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Performance analysis of reverse osmosis, membrane distillation, and pressure-retarded osmosis hybrid processes

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HIGHLIGHTS

- The performances of the RO–MD–PRO hybrid processes were evaluated using numerical approaches.
- The brine division ratio (BDR) positively influences the efficiency of the hybrid process.
- The supply cost of the MD heat source plays a crucial role in determining the total efficiency.
- The RO–MD–PRO hybrid process outperforms stand-alone RO in terms of reducing both the SEC and environmental footprint.

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ABSTRACT

A performance analysis of a tri-combined process that consists of reverse osmosis (RO), membrane distillation (MD), and pressure-retarded osmosis (PRO) was conducted by using numerical approaches in order to evaluate its feasibility. In the hybrid process, the RO brine is partially used as the MD feed solution, and the concentrated MD brine is then mixed with the rest of the RO brine to be considered as the PRO draw solution. Here, the brine division ratio, incoming flow rate of RO, dimensions of the MD and PRO processes, and the supply cost of the MD heat source were considered as influential parameters. Previously validated process models were employed and the specific energy consumption (SEC) was calculated to examine the performance of the RO–MD–PRO hybrid process. The simulation results confirmed that the RO–MD–PRO hybrid process could outperform stand-alone RO in terms of reducing the SEC and the environmental footprint by dilution of the RO brine in locations where free or low-cost thermal energy can be exploited. Despite the need for further investigations and pilot-tests to determine its commercial practicability, this study provides insights into future directions for water and energy nexus processes for energy efficient desalination.

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1. Introduction

Demands for water and energy are dramatically increasing in both developing and industrialized countries. People in developing countries suffer from a lack of access to safe drinking water and sustenance energy sources, whereas those in industrialized countries consume resources more to meet increasing standards of living [1,2]. To relieve these water and energy scarcity issues, water and energy nexus processes, i.e., the co-generation of water and energy, have received increased attention [3]. As examples, Hosseini et al. [4] analyzed a combined gas turbine and multi stage flash (MSF) desalination system in terms of exergetic, economical, and environmental aspects, and Avrin et al. [5] compared the applicability of coal-desalination and nuclear-desalination in China. However, despite the increase in research activities into water-energy nexus processes, further developments that consider sustainable and environmental impacts are still required. In particular, a combination of pressure-retarded osmosis (PRO) and membrane distillation (MD) is thought to be a favorable candidate as a water-energy nexus process. A recent publication by Han et al. [6] for instance, experimentally investigated the performance of PRO-D hybrid process through a lab-scale system.

Investigations into PRO have resumed over the last decade due to advances in membrane technology, and have received considerable attention as a salinity gradient power (SGP) process [7]. The driving force of PRO is the chemical potential difference between a low-saline feed solution and a high-saline draw solution. Specifically, water transfers from the feed side to the draw side due to osmosis phenomena, with

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