Electrodialysis Metathesis hybrid technology scale up simulations to increase brackish water reverse osmosis recovery to 98-99%

Authors:

Jeroen Van Nunen (jeroen.van.nunen@fujifilm.com) and Pol Adarve Panicot (pol.adarve@fujifilm.com).

Abstract:

The leading technology for inland brackish desalination is the reverse osmosis (RO). These facilities generate brine ranging from 20% up to 30% out of feed water volume. This brine where most of the dissolved solids are transferred becomes a waste that has to be reclaimed. Current waste disposal techniques such as surface disposal or Deep Well Injection (DWI) have negative environmental impact in the long run.

The aim of this study has been to find an efficient, cost competitive, sustainable and reliable technology to treat these brines. The technology used has been the Electrodialys Methathesis with a combination of standard and monovalent grade ion exchange membranes creating two concentrate loops, on the on hand a sulfate rich and the order hand a calcium and magnesium rich, avoiding scaling issues. A pilot test has been conducted in Almeria under the EU life project.

The results have been a concentration of Total Dissolved Solids (TDS) from 34 gr/l on the feed up to 163 gr/l without scaling in each of the tow concentrate loops while reaching a 5 gr/l of TDS on the product. At the same time achieving a volume reduction factor of 5 times and a total power consumption of 5.1 kWh/m3.

It has been demonstrated that, in conclusion, EDM is a cost effective brine concentration technology that can be used as bolt-on in existing and in greenfield brackish desalination plants increasing the total plant recovery up to 98-99%.

1 Introduction

Most common desalination technology, Reverse Osmosis (RO), has enormous benefits for water desalination at a cost effective level and has been able to increase the water supply and availability across water scare regions. However, in this pressure driven process, salts contained on the feed water are transferred to a concentrate loop with a very high Total Dissolved Solids (TDS) or salinity, forming the so called brine.

The brine becomes a hazard waste if there is no possibility to be mixed back to the sea (also not exempt of environmental issues), therefore most of the inland Brackish Water Reverse Osmosis (BWRO) desalination plants face brine management issues which compromises the plant operation and the exploitation of inland brackish resources. Current BWRO plants have a water recovery which ranges from 70% to 80% resulting in brines streams of 20% to 30% of the feed water.

This paper focuses in the Electrodialysis Methatesis concept as a high salt concentration technology. Electrodialysis itself was developed in the fifties of last century in Massachusetts Institute of Technology (MIT) and it is today a mature process. However, few studies and applications can be found using the Methatesis design and current study will provide field test data to achieve large scale, low power consumption and high brine recovery technology for BWRO plants.

1.1 Background

According United States Bureau of Reclamation (USBOR) only in the United States there are more than 430 municipal RO desalination plants and only 4% are seawater (Treatment of Concentrate Program Report No. 155).

Traditionally most common alternatives and technologies for brine disposal of BWRO have been: 1) Ocean outfall via pipeline discharge, 2) surface discharge, 3) sewer discharge, 4) Deep Well Injection (DWI), 5) land application and 6) evaporation pond.

Desalination industry is exploring for more than a decade various new system designs to increase the water recovery but scaling remains a huge problem. Ground waters in many cases consist of high amounts of Calcium, Magnesium and Sulfates that precipitates on high concentration brines.

1.1.1 Electrodialisys Methatesis Tom Davis Concept

The professor Tom Davis was the first to introduce the Electrodialysis Methatesis concept developing a four chambers Electrodialysis stack. Main concept of Tom Davis design was to split the concentrate in two streams, sulfate rich on the one side and a calcium and magnesium reach on the other side. In such a manner that the precipitation of salts was postponed at a higher concentration levels. The main inconvenient of this concept was the need to add salt to keep the process stable with the impact of high energy consumption and lose of recovery capacity (see Demonstration of a new Electrodialysis technology to reduce energy required for salinity management by Tom Davis).

The following graph shows the four chamber Electrodialysis Methatesis stack designed by Tom Davis using standard grade Ion Exchange Membranes.

