BOOK OF ABSTRACTS

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Recent designs of marine installations for desalination plants in Morocco

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INCREA has developed the design of the marine installations for many desalination plants in Morocco. It made detail design for Dakhla, Casablanca, Jorf Lasfar and Safi desalilnation plants. It also made the tender project for Nador and Tanger desalination plants. The main challange is due to the rough sea weather at the Atlantic Coast and the large capacity of these plants. This means that, for instance, intake towers for Safi desalination plants have a total height of 13,3 m and an external diameter of 7 m (10,2 m at the slab). Tunnels are a good optioin for these pipelines and PE pipes of large diameter are used for trenched sections. In many cases, dividing the tower in several parts is the only way to construct them. Joints shall be carefully studied. Dilution studies (assessing environmental impact and recirculation of brine) are the best way to optiize the layout. Wave studies (with propagation to the site) are the only way to make a correct design.

Keywords: Marine; Pipelines; Intake tower; Morocco; Tunnel; Atlantic Ocean desalination; Africa; HDPE; Concrete; Dilution; Recirculation

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Direct numerical simulation of flow and mass transfer in feed spacer-filled channels of membrane separation processes

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This study evaluates the effect of different flow regimes on the mass transfer coefficient for feed spacer-filled channels in membrane separation processes such as reverse osmosis (RO) and nanofiltration (NF) using direct numerical simulation (DNS). We computed local and global mass transfer coefficients by coupling hydrodynamics with the solute transport (convection/diffusion) and permeation through the membrane. The computational domain was built with arrangements of spacer units based on accurate 3-D CT scan of a commercial reverse osmosis feed-spacer using MATLAB. The DNS model was implemented and solved in ANSYS Fluent 2023R2. Computations were performed considering different hydrodynamic conditions (spacer "floating" within the feed channel and spacer "touching" the membrane), in a wide range of inlet channel velocities (0.02–0.6 m/s). Different flow regimes can be present simultaneously at different locations in the channel and these were categorized based on dynamics in space and time (regular and irregular laminar-steady, periodic and unsteady). The effect of external perturbation at different velocities and positions was evaluated, showing that at industrial conditions (velocity <16 cm/s), it would be difficult to grow instabilities within the flow, showing a laminar-steady behavior. Furthermore, vortex analysis showed that spacer works as static mixer and not as "turbulence promoters". Finally, The DNS model allowed to evaluate the effect of each flow regime on the mass transfer coefficient through the traditional Sh-Re power law, where the dependency of Sh with Re varied from the expected 1/3 in the laminar-steady flow to 0.9 in the transition regime.

Keywords: Desalination; Feed spacers; Computational fluid dynamics; Mass transfer correlations; Concentration polarization

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A stepwise approach to use nanofiltration membranes instead of RO to produce drinking water at high recoveries

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Reverse osmosis is now well recognized method of water desalination and treatment. Yet, some problems exist that are haunting RO from the first days of it's industrial application, such as: high concentrate discharge, high operational costs. The disadvantages of RO as a method of drinking water supply are: required large water supply production, high drinking water price.

RO OEMs really underestimate another membrane method - nanofiltration. This method still has many unfulfilled potentialities. Moreover, the main reason of unsuccessful operation of membrane facilities is the wrong membrane choice, particularly, the use of RO instead of nanofiltration.

This report presents a new technology to treat ground water based on the use of nanofiltration membranes and produce pure water for drinking and industrial needs. Instead of a single step of RO process that reduces TDS by 100 times, we use three steps, where each step reduces TDS by a factor of 5. Thus, we reduce TDS by 5 multiplied by 5 and again by 5, that is 125.

First: We get rid of scaling. Second: Change ion concentration ratios and separate solution. Third: Reduce concentrate. This technology is known as "osmotically assisted RO". A new approach solves the problems: to exclude care for scaling control, to radically decrease concentrate, to escape complicated pretreatment. The selection of NF membrane characteristics is very important factor. The difference between rejection of polyvalent and monovalent ions and organic molecules is the key factor. And another key-factor is the construction of the membrane channel. We use a modified membrane channel that enables us to reduce flow resistance due to fouling, and also increase the live cross section of the flow. Calcium carbonate scaling rates are experimentally determined that confirmed that NF membrane modules possess significantly lower scaling propensities. Thus, for majority of cases we can refuse the antiscalant dosing, control or even govern the permeate composition. For example, a simple technique enables us to remove lithium and increase calcium in permeate on the final stage.

