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Brine recovery: achieving high magnesium concentration using selective nanofiltration membranes

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ABSTRACT

Seawater brine recovery is a promising technology to recover valuable compounds out of seawater reverse osmosis brine and produce drinking water from seawater. Brine recovery enables the recuperation of natural resources from seawater through a sustainable process aligned with United Nations sustainability development goals and the transition into a circular economy. To get these compounds, different steps need to be performed. The first one involves separating divalent compounds from monovalent ones. This is achieved using selective nanofiltration membranes. The subsequent phase of the process requires the production of potable water, followed by the concentration and dewatering of the residual monovalent brine. FilmTec™ SWBR-100 and FilmTec™ SWBR-150 are two types of nanofiltration selective membranes explicitly designed to segregate divalent and monovalent compounds. This allows the isolated divalent compounds to be recovered as valuable magnesium salts, following further concentration. At a later stage in the process, the monovalent permeate stream produced by FilmTec™ SWBR-100 or FilmTec™ SWBR-150 undergoes additional concentration enhancement with the aid of FilmTec™ SWBR-200. This membrane enables the recovery of Na and Cl monovalents, even when dealing with high total dissolved solids. This research study aims to evaluate the functionality of these three membranes and highlights the benefits that nanofiltration and seawater reverse osmosis elements bring to the separation process. The membranes were tested under typical operating conditions of a brine recovery process. The experimentation was conducted at the Global Water Technology Center in Tarragona. The trials showed that FilmTec™ SWBR-100 delivers the highest divalent rejection rate while FilmTec™ SWBR-150 performs well and saves some energy. Moreover, experimentation demonstrated that FilmTec™ SWBR-200 provides satisfactory monovalent concentration levels with lower energy consumption.

Keywords: Seawater; Membranes; Brine recovery; Brine mining; Sustainability development goals

1. Introduction

The brine generated during seawater desalination process is full of minerals, that can be extracted to get resources from seawater, and therefore, transform a waste into a resource [1]. This process of resource recovery from seawater brine is referred herein refer as brine recovery [2]. Reverse osmosis has emerged as a suitable technology to concentrate these valuable minerals, so that they can be later valorized, as demand for potable water has increased, and the cost of desalination has decreased, making this technology very affordable [3]. Some species, such

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as magnesium (Mg), calcium (Ca), sodium (Na), and chloride (Cl) are among the easiest compounds to be valorized in this brine mining recovery application [4].

Selective desalination process can be described with the simple schematics provided in Fig. 1. The process consists of multiple steps. The first one is called selective nanofiltration, where divalent species are separated and later concentrated using a selective nanofiltration membrane. DuPont uses two different membranes to achieve this process, the FilmTec™ SWBR-100 and SWBR-150 membranes. These membranes provide efficient separation of monovalent and divalent ions, recover high-value species such as magnesium salts, produce high-purity sodium chloride permeate, maximize recovery in downstream seawater reverse osmosis, prevent scaling in downstream processes and offer excellent durability. The second step consists of a seawater reverse osmosis step, where potable water is produced. The third step is called the brine concentrator and focuses on concentrating sodium chloride. FilmTec™ SWBR-200 is used to concentrate sodium chloride brine, reduce wastewater volume, reduce capital costs by operating at standard seawater reverse osmosis pressures (<1,200 psi/83 bar), reduce energy consumption and offer excellent durability.

The objective of this paper is to show how both selective nanofiltration membranes can help in separating and concentrating divalent species from monovalent ones.

2. Methods

2.1. Experiment 1 – FilmTec™ SWBR-100 and SWBR-150 at 68 g/L TDS

Elements specifications for FilmTec™ SWBR-100 and SWBR-150 membranes to separate divalent from monovalent species are listed in Table 1.

The operating conditions consist of 7 elements in series and in once-through at 58% recovery and 18 LMH of flux using real SWRO concentrate, the composition of which is shown in Table 2 . The setup of this experiment is depicted in in Fig. 2

2.2. Experiment 2 – FilmTec™ SWBR-200 at 77 g/L monovalent salinity

Elements specifications for FilmTec™ SWBR-200 and membrane to concentrate monovalent species are listed in Table 3.

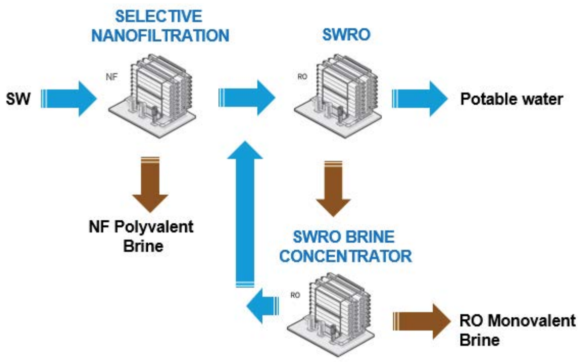

Fig. 1. Brine recovery process scheme.

