Desalination 347 (2014) 158–164

Contents lists available at ScienceDirect

Desalination

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

Treatment of model inland brackish groundwater reverse osmosis concentrate with electrodialysis — Part III: Sensitivity to composition and hydraulic recovery

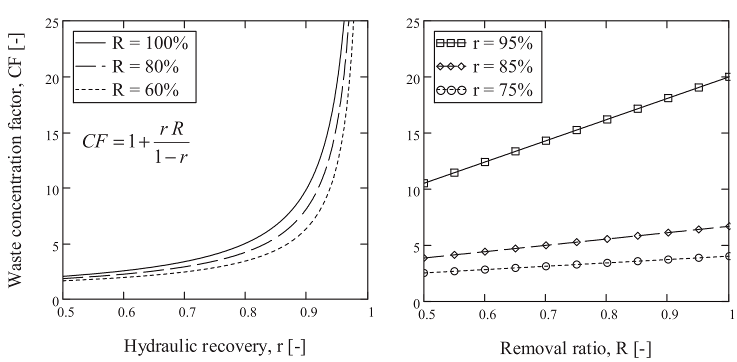
W. Shane Walker *[,1], Younggy Kim [2], Desmond F. Lawler

The University of Texas at Austin, Department of Civil, Architectural and Environmental Engineering, 1 University Station C1786, Austin, TX 78712, USA

HIGHLIGHTS

- The concentration factor of electrodialysis increases linearly with removal ratio.
- Synthetic BWRO concentrates of 7.9–18.6 g/L were desalinated by electrodialysis.
- ED treatment recovered >78% of BWRO concentrate without precipitation.
- Specific energy consumption was insensitive to solution composition.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 13 January 2014
Received in revised form 18 May 2014
Accepted 22 May 2014
Available online 17 June 2014

Keywords:
Electrodialysis
Inland brackish groundwater
High recovery
Concentrate treatment
Brine minimization
Saturation ratio

ABSTRACT

The objective of this research was to investigate the sensitivity of electrodialysis performance to variations in voltage application and membrane type when treating brackish water reverse osmosis (BWRO) concentrate waste, which typically exceeds multiple salt solubility limits. Synthetic BWRO concentrates from Arizona, Texas, and Florida of 7890–18,600 mg/L total dissolved solids were prepared with 6–10 mg/L of polyphosphonate antiscalants. Experimentation was performed using a laboratory-scale electrodialyzer a nominal transfer area of 64 cm^2 per membrane. Flow, pressure, conductivity, temperature, and pH were measured continuously, and periodic process samples were analyzed for anion and cation concentrations. The three BWRO concentrates were successfully treated with stack voltage applications of 1.0–1.5 V/cell-pair with initial current densities of 200–600 A/m^2 and final salinity removal ratios up to 98%. This paper shows consistent specific energy consumption (approximately 0.03 kWh/m^3 per Volt/cell-pair applied per meq/L separated) for electrodialysis treatment for several concentrates across a range of salinity and composition. Successive electrodialysis treatment recovered more than 78% of BWRO concentrate without precipitation, corresponding to calcite and dolomite saturation ratios of 15. These results demonstrate that electrodialysis processes can effectively minimize concentrate waste from BWRO processes, with simulated system recoveries up to 95%.

1. Introduction

1.1. Goals and objectives

The goal of this research was to experimentally quantify the efficacy and efficiency of electrodialysis separation of supersaturated synthetic

* Corresponding author. Tel.: +1 512 471 4595; fax: +1 512 471 0592.
E-mail addresses: wswalker2@utep.edu (W. Shane Walker), younggy@mcmaster.ca (Y. Kim), dlawler@mail.utexas.edu (D.F. Lawler).
[1] Present address: The University of Texas at El Paso, Department of Civil Engineering, 500 W. University Ave., El Paso, TX 79968. Tel.: +1 915 747 8729.
[2] Present address: McMaster University, Department of Civil Engineering, 1280 Main Street W, Hamilton, Ontario, Canada, L8S4L8. Tel.: +1 905 525 9140x24802.

http://dx.doi.org/10.1016/j.desal.2014.05.034
0011-9164/

brackish water reverse osmosis (BWRO) concentrates. This third paper focuses on quantifying the effects of salinity composition, supersaturation, and recovery ratio.

1.2. Background

As described in detail in Part I [1] and Part II [2] of this series, the effects of hydraulic, electrical, and chemical variables are inherently coupled in electrodialysis. With respect to chemical variables, the technical feasibility of inland desalting technologies is critically linked to the hydraulic recovery, which is typically limited by mineral scaling. Scaling is a function of the brackish water composition, with respect to the concentrations of sparingly soluble ion pairs (characterized by the solubility product), as well as overall ionic strength (which affects the activity coefficients). By mass balance (and assuming constant density), the bulk concentration factor (*CF*) of the concentrate waste stream in any membrane process is a function of the hydraulic recovery (r) and removal ratio (R), according to the following expression:

$$CF = 1 + \frac{rR}{1-r}. \quad (1)$$

Reverse osmosis (RO) systems typically operate at relatively fixed removal ratio, so the concentration factor of salt in the concentrate increases hyperbolically with increasing water recovery in RO systems, as shown in Part (a) of Fig. 1. In contrast, electrodialysis (ED) systems typically operate at a relatively fixed hydraulic recovery, so the concentration factor of salt in the concentrate increases linearly with increasing salt removal, as shown in Part (b) of Fig. 1. This linear increase in the concentration factor with the removal ratio in ED can be a technological advantage over RO for high recovery desalination and membrane scaling control.