Flow diagrams demonstrate the stages of concentrating and dilution that enables us to separate ions and achieve the required ratio of monovalent and divalent cations. When reducing concentrate flow, it is very important to escape scaling in the flow and to avoid the beginning of spontaneous homogeneous nucleation. Therefore, we should control the supersaturation ratio not to exceed the supersaturation limit. The results of calculation of supersaturation values that correspond to the beginning of spontaneous homogeneous nucleation in the concentrate flow are presented. These values were experimentally determined by "catching" of crystals containing in concentrate flow.

Keywords: Nanofiltration; RO; Ion concentration ratio; Membrane module; Rejection

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Brine-based backwash for ultrafiltration systems in seawater desalination: Chtouka (Agadir) plant – case study

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The Chtouka (Agadir) seawater desalination plant in Morocco, currently producing 275,000 m³/d and expanding to 400,000 m³/d, employs ultrafiltration (UF) as pretreatment for reverse osmosis (RO). During operation, in some seasons raw seawater quality exceeded turbidity and suspended solids often doubling expected values. This led to increased fouling rates on the UF, higher frequency of backwash (BW) and chemical enhanced backwash (CEB) cycles, reducing net permeate availability and raising energy consumption. To address these challenges, an alternative solution was implemented following allowable action from UF manufacturer: using RO brine for UF backwash instead of ultrafiltered water. Commissioned in April 2025, this approach required some piping and control modifications while maintaining UF performance (SDI 3) and RO integrity. A short forward flush was added to prevent residual salinity from affecting permeate quality which results on a negligible increase of salinity of raw water going toward RO.

Key results:

- Water savings: Eliminating the use of ultrafiltered water for BW increased the efficiency of the pretreatment.
- Energy reduction: Improved UF efficiency reduced raw seawater pumping needs, lowering specific energy consumption by 0.05–0.08 kWh/m³.
- Environmental benefits: Lower chemical usage and reduced overall reject volumes. • Technical feasibility: No adverse impact on RO operation or product water quality.

This experience demonstrates that brine reuse for UF backwash is scalable to other desalination plants, offering significant operational and sustainability benefits. By optimizing water recovery and energy efficiency, this solution contributes to reducing the carbon footprint of large-scale desalination.

Keywords: Ultrafiltration; Brine backwash; Energy efficiency; Water recovery; Sustainable desalination

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Techno-economic impacts of antiscalant selection on RO membrane performance in inland desalination systems

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This talk will present a desalination-focused techno-economic analysis of the new Grand Forks Regional Water Treatment Plant (GFRWTP), located in the greater Grand Forks region of the northern plains of the United States. The GFRWTP is a 20-MGD hybrid water treatment facility that integrates parallel conventional and membrane-based desalination processes to address evolving regulatory requirements, water quality challenges, increased regional demand, and operational limitations of the City's former 60-year-old plant. The topic will emphasize full-scale reverse osmosis (RO) membrane performance, fouling behavior, and lifecycle costs under sustained operation. The plant's performance will be benchmarked against comparable inland desalination facilities treating surface waters with similar pretreatment and chemical cleaning strategies. Results will show that while the plant experienced relatively lower costs associated with membrane fouling, overall cleaning-related expenditures were higher, primarily due to operating a larger membrane inventory at reduced metrics and performing clean-in-place procedures more frequently. A central focus will be the role of antiscalant selection in desalination economics. Comparative performance and cost tradeoffs between two commercial antiscalants will be presented, demonstrating that one antiscalant provided superior resistance to inorganic scaling and organic fouling compared to the other one, albeit at approximately twice the unit cost. Finally, the talk will discuss how a blended antiscalant strategy may optimize desalination performance by balancing fouling control, chemical costs, and membrane replacement risk, supporting a target RO membrane lifetime of 15–20 years.

