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RESEARCH ARTICLE

Impact of temperature and forward osmosis membrane properties on the concentration polarization and specific energy consumption of hybrid desalination system

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Abstract
This study investigates how temperature and forward osmosis (FO) membrane properties, such as water permeability (*A*), solute permeability (*B*), and structural parameter (*S*), affect the specific energy consumption (SEC) of forward osmosis-reverse osmosis system. The results show that further SEC reduction beyond the water permeability of 3 LMH bar^{-1} is limited owing to high concentration polarization (CP). Increasing *S* by 10-fold increases FO recovery by 177.6%, causing SEC decreases by 33.6%. However, membrane with smaller *S* also increases external CP. To reduce SEC, future work should emphasize mixing strategies to reduce external CP. Furthermore, increasing the temperature from 10 to 40 °C can reduce SEC by 14.3%, highlighting the energy-saving potential of temperature-elevated systems. The factorial design indicates that at a lower temperature, increasing *A* and decreasing *S* have a more significant impact on reducing SEC. This underlines the importance of developing advanced FO membranes, particularly for lower-temperature processes.

Keywords Membrane properties · Temperature · Forward osmosis · Hybrid forward osmosis-reverse osmosis system · Specific energy consumption · Factorial design

Nomenclature

Acronym

CECP	Concentrative concentration polarization
CP	Concentration polarization
DECP	Dilutive concentration polarization
FO	Forward osmosis
ICP	Internal concentration polarization
RO	Reverse osmosis
SEC	Specific energy consumption (kWh m^{-3})

Symbol

A	Pure water permeability (LMH bar^{-1})
A_m	Effective membrane area (m^2)
B	Solute permeability (LMH)
C	Solute concentration (mol m^{-3})
D	Diffusivity (m^2 s^{-1})
e	Number of experiments in a particular level
d_h	Hydraulic diameter (m)
f	Friction factor
h	Membrane channel height (m)
J_s	Reverse solute flux (mol m^{-2} s^{-1})
J_w	Water flux (m s^{-1})
K_{ICP}	Solute resistivity constant (s m^{-1})
K_{sT}	Temperature coefficient of solute (K)
K_{wT}	Temperature coefficient of water (K)
k	Mass transfer coefficient (m s^{-1})
l_m	Length of leaf in FO SWM module (m)
L	Length of RO SWM module (m)
L_p	RO membrane permeance (m s^{-1} Pa^{-1})
n	Number of leaf in FO SWM module
P_0	ERD low pressure stream outlet pressure (Pa)
P_a	Atmospheric pressure (Pa)
ΔP_{ch}	Pressure drop along RO membrane channel (Pa)
ΔP_{tm}	Transmembrane hydraulic pressure in RO (Pa)
ΔP_{tm0}	Inlet transmembrane hydraulic pressure in RO (Pa)
Q	Flow rate (m^3 s^{-1})
r	Response value at a particular experimental run
Re_h	Hydraulic Reynolds number

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