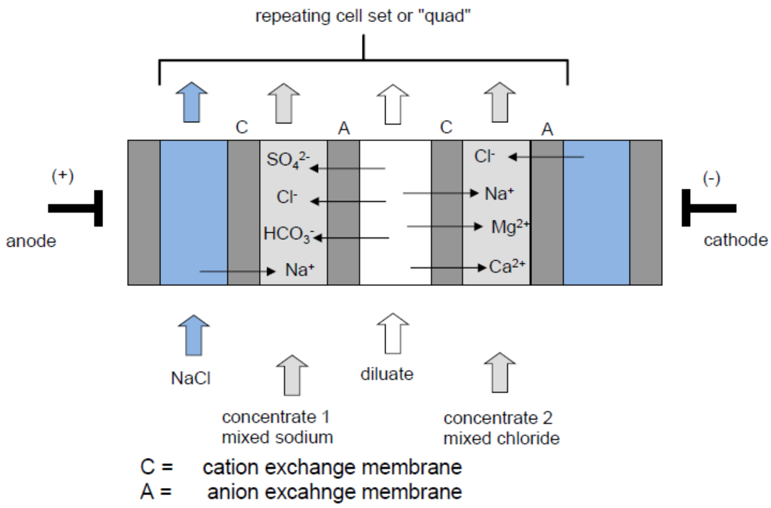

Figure 1 Tom Davis Electrodialysis Methatesis concept.

1.2 Objectives

Main goal of this study is to improve the Tom Davis concept to reduce or even eliminate salt addition, reduce energy consumption, increase water recovery and treatment capacity of the EDM stack and last but not least recover valuable salts. The study proposes to use a configuration of standard grade and monovalent grade ion exchange membranes to keep process stability without salt addition. In summary, the objective is to separate multivalent cations from multivalent anions in one process step to avoid scaling.

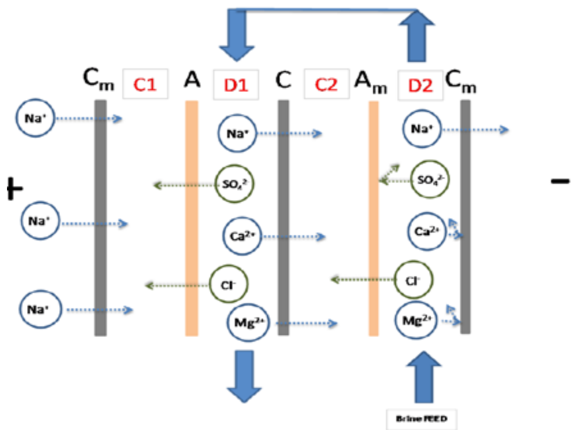

Figure 2 EDM stack with combination of standard grade and monovalent ion exchange membranes.

The main difference between this study and Davis concept was the use of monovalent membranes alternately. Main difference between standard grade and monovalent type of exchange membranes are shown in following graph:

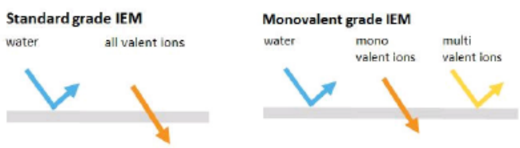

Figure 3 Difference between standard and monovalent ion exchange membranes.

2 Experiment conducted

2.1 EDM concept tested under EU Life project ZELDA

A field test under the EU Life project named Zelda was conducted in municipal seawater Desalination plant of Almeria (Spain) from years 2015 till 2017. Official partners of the pilot project were Fujifilm, Abengoa, CTM and WssTP. A full pilot unit was developed and installed on the field with following process:

Figure 4 Zelda process diagram.

The features of the EDM unit were the following:

Figure 5 Features of EDM unit.

The ion exchange used for the experiment were the following:

Fujifilm membranes	TYPE 10		TYPE 16	
homogeneous	AEM	CEM	AEM mono	CEM mono
	Anion permselective	Cation permselective	Monovalent Anion permselective	Monovalent Cation permselective
reinforcement	polyolefin		polyolefin	
Thickness dry (µm)	125	135	125	135
Resistance Ω.cm2 (1)	1.7	2.0	2.4	2.3
perm selectivity (2)	95	99	95	99
water permeance (3)	6.5	6.5	5.5	5.5

* The property values are typical values only and no waranty as to such properties is given

(1) Electrical resistance measured at 0.5M NaCl
(2) Permselectivity measured at 0.05-0.5M NaCl
(3) Water permeation (ml/bar.m2.hr)

Figure 6 Technical datasheet of membranes used.