Keywords: Desalination; Techno-economic analysis; Reverse osmosis; Membrane

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Polymers of intrinsic microporosity for high performance desalination

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Hexa-fluorinated porous membranes were prepared from 4,4'-(hexafluoroisopropylidene) diphtalic anhydride (6FDA)-2,3,5,6-tetramethyl-p-phenylenediamine (TMPD) (6FDA-TMPD), which prepared by a polycondensation reaction between the dianhydride 6FDA and the diamine TMPD at 200°C, by nonsolvent induced phase inversion process for the desalination of highly saline water (70,000 mg L^{-1}) via membrane distillation (MD) technology. Here, for the first time, we demonstrate the significance of the intrinsic porosity of 6FDA-TMPD polyimide membranes, that not only result in an excellent performance in MD without the addition of porogen chemicals but also outperform other membranes including commercially available membranes. The membrane characteristics were optimized by varying the coagulation bath, dope solution concentration, and thickness. Notably, the developed membranes possess high porosity which can be attributed to the high BET surface area (550 m^2 g^{-1}) of 6FDA-TMPD. Membranes developed from an ethanol-based coagulation bath resulted in spongy-like morphology and demonstrated excellent desalination performance with a high flux (~18.20 kg m^{-2} h^{-1}) and stable salt rejection (>99.96%). The reported fabrication approach can be used to delineate the key design parameters for the fabrication of highly efficient intrinsically porous polyimide-based membranes which may pave the way for the practical application of MD for the desalination of highly saline water.

Keywords: Porous polymers; Desalination; Separation; Water treatment

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Sustainable pretreatment strategies for desalination using recycled date palm fiber waste

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Water scarcity and increasing pressure on conventional freshwater resources have made desalination a strategic solution for arid and semi-arid regions such as Morocco. However, membrane fouling and the high cost and environmental impact of conventional chemical pretreatment remain major limitations for reverse osmosis (RO) desalination systems. Sustainable and low-cost pretreatment strategies are therefore essential to improve system performance, membrane lifetime, and overall process sustainability. This study investigates an eco-friendly pretreatment approach for desalination based on the valorisation of recycled date palm fiber waste, an abundant agricultural by-product in arid regions. The proposed pretreatment system integrates natural lignocellulosic fibers as a filtration and adsorption medium upstream of a photovoltaic-powered reverse osmosis unit. Experimental investigations were conducted on different water sources, including brackish and saline waters, to evaluate the impact of the natural fiber pretreatment on water quality parameters and desalination performance. Results demonstrate that the use of date palm fiber-based pretreatment significantly reduces turbidity and improves feed water quality prior to the RO process, contributing to a reduction in fouling potential. The integration of this natural pretreatment enhances the operational stability of the desalination unit while maintaining satisfactory desalination efficiency. In addition, coupling the system with solar photovoltaic energy further improves its environmental sustainability by reducing reliance on conventional energy sources. The findings highlight the strong potential of agricultural waste valorisation within a circular economy framework for sustainable desalination pretreatment. This approach offers a promising, low-cost, and environmentally friendly alternative for improving desalination processes, particularly in regions facing water scarcity and abundant biomass waste availability.

Keywords: Desalination; Reverse osmosis; Sustainable pretreatment; Date palm fiber; Agricultural waste valorisation; Circular economy; Solar-powered desalination

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Advanced treatment of contaminated groundwater: achieving near-zero liquid discharge through a multibarrier approach

