn from this work:

(1) As a result of pilot plant operation, our RO systems showed 33.3 and 34.4% as average values of water recovery, respectively. These are a little lower than conventional SWRO desalination plants, which have 40–45% of water recovery rate. This might be caused by a lot of temporary interrupts of permeate production by breakdowns, repairs, and renovations of pretreatment and RO facilities.

(2) Isobaric PX and PEER system was operated in rotation and showed similar high energy transfer efficiency of about 95%. Comparison suggests that isobaric type is more efficient in the energy transfer of SWRO process.
(3) The Turbocharger, PX, and PEER systems showed the average value of SEC as 5.6 kWh/m^3 (2 February 2012), 4.4 kWh/m^3, and 4.2 kWh/m^3 (15 March 2012), respectively.
(4) Because the pilot plant and domestic ERD system, PEER, is on the stage of stabilization, more long-term monitoring and analysis should be need.

Acknowledgments

This research was supported by a grant (code# SeaHEROB03-02, B02-04) from Plant Technology Advancement Program funded by Ministry of Construction & Transportation of Korean Government.

References

[1] G.W. Intelligence, Desalination Market, 2008.
[2] L.G.-R. Baltasar Penate, Energy optimisation of existing SWRO (seawater reverse osmosis) plants with ERT (energy recovery turbines): Technical and thermoeconomic assessment, Energy 36 (2011) 613–626.
[3] J.P. MacHarg, Retro-fitting existing SWRO systems with a new energy recovery device, Desalination, 153 (2002) 253–264.
[4] M.J. Dundorf S., Seacord T.F., Optimizing lower energy seawater desalination, the affordable desalination collboration, in: IDA World congress, Maspalomas, Gran Canaria, Spain, 2007.
[5] R.B.C. Ian, B. Cameron, SWRO with ERI's PX pressure exchanger device – a global survey, Desalination 221 (2008) 136–142.
[6] P.D. Christofides, A. Zhu, Y. Cohen, Minimization of energy consumption for a two-pass membrane desalination: Effect of energy recovery, membrane rejection and retentate recycling, Journal of Membrane Science 339 (2009) 126–137.
[7] P.D. Christofides, A. Zhu, Y. Cohen, Effect of thermodynamic restiction on energy cost optimization of RO membrane water desalination, Industrial & Engineering Chemistry Research 48 (2009) 6010–6021.
[8] A.R.A. Zhu, P.D. Christofides, Y. Cohen, Reverse osmosis desalination with high permeability membrane – cost optimization and research needs, Desalination Water Treatment 15 (2010) 256–266.