Desalination 344 (2014) 108–115

Contents lists available at ScienceDirect

Desalination

journal homepage: www.elsevier.com/locate/desal

Pressure retarded osmosis for power generation and seawater desalination: Performance analysis

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HIGHLIGHTS

- PRO-RO system was evaluated for power generation and seawater desalination.
- The effect of feed and draw solutions flow rates and salinities were investigated.
- FO performance increased with SW TDS and decreased with increasing feed water TDS.
- Power generation by PRO increased with SW TDS and flow rate of feed and draw solutions.
- Up to 31% decrease in the desalination power consumption achieved by the PRO-RO process.

ARTICLE INFO

Article history:
Received 12 February 2014
Received in revised form 15 March 2014
Accepted 17 March 2014
Available online xxxx

Keywords:
Forward osmosis
Pressure retarded osmosis
Reverse osmosis
Desalination
PRO–RO system

ABSTRACT

The present study evaluated the performance of pressure retarded osmosis–reverse osmosis (PRO–RO) process for power generation and seawater desalination. Two pre-developed software were used separately to estimate the performance of forward osmosis (FO) and RO process. The draw and feed solutions in the FO process were seawater and low-quality water; i.e. wastewater effluent and brackish water. The simulation results showed that the FO performance increased with increasing seawater salinity and decreased with increasing feed water TDS. Increasing the feed and draw solution flow rate resulted in an increase in the FO performance especially when brackish water was used as a feed solution in the FO process. Power generation from the PRO process was found to increase with increasing the TDS of seawater and the flow rate of feed and draw solutions. The simulation results, however, showed that the PRO process was more sensitive to the increase in the seawater TDS than the flow rate of feed and draw solutions. For fresh water supply, the diluted seawater from the FO process was treated by RO membrane system. Up to 31% decrease in the desalination power consumption can be achieved by the PRO–RO process. It was also found that the increase in the draw solution flow rate resulted in an increase of the permeate concentration and power consumption. This issue should be considered in the operation of the PRO–RO system in order to reduce the overall treatment cost.

1. Introduction

Desalination of seawater is the second largest method, after fresh water treatment, for water supply to communities and cities [1–3]. The high demands on fresh water supply, as well as surface and ground water pollution were the main reasons for seawater desalination. Reverse osmosis (RO) is the most common process for seawater desalination although thermal processes are still keeping a decent market share [4–7]. A common problem in the RO and thermal processes is the high energy requirements for seawater desalination. This issue has been intensively investigated and the recently developed RO membranes exhibit high water permeability and salt rejection rate. Scientists and researchers thought of using renewable energy sources for power supply to the RO plant in order to reduce the cost of desalination. Pressure retarded osmosis (PRO) is one of the emerging technologies for power generation from renewable resources [8–12]. The concept of the PRO is back to the seventies of last century and it was first proposed by Sidney Loeb [11–14]. In principle, the process relies on the osmotic energy induced by the pressure gradient across a semipermeable membrane separating between the feed solution and the draw solution. Freshwater is transported across the membrane from the feed to the draw solution side of the forward osmosis (FO) membrane and dilutes the draw solution. After leaving the FO membrane, the diluted draw solution is sent to a turbine system for power generation. Scientist

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http://dx.doi.org/10.1016/j.desal.2014.03.022