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Groundwater is a critical resource for drinking water, agriculture, and industry, yet progressively compromised by extensive contamination, while increasingly stringent regulations highlight the limitations of conventional single-unit treatment strategies. In this framework, an industrial site in Italy, facing the need to upgrade its treatment line for contaminated groundwater remediation, provided a unique opportunity to investigate advance water treatment technologies and innovative integrated strategies. Specifically, this study evaluates the technical feasibility and operational trade-offs of combining advanced unit operations into a multibarrier treatment train, targeting both regulated and emerging contaminants under a stringent water recovery goal of 99.75% to achieve near zero liquid discharge (near-ZLD). Over 60 target contaminates across nine chemical classes, including amines, sulfolane, BTEX, aldehydes, PAHs, glycols, organohalogens, hydrocarbons, and heavy metals, were monitored. Effluent concentration limits were set according to Italian legislation for discharge to surface waters (D.Lgs. 152/2006) and, for non-regulated compounds, by instrumental limits of detection or other stringent targets agreed with environmental authorities, resulting in removal efficiencies above 75%, and in some cases exceeding 99%. Bench-scale testing of individual unit operations, namely pre-oxidation–coagulation–flocculation (OCF), ultrafiltration (UF), reverse osmosis (RO), chemical transformations (reduction and oxidation processes), granular activated carbon (GAC), and granular ferric oxide-hydroxide (GFH), was performed on real groundwater samples under different process parameters. Single-unit tests achieved removal rates above 95% for Fe, Mn, Zn, and some organics, whereas persistent compounds such as aliphatic aldehydes and vanadium were often not effectively removed. Based on these results, the most effective unit operations were integrated into a sequential multibarrier treatment train and tested at laboratory scale. Starting from 300 L of contaminated groundwater, the system achieved 99.75% water recovery, generating only 0.7 L of residual waste, while still meeting removal targets. Sulfolane decreased from 1,188 $\mu g L^{-1}$ to 5 $g L^{-1}$ (>99.6%), amines from 3.0–1.8 $\mu g L^{-1}$ to below detection, naphthalene by >99%, and most heavy metals by >95%. Aliphatic aldehydes, however, increased to ~780 $\mu g L^{-1}$ after oxidative pre-treatment and required post-RO reduction with sodium borohydride to reach a 100 $g L^{-1}$ and meet discharge limits. Vanadium exhibited complex behavior, rising from 0.6 $\mu g L^{-1}$ to >3 $\mu g L^{-1}$ in some configurations, suggesting possible trace-metal release from the filtration media. Overall, results demonstrate

the feasibility of the designed multibarrier approach, providing quantified compound-specific removal efficiencies and revealing process bottlenecks, and synergistic interactions, while identifying challenges in achieving near-ZLD.

Keywords: Groundwater remediation; High water recovery; Multibarrier process; Reverse osmosis; Adsorption

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How to design a desalination plant for the safe transport of chemicals

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The global expansion of desalination infrastructure has increased the demand for safe and reliable transport of aggressive chemicals used in membrane cleaning, pretreatment, post-treatment, and brine management. These chemicals, including acids, alkalis, coagulants, antiscalants, and disinfectants, pose risks to personnel, the environment, and plant availability if leaks or failures occur. Double containment piping systems provide an effective means of reducing these risks by preventing uncontrolled releases, enabling early leak detection, and supporting compliance with increasingly strict environmental regulations. This paper outlines the key engineering principles involved in the design of double containment networks for desalination facilities, with a focus on material selection, structural design, jointing methods, and modular leak monitoring concepts. The discussion demonstrates how thermoplastic double containment systems designed in accordance with DVS 2210-2 guidelines can improve safety, extend service life, and reduce corrosion-related failures. The study concludes that corrosion-free thermoplastic containment solutions significantly enhance operational reliability and environmental protection and are well suited to modern desalination plants.

Keywords: Desalination; Reverse osmosis (RO); Double containment piping; Chemical dosing; Environmental protection; Corrosion-free thermoplastics; Leak detection; DVS 2210-2; Pretreatment systems; Membrane cleaning; Safe chemical handling

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SWAP™: Ultra-low-energy, atmospheric-pressure desalination with high-salinity tolerance

