Journal of Water Process Engineering 57 (2024) 104535

Contents lists available at ScienceDirect

Journal of Water Process Engineering

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

CFD simulation of hydrodynamics and concentration polarization in osmotically assisted reverse osmosis membrane systems

Y.K. Chong [a], D.F. Fletcher [b], Y.Y. Liang [a,*]

[a] Faculty of Chemical and Process Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, Lebuh Persiaran Tun Khalil Yaakob, 26300, Kuantan, Pahang, Malaysia
[b] The University of Sydney, School of Chemical and Biomolecular Engineering, NSW 2006, Australia

ARTICLE INFO

Keywords:
OARO
CFD
Verification and validation
Concentration polarization
Hypersaline water treatment

ABSTRACT

Osmotically assisted reverse osmosis (OARO) has been recently suggested as an alternative to improve water recovery of reverse osmosis (RO) for applications in which RO has reached its limit. To elucidate the physics, a computational fluid dynamics (CFD) methodology is developed that describes all important physical phenomena occurring in the feed, porous and draw sides of OARO. The CFD model shows good agreement with the reported experimental data and predicts the water flux better than a simplified analytical model. This paper reveals that external concentration polarization (ECP) at the feed side is more important than internal concentration polarization (ICP) within the porous support layer, especially for a system with a high transmembrane pressure, Δp ($\geq$40 bar). In contrast to conventional RO, where concentration polarization (CP) at the permeate side is negligible, OARO experiences a non-negligible ECP at the draw (permeate) side, particularly in cases with high Δp. This analysis also found that both counter-current and co-current configurations show similar flux performance at module scale.

1. Introduction

The world community is looking for a breakthrough to treat hypersaline brine due to environmental concerns. To achieve minimum (MLD) or zero liquid discharge (ZLD), as much water as possible needs to be extracted from the hypersaline brine that is discharged to landfill in the next stage. The fluid extraction can be performed by using desalination technology [1,2] in which a high transmembrane pressure is used to overcome the huge osmotic pressure gradient between the feed and permeate solutions.

However, brine water reverse osmosis (RO) desalination requires a much higher transmembrane pressure than that for seawater treatment [3] because of the larger osmotic pressure difference between the feed and permeate side. This transmembrane pressure can easily exceed the membrane burst pressure, which is the major drawback of the RO membrane process. For instance, the salinity constraint for RO is approximately 7 wt% due to the maximum operating pressure being set at 80 bar [4]. Thus, a reduction of the osmotic pressure difference is necessary, not only to avoid membrane failure, but also to reduce the pressure requirement. This can be achieved by including a solution on the draw (or permeate) side which has a smaller concentration than the feed solution to reduce the concentration difference between the feed and draw solutions, hence requiring a lower transmembrane pressure [5]. This technology is commonly known as osmotically assisted reverse osmosis (OARO) [6–8]. It is important to note that several stages of OARO are required to reduce the feed brine concentration to a level that is equivalent to those used in typical RO technology before freshwater can be produced [9,10]. Through the application of OARO, a water recovery rate of 35 % to 50 % can be attained for brine with high salinity levels (ranging from 10 to 14 wt%) under a transmembrane pressure of 65 bar [6].

Attaining a high level of water recovery in the OARO process holds great importance in hypersaline brine desalination. This is because achieving high water recovery enables the extraction of more clean water from the hypersaline brine, thereby contributing to meeting the increasing demand for freshwater. Furthermore, it is worth noting that OARO consumes less energy than traditional RO when it comes to achieving the same water recovery from brine with an identical concentration [11,12]. This energy efficiency factor enhances the economic viability of OARO, given that energy consumption plays a crucial role in determining the operational costs of the desalination process [13].

To enhance the flux performance of a membrane, the research

---

* Corresponding author.
E-mail address: yongyeow.liang@umpsa.edu.my (Y.Y. Liang).

https://doi.org/10.1016/j.jwpe.2023.104535
Received 8 March 2023; Received in revised form 8 October 2023; Accepted 6 November 2023