conceived that desalination cost can be reduced when the PRO process is coupled with the RO process in a hybrid system for power generation and seawater desalination [15–17]. Early studies by Loeb investigated the feasibility of using the Red Sea water as the feed solution and the Dead Sea water as the draw solution in the FO membrane system [11, 12]. After leaving the FO membrane, the seawater would pass through a suitable turbine system to convert the hydraulic energy into electrical power. Downstream the turbine system, seawater would be further treated by an RO membrane system for freshwater production. The concept of power generation and seawater desalination by PRO and RO processes from Red and Dead Sea water was infeasible due to a number of technical and environmental issues. Scientists have also proposed using wastewater effluent or low salinity water and seawater as feed and draw solutions in the PRO process [15,16]. Statkraft built the world's first PRO pilot plant for power generation only [18]. The pilot plant was able to generate about 10 kW energy using freshwater and seawater as the feed and draw solutions respectively. The process starts with seawater being pressurized up to 15 bar and sent to the FO membrane for freshwater extraction from the feed water. 70% to 80% recovery rate can be achieved in the FO membrane. The pressurized seawater is diluted by the freshwater crossing the membrane. Once it comes out of the FO membrane, the diluted seawater splits into 2 streams. About 30% goes to the turbine system for power generation and the rest goes into a pressure exchanger to pressurize the seawater going to the FO membrane. The Statkraft pilot plant focused on the osmotic energy for power generation and didn't address the desalination of seawater which is covered by Loeb concept. Elimelech and co-worker investigated the application of wastewater effluent and seawater as feed solution and draw solutions [15]. Most studies have been focused on the application and performance of the FO membrane instead of investigating the cost and performance of the whole system, which includes the RO desalination system as well. Tai-Shung investigated the application of the PRO in power generation and seawater desalination using a three stage membrane treatment [19]. In the first stage, seawater and wastewater are used as draw and feed solutions. The diluted draw solution from stage-one is sent to a second stage FO treatment using a tailor design concentrated draw solution. Finally, the draw solution is further treated by special membrane processes in stage-three for freshwater extraction and osmotic agent regeneration. Although the concept is very attractive, the process is resource-intensive and requires multi-stage membrane treatment. Furthermore the study didn't investigate the performance of the whole system, which includes the PRO and the RO processes. In an attempt to make the system more streamlined, Ali proposed a two-stage PRO–RO system for power generation and seawater desalination [16]. Seawater and wastewater effluents were suggested as the draw and the feed solutions in the first stage. In the second stage, the diluted seawater was taken to an RO membrane system for seawater desalination. The study didn't investigate the

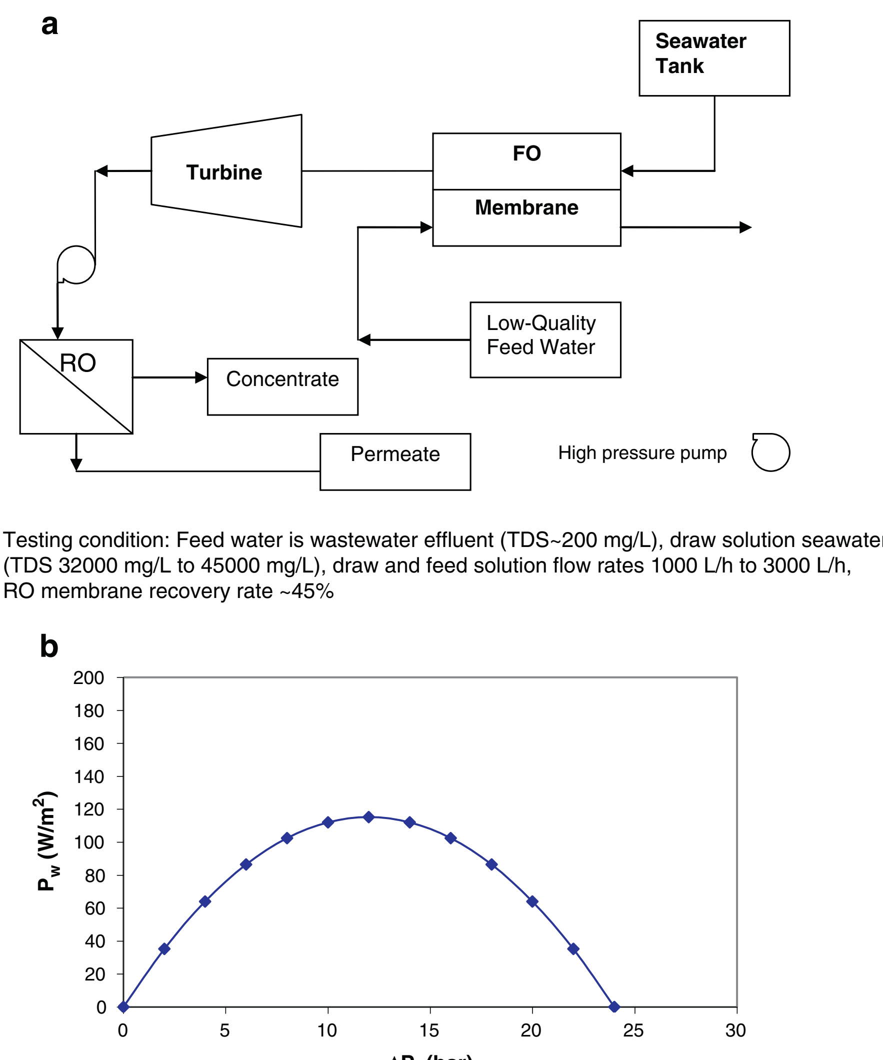

Fig. 1. (a) Schematic diagram of the PRO–RO system for combined power generation and seawater desalination. (b) Impact of transmembrane hydraulic pressure on the PRO power density.