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SWAP (Salty Water Purification) is a patented, modular thermal desalination and water reuse process designed to reduce energy use, eliminate membrane/chemical consumables, and avoid toxic brine discharge. Conventional reverse osmosis (RO) and thermal systems become costly and environmentally burdensome as salinity increases and disposal requires brine management or crystallization; this is especially acute for RO brines and produced water, where high TDS and organics drive fouling, high pressure, chemicals, and large waste streams. SWAP uses repetitive evaporation/condensation cycles driven by low-grade solar or waste heat. The process operates below 100°C at atmospheric pressure (no vacuum or high pressure) and recovers ~75-80% of thermal energy through internal recycling. By operating sub-boiling with very low air velocity, SWAP suppresses aerosol formation and salt carryover ("salt does not cross the barrier"), enabling production of near-zero dissolved-solids water without membranes or chemical consumables. Residual brine can be concentrated to dryness, enabling a standalone zero-liquid-discharge (ZLD) pathway with dry salt and recoverable minerals as byproducts. Performance was evaluated on seawater, RO brines, and produced water/oilfield wash water at ~80,000-250,000 ppm total dissolved solids (TDS) (about 3x RO's practical upper feed limit and up to ~8x seawater). Validation included: (i) a solar-thermal pilot at Merlin Farms in Sharjah, UAE (2018-2020; supported by the Mohammed Bin Rashid Innovation Fund), demonstrating seawater conversion for agricultural reuse and transforming infertile desert soils into productive oases within ~1.5 years; and (ii) an industrial wash-water project in New Mexico, USA (2022), with salinity reduction verified by a certified environmental laboratory. Across sources, SWAP produced product water 5 ppm TDS at >80% recovery with 1-1.5 kWh/m^3 energy use, while removing >99% hydrocarbons/organic contaminants from feeds containing ~300–1,200 ppm hydrocarbons and meeting reuse standards. In the New Mexico project, measured salinity reduction reached 99.71%. For context, typical energy ranges for RO are ~2.5-5 kWh/m^3 and for common thermal desalination (MED/MVC/MVR/MSF) ~7-27 kWh/m^3, with crystallizers higher; SWAP therefore targets a low-energy/high-salinity regime. These results suggest low-temperature, atmospheric-pressure thermal cycling can deliver RO-class (or better) energy performance while treating ultra-saline and contaminated streams that typically require hybrid trains (RO + thermal + crystallizers) to approach ZLD. An international patent, filed under the Patent Cooperation Treaty (PCT; WIPO, with 158 countries) and operating across two continents, supports the scale-up of municipal desalination retrofits and industrial brine management, where decarbonization, consumables, and brine disposal are primary constraints.

Keywords: Thermal desalination; Humidification–dehumidification (HDH); Low-temperature desalination; High-salinity brine treatment; Zero liquid discharge (ZLD); Water reuse

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Confined water channels in polyamide RO membranes for energy-efficient desalination

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Improving the energy efficiency of reverse osmosis (RO) desalination remains a central challenge for sustainable water production. Although membrane materials and system designs have advanced, further performance improvements are increasingly limited by the trade-off between water permeability and solute rejection. Conventional design concepts based mainly on pore size and membrane morphology provide only a static description of membrane structure and cannot fully explain water transport behavior. In polyamide RO membranes, membrane pores are filled with water during operation, and strong interactions between water molecules and the polymer matrix govern selective permeation. In this context, increasing attention has been paid to water channels, defined as hydrogen-bonded networks of water molecules confined within the polyamide functional layer. Understanding the structure and behavior of such confined water is essential for elucidating the molecular origin of water selectivity. This study presents a unified understanding of water channels in cross-linked aromatic polyamide RO membranes by integrating nanostructure analysis and molecular-level characterization of confined water. Molecular dynamics simulations and neutron scattering measurements show that water molecules inside the functional layer can be classified into bound water and more mobile water clusters, which become interconnected through hydrogen bonds and form continuous transport pathways. To obtain direct experimental evidence for the structure of confined water, synchrotron-based soft X-ray absorption and emission spectroscopy was applied. The results reveal that water confined in sub-nanoscale polyamide pores exhibits hydrogen-bond structures distinct from bulk water, characterized by a lower average coordination number and a higher fraction of distorted hydrogen bonds. Importantly, water molecules in different pore environments remain hydrogen-bonded, forming continuous networks across the functional layer. These findings demonstrate that selective water permeation in polyamide RO membranes is governed by the connectivity and hydrogen-bond structure of confined water rather than by pore size alone. This water-channel-based perspective bridges molecular-level water science and practical desalination technology, contributing to the development of high-performance and energy-efficient RO membranes.

Keywords: Hydrogen bonding; Polyamide; Reverse osmosis; Synchrotron X-ray spectroscopy; Water channels

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Early warning for marine biofouling risks at seawater intake of coastal SWRO plants

