Low Energy Seawater Desalination Using NEXED® Electro-dialysis

Present by Xiangyi Qiao
Evoqua Singapore R&D Center
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Outline

1. Introduction
   - What is electrodialysis?
   - ED/EDR Overview
   - Project Background
   - NEXED® System Features

2. Seawater Desalination Using NEXED System
   - Phase I Development
   - Phase II & Phase III Design, Construction and Operation
   - Future Plan

3. Summary
1. Introduction
What is electrodialysis?
Salt Movement in Solution with Electric Field

Opposite charges attract
Like charges repel
Anions migrate towards anode
Cations migrate towards cathode
What is electrodialysis?

Add Ion Exchange Membrane

Electrochemical Desalination (ED)

- Electricity drives the transport of dissolved ions such as Na\(^+\) and Cl\(^-\).
- Ion Exchange Membranes (IEM) allow the removal of selected ions.
- Allows the separation into a dilute and a concentrate stream.
ED/EDR Overview

• ED is a mature technology, developed in 1950’s
• Applied mainly to brackish water desalting
  – Power consumption thought too high for seawater
• Tolerant of difficult feed water conditions
  – Water flows past, not through membrane
  – Requires less pretreatment than RO
• Polarity reversal reduces scale formation potential
ED/EDR Overview

- Traditional rectangular, plate-and-frame devices
  - Low membrane utilization, ~65% membrane utilization
  - High assembly cost, difficult to automate manufacturing
Project Background

Evoqua NEXED® System

• It began as a technology development endeavor through an Economic Development Board (EDB) RISC grant in October of 2007.

• Electrodialysis reimagined from the leader in electrochemical deionization to meet the increasing demands of brackish and seawater salt removal

• Technology development phase from 2008 to 2011 culminated in a 50m³/day demonstration system in a Variable Salinity Plant (VSP)

• Received approval to construct a new 3,800 m³/day (1 USMGD as feed capacity) demonstration plant in Nov 2015
Project Background

Target: Retain advantages of ED/EDR while addressing main limitations

• Advantages
  – Tunable salt removal
  – Low pressure
  – Minimal pretreatment
  – Chlorine tolerant (in some cases)
  – High water recovery

• Limitations
  – Expensive membrane material
  – High capital cost
  – High power consumption
NEXED® System Features

- Evoqua’s new ion-exchange (IX) membranes
  - Low resistance: less voltage / power required
  - Very thin, yet strong: reduced material cost

<table>
<thead>
<tr>
<th>Membrane</th>
<th>Electrical Resistance (ohm-cm²)</th>
<th>Permselectivity (%)</th>
<th>Osmotic Coefficient (mL/m²-h-bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benchmark CEM</td>
<td>3</td>
<td>98</td>
<td>3</td>
</tr>
<tr>
<td>Benchmark AEM</td>
<td>2.8</td>
<td>98</td>
<td>3</td>
</tr>
<tr>
<td>Evoqua CEM</td>
<td>1.7</td>
<td>98</td>
<td>6</td>
</tr>
<tr>
<td>Evoqua AEM</td>
<td>0.8</td>
<td>97</td>
<td>18</td>
</tr>
</tbody>
</table>
NEXED® System Features

Evoqua’s ED Sub-block

~85% Membrane Utilization
Automatable Assembly
Molded Components

Concentrate flow

Product flow
NEXED® System Features

Advanced building block design

‘Innovative, next generation configuration of a commercially accepted and proven technology process’
NEXED® System Features

1) Low Pressure
2) Quieter
3) Cost competitive automated design
4) Up to 30% less energy with thin low energy membrane
5) Adaptable internal configuration for optimized solutions
6) Modular design – NEXED modules are stackable
7) Tunable for different feed salinity conditions
8) Membranes designed for high cleanability
2. Seawater Desalination Using NEXED® System
Phase I: Process Optimization

May 2016

Oct 2016

Dec 2016

20 SB modules

Two 10SB modules
# Phase I: Product Improvement

<table>
<thead>
<tr>
<th>Development activities</th>
<th>Detailed description</th>
<th>Energy consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manifold design</td>
<td>Improved current efficiency</td>
<td></td>
</tr>
<tr>
<td>Flow distribution</td>
<td>Improved current efficiency</td>
<td></td>
</tr>
<tr>
<td>Process improvement</td>
<td>Reduce concentration gradient (reduce voltage, water loss)</td>
<td></td>
</tr>
<tr>
<td>Module configuration improvement</td>
<td>Improve current efficiency</td>
<td></td>
</tr>
</tbody>
</table>
Phase I: Improvement on Power Supply

- **Comparison of two types of power supply**

  **SCR type power supply with averaged DC output: Fusion**
  
  **Switch-mode type power supply with stable DC output: Magna or TDK-Lambda**

  - DC Voltage output is a waveform with double the input AC frequency
  - DC Voltage output is stable
Phase I: Improvement on Power Supply