Although pilot plant was installed in Almeria seawater desalination plant due to logistic matters, the brine treated was from Helios solar thermal plant.

Brine composition used as a feed had following parameters:

Helios composition

Ca	Mg	Na	SO4	Cl	TDS	EC
mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mS/cm
50	90	11500	16677	6027	34343	37

Figure 7 Brine composition feed.

3 Results obtained under Zelda Project

The brine treated as a feed had 34 gr/l of salts and after passing through the EDM stack went to a concentration of 163 gr/l (4.7 times more) in two different concentrate loops, on the one side the sulfate rich and the other side the calcium-magnesium rich to avoid scaling. In the case of this experiment the dilute target was 5.6 gr/l and depending on the quality of the product (as drinking water or re-feed upstream) can be further optimized. In terms of flow, 80% of water recovery took place out of the brine treated. In terms of volume reduction, a factor of 5.06 was experienced from 324 l/h initial to 64 l/h (the sum of both concentrates). Following diagram shows the concentration and mass balance obtained.

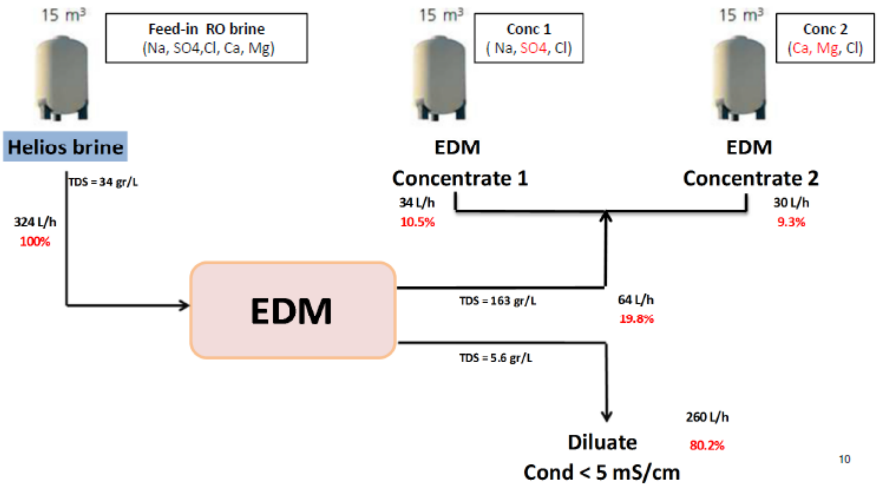

Figure 8 Diagram of results obtained.

In terms of detailed composition, the results obtained were the following:

- Product water (ED-M diluate)

Product water (ED-M diluate)

Ca	Mg	Na	SO4	Cl	TDS	EC
mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mS/cm
0	0	640	111	4899	5650	4

- Concentrate 1

Concentrate 1

Ca	Mg	Na	SO4	Cl	TDS	EC
mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mS/cm
24	44	68620	86745	22239	174797	164

- Concentrate 2

Concentrate 2

Ca	Mg	Na	SO4	Cl	TDS	EC
mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mS/cm
238	422	67830	6624	75427	150541	123

Figure 9 Details of results obtained in terms of water composition.

In terms of qualitative results, no scaling occurred and stable operation could be observed without having significant pressure build-up.

And finally, energy consumption measured was 5.1 kWh/m3.

4 BWRO-EDM hybrid scale up simulations (follow-up work after Zelda project)

In the original Zelda project the main focus was to recover valuable salts. The EDM technology showed to be good pre-concentrator (around a factor of 5), while also the brine volume was reduced in the same order of magnitude. To explore more options for the EDM technology the inland brackish water industry was investigated. BWRO systems are commonly used for inland desalination with water recovery typically in range from 70-80%, resulting in brine streams (20-30% volume).

Conventional brine disposal by evaporations pounds, discharge to a brine pipe for ocean outfall or deep well injection are costly. The desalination industry is exploring for more than a decade various new system designs to increase the water recovery for inland desalination but scaling remains a huge problem because, ground waters in many cases consist of high amounts of Calcium, Magnesium and or Sulphates.

Major goal at inland BW desalination municipalities is to increase water recovery to increase water income and lower brine disposal cost.