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Many coastal regions are vulnerable to marine biofouling due to its unique marine conditions. In some places the specific condition, e.g. Chilean coastline with the Humbolt current or the Moroccan Atlantic coastline, nutrient-rich and oxygen-poor water is brought to the surface through coastal upwelling, enhancing biological productivity. The marine biofouling pressure depends very much on the specific location of the seawater intake. Coastal industries like SWRO (Sea Water Reverse Osmosis) plants use large volumes of seawater to produce potable water. However, besides seawater this can also introduce marine biofouling larvae within the intake system. The conditions inside the intake pipes, such as flow velocity, turbulence, and extensive surface area, make them highly susceptible to marine biofouling attachment. With the continuous flow of water, they receive food and oxygen, enabling rapid growth into hard shell organisms. When a clean pipe is exposed to seawater, it can be colonized with marine biofouling (like mussels and barnacles) within several weeks and put plant production rates at risk. Operators often lack real-time insight into marine biofouling settlement and growth inside the intake pipes and only detect problems once performance has already been affected. One of the biggest threats for seawater intake pumping stations is head loss. Head loss is a result of increased wall roughness of the intake pipe, mostly caused by marine biofouling attachment. This results in increased head loss and could reduce the production capacity of the SWRO plant. To provide operators with insight into the actual fouling situation and an early warning for head loss, a monitoring system serves as a valuable early warning tool. One such system is the Biovision® Monitor, which is specifically designed to provide ideal conditions for marine biofouling species settlement and growth, and therefore replicates the conditions inside seawater intake pipes. It can be installed as a bypass to the main seawater intake system and provides real-time data on the biofouling settlement situation inside the intake pipes. This early detection capability enables operators to take timely, pro-active measures to prevent extensive biofouling growth, avoid operational disruptions, and optimize cleaning or biocide dosing schedules.

Keywords: Marine biofouling; Fouling; Headloss; Biomonitoring

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Comparative life cycle assessment of a brine treatment plant in Morocco under different energy sources

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Membrane distillation (MD) is a thermally driven desalination process offering high salt rejection and the ability to treat hypersaline brine at relatively low operating temperatures. Despite its potential, large-scale deployment remains limited due to high energy consumption and membrane fouling. In water-scarce regions such as Morocco, where desalination is essential for water security, coupling MD with renewable energy represents a promising pathway toward sustainable freshwater production. This study used a comprehensive Life Cycle Assessment (LCA) to evaluate the environmental performance of MD systems under various energy supply scenarios reflecting both conventional and renewable pathways. Following ISO 14040 and 14044 standards, with system boundaries defined from-cradle-to-grave involving all significant phases of the process (construction, maintenance,and dismantling), and a functional unit of 1 m^3 of produced freshwater via MD technology. Environmental impacts were assessed using the ReCiPe 2016 methodology, focusing on global warming potential, ecosystem toxicity, and land-use intensity. Preliminary Results reveal that the baseline energy scenario produces the highest Global Warming Potential (GWP) (45 Disability-Adjusted Life Years (DALY)), dominated by fossil-fuel-based electricity. Substituting with renewable sources substantially reduces impacts: solar energy lowers CO_2 emissions by 90%, while wind energy achieves the lowest overall environmental burdens, with reductions of up to 96% in GWP and over 90% in water consumption. These findings demonstrate that renewable-powered MD systems can drastically enhance the environmental sustainability of desalination processes. The study provides actionable insights for policymakers and industry stakeholders to support Morocco's transition toward low-carbon, resource-efficient desalination aligned with its national water–energy nexus strategy.

Keywords: Membrane distillation; Life cycle assessment; Brine treatment; Renewable energy; Desalination; Sustainability; Water–energy nexus; Morocco

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Advancing Morocco's water future through sustainable solar-powered electrodialysis: a simulation-based economic analysis

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Water scarcity and declining rainfall pose critical challenges to Morocco's long-term water security, particularly in rural and remote areas where daily water consumption often remains below 50 L per capita. To address increasing water stress, Morocco has set an ambitious national target of achieving a desalination capacity of 1 billion m^3/year by 2050. However, the large-scale expansion of desalination infrastructure is expected to substantially increase electricity demand and greenhouse gas (GHG) emissions if conventional, hydrocarbon-based energy sources continue to dominate the energy mix, highlighting the urgent need for renewable energy integration. Morocco benefits from exceptional solar energy potential, characterized by high solar irradiation levels and long sunshine duration, making photovoltaic-powered water treatment systems particularly attractive. In this context, the present study provides a technical and economic assessment of a solar-powered electrodialysis (PV–ED) desalination system designed for decentralized, off-grid applications using low-salinity brackish groundwater. Electrodialysis is especially suitable for groundwater salinities below 3 g/L, where it exhibits significantly lower energy consumption than reverse osmosis and is well adapted to small- and medium-scale water production. The proposed system is evaluated under local climatic conditions using key economic performance indicators, including the levelized cost of electricity (LCOE), capital expenditures (CAPEX), operating expenditures (OPEX), and net present cost (NPC). Simulation results indicate that the PV–ED system can reliably produce 24 m^3/d of drinking water while meeting an electrical demand of approximately 85 kWh/day, based on an average solar irradiation of 5.4 kWh/m^2/d. The calculated LCOE of \$0.420/kWh, together with total CAPEX and OPEX estimated at \$149,744.48 and \$8,480 respectively, confirms the technical feasibility and economic competitiveness of the proposed stand-alone configuration. Overall, the results demonstrate that solar-powered electrodialysis represents a sustainable, low-emission, and economically viable solution for decentralized drinking water production in water-stressed regions of Morocco, supporting national desalination objectives while reducing environmental impact. In addition, the possibility of coupling the PV–ED system with the electrical grid is identified as a cost-optimization option, as it could further reduce capital investment by limiting battery storage requirements and improving overall system economics.