With respect to recent research in electrodialysis desalination of brackish waters, several general observations are summarized here:

- Electrodialysis research has focused on treatment of synthetic binary [3–11] and ternary [4,7] salts, with salinities less than 1 g/L [3–5,7–9] or between 1 and 10 g/L [6,10,12–14], though some research has treated real and model waters [12,13,15–19].
- Ions move at different speeds depending on solution composition and membrane properties [20–22]. More specifically, it has been observed that binary salts of potassium were removed more efficiently than sodium salts, and the sulfate salts were removed less efficiently than others [7].
- Most total organic carbon (TOC) is not separated even when most of the initial total dissolved solids (TDS) are removed [15,16]. Small organic ions can be separated, but zwitterionic compounds are not separated [16].

2. Material and methods

2.1. Experimental plan and variables

As described in detail in Part I [1] of this series, this experimentation was designed to observe the effects of (1) velocity, (2) voltage, (3) ion exchange membranes, (4) feedwater composition, and (5) concentrate recovery on electrodialysis treatment of inland brackish groundwater reverse osmosis concentrate. The focus of this paper is to characterize the sensitivity of electrodialysis treatment with respect to variation in solution composition and concentrate recovery. Discrete values and ranges of these parameters are shown in Table 1.

2.2. Experimental solutions

2.2.1. Brackish concentrates

Three representative brackish groundwaters were selected to provide a practical variation in the following water quality characteristics: total dissolved solid (TDS) concentration, hardness, alkalinity, silica concentration, and boron concentration. With pressure-driven and electrically-driven membrane processes, more energy is required to desalinate waters of greater salinity, and the scaling potential of the water is correlated with hardness, as the salts of multivalent ions are generally much less soluble than those of monovalent ions. Almost all of the alkalinity in natural waters is from the carbonate system, which contributes to scaling potential. Silica is also problematic because of its low solubility, abrasive crystalline geometry, and contribution to irreversible scaling. Boron is a difficult species to remove with RO and sometimes controls the design of RO systems.

Representative source waters were selected from Arizona, Texas, and Florida. A brackish groundwater treatment study in Maricopa County, Arizona by the US Bureau of Reclamation [23] detailed the composition (TDS = 1585 mg/L, pH = 7.5) of Well S5 in Avandale (southwest of Phoenix). Similarly, a water composition analysis of groundwater (TDS = 3730 mg/L, pH = 7.8) that supplies the North Cameron RO facility in Cameron County, TX was performed by Ana-Lab Corp. (Kilgore, TX) in 2007. Water quality data of groundwater (TDS = 3775 mg/L, pH = 7.7) in Florida was gathered from the South Florida Water Management District's DBHYDRO database [24], and Sample P9750-2 from Station MF-37 at a depth of 2049 ft on 26 OCT 2001 was selected as the representative water for this study. By approximating 100% RO rejection and RO recoveries of 80%, 75%, and 80% for AZ, TX, and FL sources, respectively, the concentration factors (*CF*) in RO concentrate

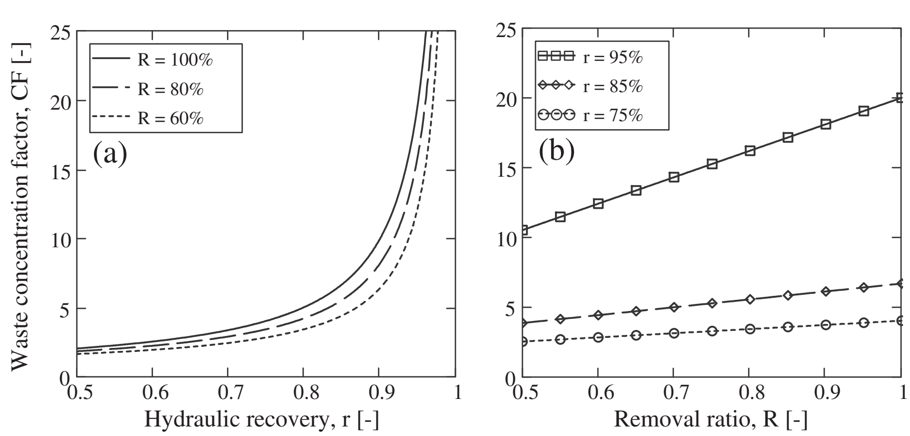


Fig. 1. Waste concentration factor sensitivity to: (a) hydraulic recovery and (b) removal ratio.