# COMPARISON OF HIGH-WATER RECOVERY METHODS IN REVERSE OSMOSIS (RO) OF BRACKISH WATER USING RO MODELING SOFTWARE

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## Introduction

The availability of freshwater is diminishing with growing population, industrial and agricultural usage, and droughts regarding both quantity and quality of freshwater [1]. To mitigate this water stress, high recovery reverse osmosis desalination has become an attractive option to treat non-traditional water sources to meet the freshwater demand [1]. Reverse osmosis (RO) can meet this demand with membrane filtration achieving high water permeability, salt rejection, and treatment to meet the highest drinking water standards [2].

A main concern of RO is fouling and scaling on the membranes due to the accumulation of inorganic salts and organic matter on the membrane. Scale formation is a serious limitation of the system as it shortens membrane lifetime, lowers flux and rejection, as well as requires hazardous chemicals for membrane maintenance cleaning [4]. To mitigate membrane fouling and scaling, various methods can be used such as a feed water pre-treatment usually in chemical form, changing operating conditions, or changing the system design [5]. Using an alternative pre-treatment such as an electromagnetic field (EMF) has the capability to reduce fouling and scaling during treatment of challenging waters without chemicals to reduce membrane fouling [6].

The EMF inducer functions by transmitting a ± 150 Hz signal aiding the removal of existing deposits and prevents scale formation to reduce the need for chemicals during pre-treatment [7]. This study compares chemical pre-treatment to the use of EMF in a conventional and high recovery reverse osmosis (HRRO) design by comparing water recovery, energy consumption, and greenhouse gas emissions. By analyzing both chemical and EMF pre-treatment systematically, this aims to contribute to the advancement of high recovery reverse osmosis systems and reduction of their environmental impact.

## Methods

This study examines three reverse osmosis software: ROSA, IMS Design, and Avista Advisor CI to simulate conventional RO and HRRO in terms of energy consumption, cost, and chemical quantity. Each software was downloaded from their respective websites, open to the public. Water constituent data was consistent across all software programs; acquired from the 2019 Bureau of Reclamation report analyzing the brackish ground water supply in Santa Teresa, New Mexico [8]. All water parameters were collected from Camino Real Regional Utility Authority (CRRUA) Well 19 and a functional unit of 1 MGD of permeate was consistent across software. To assess water recovery and system design, Rosa and IMS Design were used accordingly. This data was then used as a baseline and then cost and energy consumption values compared with EMF literature data. Total energy consumption was calculated using both literature values and software calculations to compare processes. Both of these software programs did not provide chemical anti-scalant data, which called for the use of Avista Advisor CI. Energy cost and greenhouse gas emissions were calculated based on El Paso Electric industrial electricity rates provided by the National Renewable Energy Laboratory and EPA emission factors [9-10].

**Results**

The comparative software data are shown in Table 1. ROSA HRRO and IMS Design were able to simulate the highest water recovery at 92% and 93%. The HRRO was simulated using Desalitech technology implementing closed circuit desalination recycling RO concentrate. When directly comparing the ROSA conventional system and HRRO, the HRRO can achieve a 7% higher recovery with approximately the same total membrane area.

Table 1. Comparison of the design of high recovery RO systems using software

| Software | ROSA | | ROSA | IMS Design | | Avista | |
|---|---|---|---|---|---|---|---|
| System | Conventional | | CCRO | Conventional ** | | Conventional with Brine Concentrator | |
| Feed Flow (gpm) | 1390 | | 772.22 | 1275 | | 952 | |
| Stage | Stage 1 | Stage 2 | Stage 1 | Stage 1 | Stage 2 | Stage 1 | Stage 2 |
| Membrane Type | XLE-440 | XLE-440 | BW30XFRLE-400/34 | ESPA2-MAX | ESPA2-MAX | ESPA2-MAX | ESPA2-MAX |
| Membrane Area ($ft^2$) | 440 | 440 | 400 | 440 | 440 | 440 | 440 |
| Spacer Thickness (mil) | 28 | 28 | 37 | 28 | 28 | 28 | 28 |
| Elements x PV | 8 x 18 | 8 x 18 | 5 x 42 | 8 x 12 | 8 x 4 | 8 x 12 | 8 x 4 |
| RO Water Recovery | 81% | | 90% | 90% | | 88% | |
| Overall Water Recovery | 85% | | 92% | 93% | | * | |

* Information not provided by software
** System uses energy recovery device (ERD)

Table 2 presents energy consumption and greenhouse gas emission data per each software. Avista did not provide energy data therefore, it was not included in the GHG emission chart. Power consumption was calculated for the conventional systems with chemicals (IMS Design and ROSA) and then conventional with EMF (EMF) and HRRO with EMF (ROSA HRRO+EMF). The HRRO + EMF was concluded to have the highest power consumptions of the treatment trains, while the ROSA conventional system had the lowest. Each system produced 1MGD of permeate water with a 500 mg/L TDS and ~ 290 gpm blending flow to satisfy the secondary water drinking standard.

Table 2. Energy, cost and greenhouse gas emissions comparison

| Software | Power (kW) | Energy (kWh/year) | Energy (MWh/year) | EPA CO2 equivalent EF (lb/MWh) | GHG emissions as $CO_2$ eq (tons/year) | GHG emissions as $CO_2$ eq ($lb/m^3$) |
|---|---|---|---|---|---|---|
| IMS Design | 59.70 | 522,972.00 | 523 | 1,097.16 | 286.89 | 0.415 |
| ROSA | 43.38 | 380,008.80 | 380 | 1,097.16 | 208.46 | 0.302 |
| EMF | 56.24 | 492,662.40 | 493 | 1,097.16 | 270.26 | 0.391 |
| ROSA HRRO+EMF | 73.23 | 641,512.32 | 642 | 1,097.16 | 351.34 | 0.509 |

**Conclusion**

This study provides perspective by comparing reverse osmosis software and their capabilities to achieve high recovery with chemical and EMF pre-treatments. It is expected that the Hydroflow EMF device will have a lesser environmental impact regarding GHG emissions than the traditional chemical anti-scalant. In addition, the combination of EMF and the HRRO could yield a solution to achieve high recovery without the dangerous use of chemicals. This cannot be measured to its full potential as Life Cycle Assessment reports regarding chemicals and membrane manufacturing information were not provided by the respective companies.

Access to energy and GHG emission data could be beneficial to membrane companies as environmental impact is becoming a key role in product decision making. Customers may be willing to invest in a good product with the mindset of a payback period if such data were available to the public. Further research may include an LCA from anti-scalant and EMF manufactures to accurately compare the emissions of different inputs and outputs of the system.

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