Keywords: Electrodialysis (ED); Solar energy; Solar-powered desalination; techno-economic assessment

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Public acceptance of desalinated and reclaimed water: Evidence from Spain

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Desalinated and reclaimed water are increasingly used as alternatives to conventional water sources in water-scarce regions, yet public acceptance remains uneven, particularly for potable uses. While these resources are technologically mature and increasingly deployed in countries such as Spain, a global leader in desalination and water reuse, their effective contribution to water security depends not only on technical and economic factors, but also on social acceptance and public trust. Understanding the determinants of willingness to use non-conventional water resources is therefore critical for their sustainable implementation. This study analyses public perceptions and willingness to use desalinated water, comparing acceptance patterns with reclaimed water across different applications. The analysis is based on data from a representative survey of 1,400 respondents and is grounded in the Theory of Planned Behaviour. Logistic regression models are applied to identify the main determinants of desalinated water acceptance for different uses, while allowing comparison with reclaimed water patterns. Results show high acceptance of desalinated water for non-potable uses (over 85%), including toilet flushing, irrigation, industrial applications, domestic cleaning, swimming pool filling and agricultural uses, while willingness to use it for drinking purposes remains substantially lower (43% for desalinated water versus 25% for reclaimed water). Distrust in water quality emerges as the main barrier to acceptance (64%), followed by concerns related to taste, cost, and energy consumption. Willingness to use desalinated water is influenced by socioeconomic characteristics, social norms, territorial factors, and willingness to pay. Crucially, acceptance of one non-conventional resource strongly predicts acceptance of the other, revealing significant cross-effects between desalinated and reclaimed water. These findings contribute to the limited empirical evidence on public acceptance of non-conventional water resources in Europe and provide actionable insights for policymakers and water managers. They highlight the importance of targeted communication strategies, transparency, and trust-building measures to enhance the social viability of these resources as part of climate adaptation and long-term water security strategies.

Keywords: Desalinated water; Reclaimed water; Public perception; Willingness to use; Water security

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Pyxis Lab — Advanced online monitoring solutions for reverse osmosis systems

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Core Technologies and Integrated Solutions

1. DW-2030P Multi-Parameter Inline Analyzer The DW-2030P serves as a turnkey monitoring solution specifically for clean water and beverage applications, including drinking water production and supply networks. Parameters: It continuously measures ultra-low turbidity, free residual chlorine, pH, conductivity, total dissolved solids (TDS), and temperature. Benefits: Real-time visibility allows operators to detect membrane fouling, identify changes in feedwater quality, and verify treatment performance. Monitoring turbidity and TDS supports early detection of particulate breakthrough, while pH and temperature control optimize chemical dosing and prevent scaling.

Shutterstock 2. IK-765DCL Real-Time Dechlorination Panel To prevent irreversible membrane oxidation, Pyxis Lab offers the IK-765DCL, a fully integrated monitoring and control system. Operation: It measures residual chlorine and automatically regulates sodium bisulfite (SBS) dosing to maintain zero free chlorine at the RO inlet. Impact: This system eliminates the uncertainty of manual dosing, prevents chlorine breakthrough, and reduces chemical costs while extending membrane service life.