Based on the Zelda result handling high scaling water, an RO-EDM hybrid technology might be of interest for the inland desalination industry.

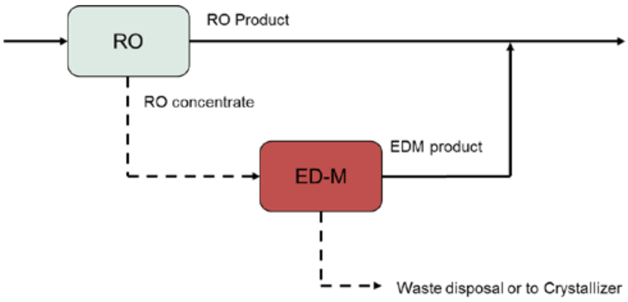

Figure 10 RO-EDM hybrid concept.

To understand the technology benefits when used in a hybrid (RO-EDM) system, additional lab simulations were conducted for various RO brine conductivities and water recovery ranges to get a first understanding of potential BWRO- EDM hybrid system water recovery ranges.

For simulation a brine composition used as a feed had following parameters:

Na	K	Ca	Mg	NH4	Cl	NO3	SO4	HCO3	TDS	EC
mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mS/cm
1239	569	584	236	88	1912	301	2331	888	8148	10.1

Figure 10 brine composition feed.

Two different simulations were selected: a) feed conductivity of 10mS/cm to product water of 2mS/cm
b) feed conductivity of 10mS/cm to product water of 0.5mS/cm

To either blend the EDM product water directly with RO product water (case b) or to feed it back to RO feed-in water (case a).

Furthermore the RO system water recovery parameter was simulated for 70%, 75% and 80% meaning an RO brine (feed stream to the EDM system) of 30%, 25% and 20%.

In terms of simulation results,

The EDM process (as single process step) was able to reach a water recovery of 96.5% @ energy consumption of 6-7 kW/m3 for case A and 95.6% @ energy consumption of 7-8 kW/m3 for case B.

This resulted in a total system (RO-EDM hybrid) water recovery 99.0 -99.3% for case A and 98.7 -99.1% for case B.

BWRO water recovery	EDM Feed-in (RO brine)	EDM Product water	EDM water recovery (RO brine)	RO+EDM hybrid water recovery
70% => 30% brine	10 mS/cm	2 mS/cm	96.5%	99.0% => 1.0% brine
75% => 25% brine	10 mS/cm	2 mS/cm	96.5%	99.1% => 0.9% brine
80% => 20% brine	10 mS/cm	2 mS/cm	96.5%	99.3% => 0.7% brine

Figure 11 RO-EDM hybrid water recovery – simulation a

RO water recovery	EDM Feed-in (RO brine)	EDM Product water	EDM water recovery (RO brine)	RO+EDM hybrid water recovery
70% => 30% brine	10 mS/cm	0.5 mS/cm	95.6%	98.7% => 1.3% brine
75% => 25% brine	10 mS/cm	0.5 mS/cm	95.6%	98.9% => 1.1% brine
80% => 20% brine	10 mS/cm	0.5 mS/cm	95.6%	99.1% => 1.1% brine

Figure 11 RO-EDM hybrid water recovery – simulation b

5 Conclusions

Main conclusions obtained out of present study are differentiated in two main blocks.

Benefits of EDM technology:

- High concentration process for SO4 and or Mg/Ca rich waters in 2 separated concentrate streams.
- EDM technology is ideal for scaling risk waters.
- EDM is suitable as hybrid (bolt-on) brine concentration technology for existing BWRO.
- RO-EDM hybrid concept can achieve water recoveries of 98-99% resulting in higher water income and lower disposal cost.
- EDM technology is suitable as (non-thermal) pre-concentrator technology for salt recovery.
- The use of monovalent membranes eliminates the salt addition in Zelda case.

EDM technology Limitations

- Surplus of monovalent anions and cations in feed stream required. Otherwise NaCl addition into feed stream needed to keep mass balance, which will impact energy consumption and water recovery.

6 References:

Demonstration of a New Electrodialysis technology to reduce energy required for salinity management. Professor Tom davis et al. 2015. http://www.energy.ca.gov/2015publications/CEC-500-2015-097/CEC-500-2015-097.pdf

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