Reduction of reverse osmosis desalination energy demand by osmotic dilution/osmotic energy recovery – a realistic modelling approach

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Providing the increasing world population with fresh water and clean energy at affordable cost is a major challenge. Although Reverse Osmosis (RO) is an established technology for the desalination of seawater, its practical recover is limited to 30-50% and its energy consumption amounts to 2-3 kWh/m³. Direct reuse of impaired water through membrane technology costs up to 1.7 kWh/m³ and has a negative connotation. The combination of impaired water and seawater however, offers interesting perspectives. Although direct use of wastewater may not be allowed, the controlled pre-dilution of seawater with impaired water might serve as a solution for the high energy demand. A possible hybrid process using osmotic dilution/osmotic energy recovery devices (OD/OER) is shown in Figure 1.

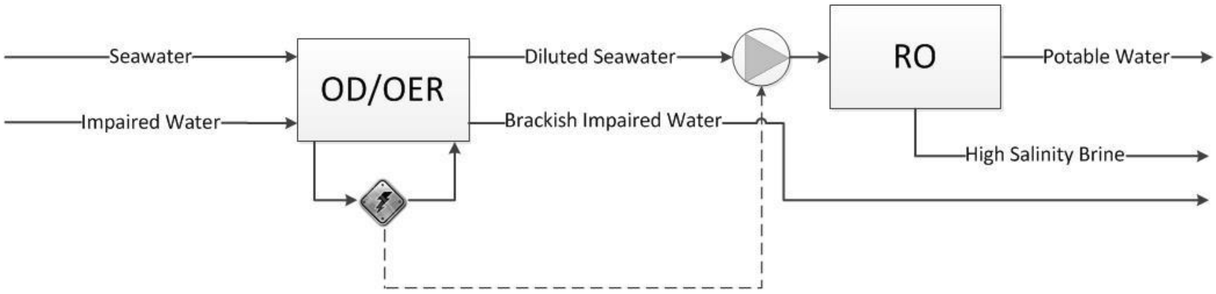

Figure 1 Schematic representation of the OD/OER-RO process under investigation

Based on the concentration gradient between both streams, the seawater concentration can be decreased while simultaneously generating energy. This can be done by transferring salt ions from seawater to wastewater (Reverse Electrodialysis) or by transferring water molecules from wastewater to seawater (Pressure Retarded Osmosis). By using primary or secondary treated wastewater in combination with these membrane barriers, the negative perception of wastewater reuse can be overcome. In recent literature, Feinberg et al. have already compared RED and PRO as OD/OER for RO, but purely from a thermodynamic point of view. We take this effort to the next level by incorporating major losses encountered in practice, allowing for a more realistic insight into the possibilities of the hybrid process. As an example, the more realistic energy demand for the RED-RO process is shown in Figure 2.

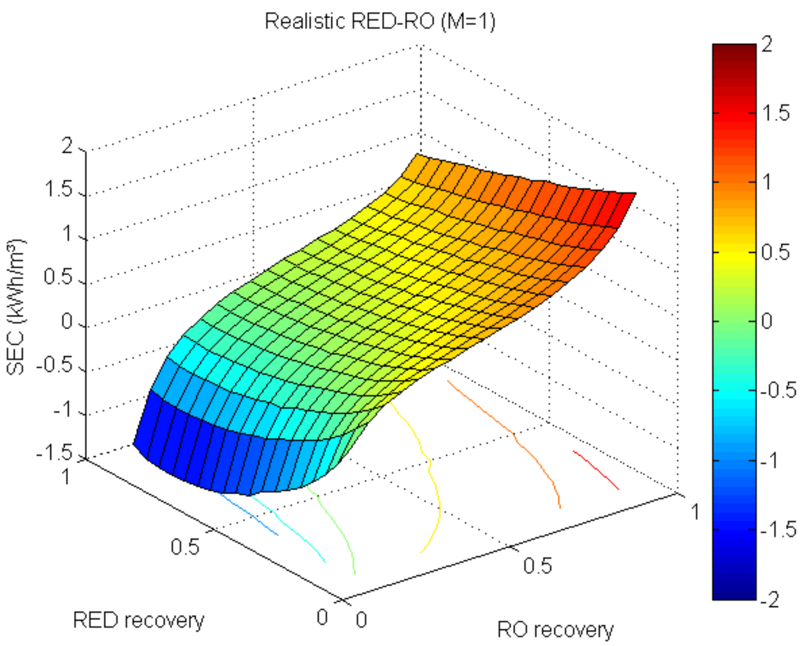

Figure 2 Realistic modelling of the energy demand for the RED-RO hybrid process for a mixing ratio of 1 (equal amounts of seawater and impaired water used) (SEC = Specific Energy Consumption, M = Mixing Ratio)

Furthermore, other OD processes will be considered, such as Forward Osmosis (FO) and Assisted FO (AFO). In FO, no external hydraulic pressure is applied, while in AFO, an additional pressure is applied to the seawater. Similarly, in short-circuited RED (scRED), no external potential is applied, while in assisted RED (ARED), a small potential in the direction of the natural ion flow is applied. Because these latter processes do not produce energy, they will allow mixing to go faster, resulting in a lower required membrane area and thus a decrease in capital costs in respect to the energy producing OD/OER (RED and PRO). The different OD/OER processes will thus be evaluated regarding their influence on energy demand and capital costs of the hybrid process.

This modelling work will provide valuable information concerning the energy consumption/production of the hybrid system with respect to the mixing ratios of sea- and wastewater, recovery of the RO system and total recovery of the system. The different hybrid processes will be compared based on energy demand and capital costs (estimated based on required membrane area) and a sensitivity analysis will be performed, identifying the most influential parameters. This will provide a theoretical optimisation of the process and a more thorough understanding of the influential factors and their relative importance on the hybrid OD/OER-RO process. Furthermore, the choice of operational parameters in further lab- and pilot experiments will be supported by the results gained in this research.

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