The objective of the second experiment is to show elements performance under 77 g/L monovalent salinity. The operating conditions consist of 7 elements in series and in once-through at 26% recovery and 11 LMH of flux using real synthetic monovalent brine, the composition of which is shown in Table 4. The setup of this experiment is depicted in in Fig. 3

3. Results

3.1. Experiment 1 – FilmTec™ SWBR-100 and SWBR-150 at 68 g/L TDS

The results of Experiment 1, shown in Fig. 4, demonstrate that SWBR-100 offers higher divalent rejection while

Table 1
Elements used in selective nanofiltration

Element	Flow (GPD)	Rejection $MgSO_4$ (%)	Key feature
SWBR-100	7,000	99.82%	Higher divalent concentration
SWBR-150	10,500	99.62%	Energy saving

Table 2
Water composition of Experiment 1

Ions	Content (ppm)
Sodium	20,200
Potassium	753
Magnesium	2,200
Calcium	731
Strontium	14.7
Boron	8.7
Chloride	38,900
Bromide	139
Sulfate	5,100
Alkalinity	267
TDS	68,300

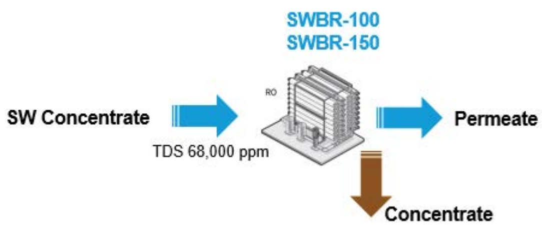

Fig. 2. Experiment 1 setup.

Table 3
Elements used in monovalent concentration

Element	SWBR-200
Flow (GPD)	12,750
Rejection NaCl (%)	90
Key feature	Monovalent concentration

Table 4
Synthetic concentrate composition

Ions	Content (ppm)
Sodium	29,600
Potassium	14
Magnesium	178
Calcium	196
Boron	8
Chloride	46,500
Sulfate	93
TDS	76,700

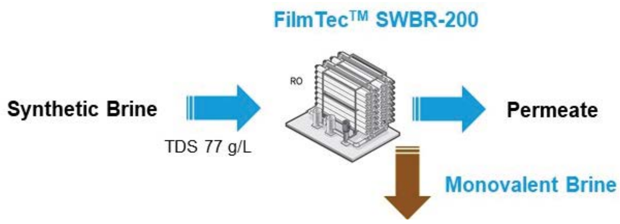

Fig. 3. Experiment 2 setup.

SWBR-150 offers high divalent rejection at low energy. Specifically, SWBR-100 and SWBR-150 have a rejection of 95.6% and 93.9% magnesium, using a pressure of 26.1 and 23.0 bar, respectively. This difference in rejection is kept for calcium, while for sulphate values are more similar.

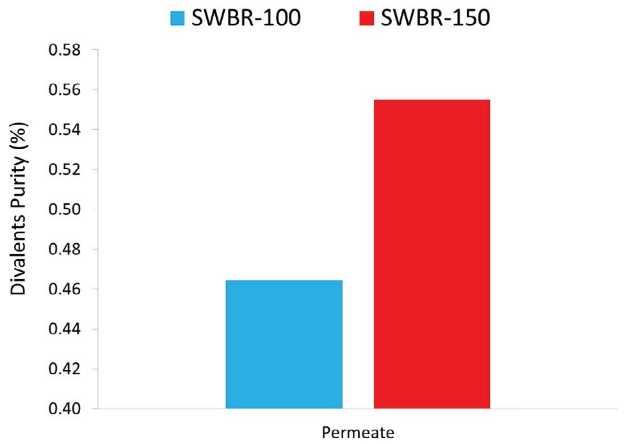

Fig. 5. Divalent ions purity for FilmTec™ SWBR-100 and FilmTec™ SWBR-150 in Experiment 1.

