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Saving energy consumption and CO_2 emission from sustainable efficient operating zones in inland electrodialysis reversal desalination

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ABSTRACT

A pre-design parameter, system efficiency (SE) was modeled for operations with water recovery rate through cell pairs (WRRTC) >0.5. The variables for equation were validated with data from a pilot scale study of electrodialysis reversal (EDR). The correlation between experimental and predicted SE are good at overall R^2 0.924 with significant p 0.000. System efficiency-to-polarization degree ratio is inversely linear with demineralization, WRRTC, and polarization degree (PD). The most sensitive operational parameter was found to be PD. The sustainable efficient zones for PD, WRRTC, and demineralization were found to be 1040–1315 (A/m^2) (L/eq), 0.57–0.67, and 62–90%. By operating EDR in this zone, 8–15% of energy consumption and CO_2 emission were saved.
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1. Introduction

Electrodialysis reversal (EDR) is made up of a series of cell pairs. One cell pair contains each channel of diluate and concentrate streams partitioning by a cation-ion-exchange membrane followed by the first spacer, an anion-ion-exchange membrane, and the second spacer. A spacer exists between each cation- and anion-exchange-membrane. The feed water is fed into both diluate and concentrate stream. Cations (anions) in the diluate stream permeate into the concentrate stream through the

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Nomenclature

a, b, c, d	variables for Eq. (2)
A_{ewampf}	effective surface area of anion-exchange membrane parallel to the flow, m^2
A_{ewcmpf}	effective surface area of cation-exchange membrane parallel to the flow, m^2
Demi	demineralization degree, %
i	current density resulted from applied voltage, A/m^2
i/N_{davg}	polarization degree (PD), (A/m^2) (L/eq)
N_{davg}	average of dissolved ions maintained in dilute stream from inlet to outlet, eq/L
$Q_{one\ cell}$	flow rate in one cell pair, L/h
SE	system efficiency, L meq/(s^2 A m^2)
WRRTC	water recovery rate through cell pairs, fraction or no unit

cation-(anion)-ion-exchange membrane from influent to effluent by attraction of direct-current. The efficiency of ionic permeation through the ion-exchange-membrane (IEM) is based on both physicochemical properties of the membranes used and hydrodynamic conditions and coupling between the ionic transferring area in and out of membrane [1,2,3].

The higher demineralization percentage, scalability, and ion controllability are advantages of EDR. The existing ion-exchange membranes used in ED have 96–99% ion selectivity and resulted in only ~5% of the total voltage drop of the entire system. Therefore, it is difficult to achieve any further improvement of the ED process [4,5] from IEM, but likely from other areas, ion-transport through solvent and membranes, efficient operating zones, etc.

1.1. Efficiency of EDR desalination with the higher water recovery rate and demineralization

It is inaccurate to attempt to increase the efficiency by increasing the water recovery rate and demineralization. The higher the water recovery rate and demineralization operate, the higher is the ions concentrate in the concentrate stream and the longer mean-ion-residence time in concentrate stream [6]. At these conditions, one or more ion species have more opportunity to dissolve in supersaturated solubility and precipitate as scaling on the surface of the membrane [7]. Scaling decreases the product water flow rate and percentage of demineralization, damages and shortens the life of membrane system, and increases operating and maintenance costs [8,9]. Although $CaCO_3$, and $CaSO_4 \cdot 2H_2O$ are normally found in scaling, $BaSO_4$, $SrSO_4$, $Ca_3(PO_4)_2$ and ferric and aluminum hydroxides are also potentially deposited as scaling [7,10,11]. Frequent chemical cleaning, extensive pretreatment, and replacement of membrane are recommended to minimize these deleterious effects. Frequent chemical dosing declines the membrane integrity and reduces the life-span of the membrane [3]. Extensive pretreatment and replacement of the membrane increase the operational cost. The other option is to operate EDR in the efficient zone. A model or pre-design parameter, therefore, might be needed to predict the most efficient operating conditions for low energy and high efficient ions removal rate per effective surface area of the membrane. The most efficient operating zones of polarization degree, demineralization, and water recovery rate through cell pairs (WRRTC) is the preliminary objective of this article.

1.2. System efficiency and polarization degree

Concentration polarization at the surface of an IEM controls the efficiency of EDR [12]. Davis and Brockman [13] mathematically defined polarization as i/N_{ln} where i is the current density applied and N_{ln} is log-mean concentration along the flow path between influent and effluent. Davis and Brockman [13] used concentration polarization degree to evaluate the performance of the different feed ions concentration in the same apparatus. System efficiency (SE) is defined as product output divided by input materials. Outputs in EDR are volume of product water produced and mass of ion desalinated rates. Inputs are effective surface area of membrane cell pairs and current resulted from

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