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A simulation study with a new performance index for pressure-retarded osmosis processes hybridized with seawater reverse osmosis and membrane distillation

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ABSTRACT

Despite many kinds of research on pressure-retarded osmosis (PRO), feasibility studies for PRO are still insufficient. To provide a better understanding of PRO-hybridized processes, an energy efficiency analysis should reflect the hybridization features of three processes, including PRO, seawater reverse osmosis (SWRO), and membrane distillation (MD). To this end, a new dimensionless (i.e., unitless or scale-free) performance index is proposed to facilitate a fair comparison of energy efficiency between SWRO-PRO and SWRO-MD-PRO. The new performance index physically implies a ratio of the total energy recovered by PRO to the total energy consumed by SWRO and MD. The performances of hybridized processes were estimated with the new index and compared to each other after running several simulations. The simulation results showed that SWRO-MD-PRO generally has a higher energy efficiency than SWRO-PRO if an inexpensive heat source, such as waste heat, is used. However, the energy efficiencies of both PRO-hybridized processes were different according to the simulation conditions. Therefore, it can be concluded that energy optimization for PRO-hybridized processes should be conducted differently than for SWRO. The results from this study are expected to play a key role in providing a new roadmap for PRO-hybridized process research.

1. Introduction

Greenhouse gas (GHG) emissions and global warming are by far the most controversial issues of the twenty-first century. Countries around the globe have continually tried to find an optimal solution that can satisfy each country, resulting in various important outcomes such as the so-called Paris Agreement [1, 2]. Such efforts are leading the world into a new climate regime that will implement urgent actions to reduce the magnitude of GHG emissions. However, shifting a national industrial structure to an environmentally sound one is almost impossible, so most developed countries are seeking solutions that can decrease GHG emissions.

In this context, pressure-retarded osmosis (PRO) is being recognized as an excellent alternative to conventional energy generation processes since it gives off no carbon-related compounds, at least in theory. PRO utilizes a higher-concentration solution (e.g., seawater) and a lower-concentration solution (e.g., treated wastewater) to generate energy by letting the solutions mix. When first invented, PRO was thought of as an impractical technology because of the poor performance of membranes at the time, but it was rediscovered in the 2000s and started to be investigated again thanks to great advances in membrane technology [3, 4].

Encouraged by previous research, the Norwegian company Statkraft constructed a PRO pilot plant for the first time ever in 2009 [5, 6]. After the construction of the pilot plant, many countries, inspired by Statkraft, started to use PRO and began nationwide projects. The global MVP project from the Republic of Korea and the Megaton project from Japan are representative cases [7–9]. Those projects produced many valuable results that contributed to the progress of PRO. However, the viability of PRO is still controversial due to its productivity limits, which can be predicted through thermodynamic analysis [10–14]. Many researchers claim that using stand-alone PRO with status quo technology makes it hard to secure enough energy to reach a break-even point. To overcome such an obstacle, many new research approaches have been attempted recently. Accordingly, research on PRO can be grouped into three categories: thermodynamics [10–17], new membrane modules for PRO

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