- Test results of two types of power supply

- Current efficiency was improved by 70% with switch mode power supply, indicating the choice of power supply has significant influence on ED process.
## Phase I: Performance Results

#### Summary of process optimization results (Phase I)

<table>
<thead>
<tr>
<th>Feed Flow-rate (m³/day)</th>
<th>Recovery</th>
<th>Product Quality (mS/cm)</th>
<th>DC Energy Consumption (kWh/m³)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>199</td>
<td>33%</td>
<td>48 → &lt; 2</td>
<td>4.3</td>
<td>- Aug 2016</td>
</tr>
<tr>
<td>131</td>
<td>31%</td>
<td>48 → &lt;1.5</td>
<td>3.9</td>
<td>- Dec 2016 - Process configuration #1</td>
</tr>
<tr>
<td>132</td>
<td>31%</td>
<td>48 → &lt;1.5</td>
<td>3.6</td>
<td>- Jan 2017 - Process configuration #2</td>
</tr>
<tr>
<td>134</td>
<td>34%</td>
<td>48 → &lt;1.5</td>
<td>3.2</td>
<td>- Feb 2017 - Process configuration #3</td>
</tr>
<tr>
<td>129</td>
<td>36%</td>
<td>48 → &lt;1.5</td>
<td>2.74</td>
<td>- Jun 2017 - Process configuration #4</td>
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</tbody>
</table>
Phase I: Operational history >2200 hour

Feed & Product Conductivity Trend

- Stage 1 Feed
- Stage 1 Dilute Out
- Stage 2 Dilute Out
- Stage 4 Dilute Out
Phase II& III: Design, Construction & Operation

- **Phase II & III Block Diagram**

  UF Filtered Sea Water → ED Stage 1 (30mS/cm) → ED Stage 2 (15mS/cm) → ED Stage 3 (15mS/cm) → ED Stage 4 (<1.5mS/cm)

  ED performance was optimized at each stage

- **Engineering Design for Phase II& III**

  Phase II& III PFD

  Phase II & III Layout
Phase II& III: Design, Construction & Operation

- **Module Production**
  - Total 45 modules were installed

- **Skid Engineering Design**
  - Piping is properly designed flow distribution among modules and is improved for accessibility
  - Overall ergonomics of the skid has been improved for installation and maintenance
Phase II& III: Design, Construction & Operation

Scaled up from 90m³/d to 3800m³/d in 2.5 years

Phase I
- Feed: 90m³/d
- Completed May 2016
- 4 Modules Installed
  - Product improvement
  - Process configuration
  - Intelligent control system

Phase II
- Feed: 1200m³/d
- Completed Aug 2017
- 15 Modules Installed
  - A lot has been learned in terms of piping design, system design, and process optimization in a larger scale.

Phase III
- Feed: 3800m³/d (1USMGD)
- Completed Mar 2018
- Total 45 Modules Installed
  - Skid is simpler, neater and more ergonomically designed
  - Easy for operation and maintenance
  - Fine-tuning and further optimization of process to achieve best performance
## Future Plan

### Continuous Improvement

<table>
<thead>
<tr>
<th>Items</th>
<th>Detailed description</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module configuration</td>
<td>Optimize residence time and cutoff point of each stage</td>
<td>Reduce energy consumption</td>
</tr>
<tr>
<td>Flow distribution</td>
<td>Further test on flow distribution is on-going</td>
<td>Reduce energy consumption</td>
</tr>
<tr>
<td>Pretreatment test</td>
<td>To evaluate pretreatment requirement</td>
<td>Reduce pretreatment cost</td>
</tr>
<tr>
<td>Continuous enhancement</td>
<td>Other process and control improvement</td>
<td>Increase recovery or reduce energy consumption</td>
</tr>
<tr>
<td>Module improvement</td>
<td>To increase feed pressure limit and enable higher flow rate for each module</td>
<td>Reduce CAPEX</td>
</tr>
</tbody>
</table>
3. Summary
Summary

TechPioneer – the largest NEXED® electrodialysis pilot plant

• Evoqua NEXED technology advantages: low resistance ion-exchange membranes, novel sub-block and module design, intelligent process and control system

• Through product improvement, system optimization and plant optimization, we have demonstrated low energy sea water desalination using NEXED system in a pilot plant in Singapore

• Evoqua Singapore R&D team is working on fine-tuning the system and further optimization of the process to achieve the optimum performance results.

• Upon success of this pilot plant, it is expected to be scaled up to 10,000m3/d at Tuas Desalination Plant

• Evoqua will continue to improve this technology and further expand NEXED system in broader applications
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Evoqua project team members: Xiangyi Qiao, Hui Han, Conde Romulo Dador, Kris Lim, Henry Lim, Cheng Tau Pho, Michael J. Shaw, Keng Hoo Yeo, Li-Shiang Liang, Charles P Buzzell

Email: Xiangyi.qiao@Evoqua.com