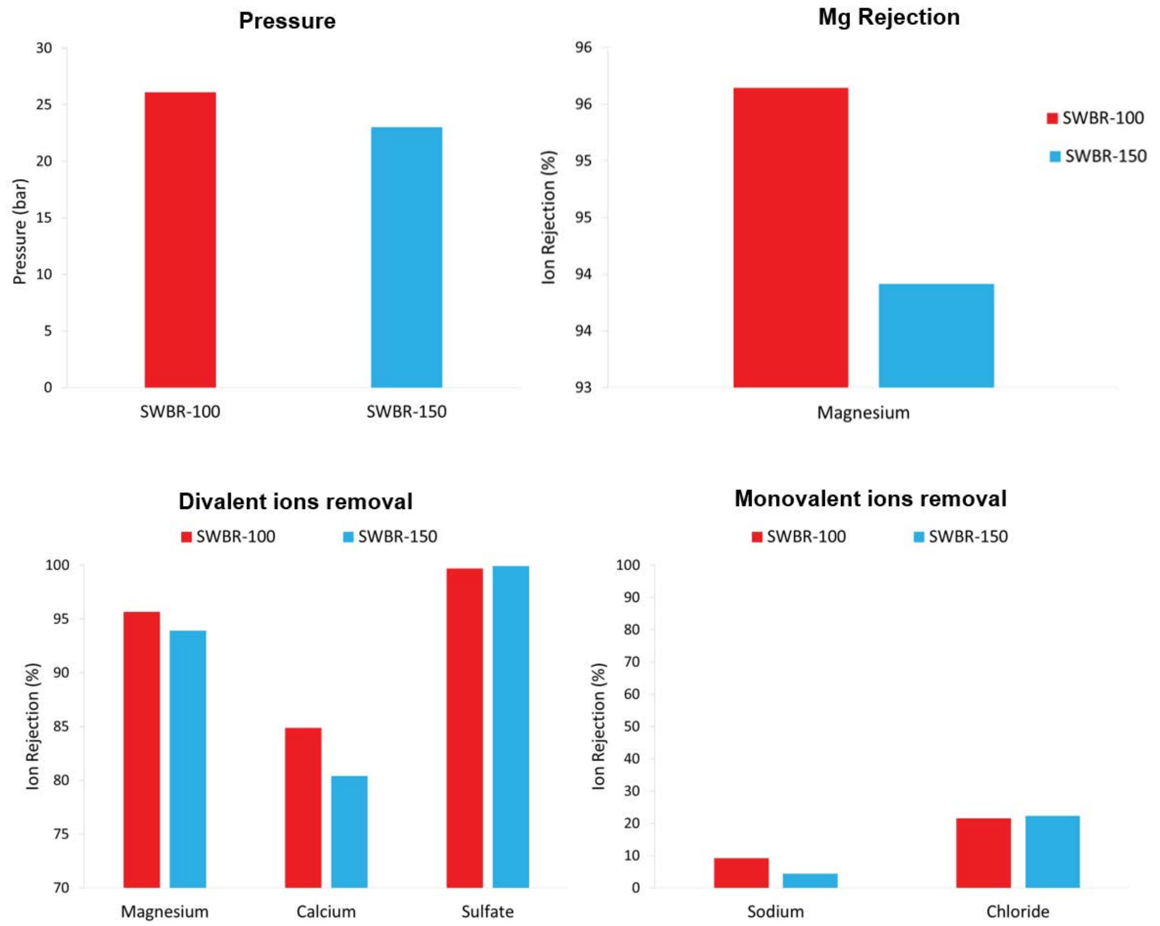

Fig. 4. Rejections and feed pressure for FilmTec™ SWBR-100 and FilmTec™ SWBR-150 in Experiment 1.

Fig. 6. Feed pressure and rejection for FilmTec™ SWBR-200 in Experiment 2.

Furthermore, the results depicted in Fig. 5 demonstrate that both FilmTec™ SWBR-100 and FilmTec™ SWBR-150 elements present excellent selectivity for the separation of divalent ions from monovalent ions. However, it is important to note that the FilmTec™ SWBR-100 element exhibits a selectivity of divalent to monovalent ion separation that is 20% greater than that of the FilmTec™ SWBR-150 element.

3.2. Experiment 2 – FilmTec™ SWBR-200 at 77 g/L monovalent salinity

The findings of Experiment 2 as portrayed in Fig. 6 provide evidence that SWBR-200 delivers excellent monovalent concentration rates at an energy consumption level which is deemed satisfactory, particularly given the relatively high quantity of total dissolved solids present in the water. The innovative element enables an increase in the concentration of monovalent ions from 72,000 to 95,000 ppm while consuming less than 70 bar throughout the process.

4. Conclusions

Brine recovery is a novel application that can recover valuable compounds from seawater brine. This paper shows how this can be achieved thanks to using three different selective nanofiltration and reverse osmosis membranes, the FilmTec™ SWBR-100, FilmTec™ SWBR-150 and FilmTec™ SWBR-200 membranes. The first offers the highest divalent rejection, while the second delivers an excellent divalent rejection at slightly lower energy. Finally, FilmTec™ SWBR-200 allows a concentration of monovalent ions in a water stream containing a high rate of total dissolved solids at moderate energy consumption.

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