3. ST-712 Inline ORP Sensor For small to medium RO plants where a full panel is not viable, the ST-712 sensor provides stable oxidation-reduction potential (ORP) monitoring. Function: It ensures effective disinfection control and limits biological fouling. Reliability: By preventing excessive oxidation, it protects membranes from damage and improves overall system reliability.

4. ST-500RO PTSA Monitoring System The ST-500RO is designed for the continuous measurement of PTSA, a common fluorescent tracer used in scale inhibitors. Precision: It provides direct confirmation of scale inhibitor presence, preventing under-dosing (which leads to scaling) and over-dosing (which increases costs and fouling potential). Optimization: Continuous data allows for rapid troubleshooting of chemical feed systems and optimization of chemical consumption. Conclusion The integration of the DW-2030P, IK-765DCL, ST-712, and ST-500RO establishes a data-driven framework that delivers measurable improvements in process stability, membrane protection, and long-term operational sustainability.

Keywords: Inline instrumentation; Reverse osmosis (RO); Real-time monitoring

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Experimental evaluation of multi-stage, multi-pass (batch) electrodialysis desalination brackish water at pilot plant scale

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There is a growing demand for high recovery, brackish groundwater desalination technologies in decentralized regions of the world. Multi-stage, multi-pass electrodialysis is a promising technology for high recovery desalination in decentralized and variable power and water conditions. By operating with variations in voltage over space and time, these alterations have potential to reduce CapEx while maintaining energetic benefits. However, these approaches have not been tested at scale under practical design considerations. We thus constructed a flexible, multi-stage, multi-pass (batch) electrodialysis platform at pilot plant scale. We conducted comprehensive experimental evaluations under varied feed salinities, recoveries, hydraulic conditions, and current densities, characterizing their energy, productivity, and cost performance. Our experimental campaign consisted of over 200 individual, automated batches, at 75+/-2% recovery, 25+/-2 C over the course of several months. In our initial (1-2 stack) batch testing campaign, we find an all-inclusive, Pareto-optimal system SEC bandwidth of 2 to >14 kWh/m^3 with a time-averaged production rate of roughly 1 to 8.5 m^3/h, respectively, in operation on 6000 and 12000 µS/cm NaCl solution with a target salinity of 1000 µs/cm. We find the pareto optimal (minimum SEC, maximum productivity) points are typically at the upper range of our applicable constant current operation; constant voltage operation does not ever appear in these experiments, on the pareto frontier—indicating constant current as desirable for batch operation at scale. Additionally, we find the SEC components from practical auxiliary and hydraulic losses can often account for a third of the SEC – these are areas often neglected or overlooked at lab scales in literature. The as-built levelized cost of water (LCoW) was a minimum of $1.89 USD/m^3, with projected practical opportunities to lower the LCoW to $0.42 given improvements in energy efficiency (reducing hydraulic and auxiliary SEC), extending system lifetime, and reducing the system CapEx in half (by removing extraneous sensing, control, margins on component prices). These experimental results establish how multi-stack configuration and operating strategy govern the achievable performance envelope of batch electrodialysis systems at pilot scale.

Keywords: Electrodialysis; Multi-stage; Multi-pass; Batch; Pilot; Renewables; Experimental campaign

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Custom tailored loose nanofiltration membrane incorporating cationic/zwitterionic polymer for enhanced separation performance

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The nanofiltration (NF) membranes have a tight polyamide layer on the polymeric support that facilitates the high rejection of most of the salts and organic solutes. The conventional polyamide layer, which is produced by the piperazine and trimesoyl chloride reaction, is reported to have critical membrane fouling and high concentration polarization that effectively decreased the filtration efficiency. Development of NF membranes that comprise unique properties and characteristics is an emerging area of research in water treatment. In this work, the selectivity of the polyamide NF membranes containing diethylenetriamines has been tuned with the addition of a new rationally designed terpolymer containing cationic/zwitterionic motifs. The novel terpolymer was synthesized from diallyl dimethylammonium chloride (DADMAC), 3-(N,N-diallyl-N-methylammonio)propanesulfonate (DAMAPS), and N,N-diallyldodecane-1,12-diamine (DADA), and then grafted in situ in the polyamide active layer of the membrane via interfacial polymerization to enhance the permeability of the salts while maintaining the rejection of the dye (EBT). The fabricated membrane exhibited 5.8 times increase in water flux, with a remarkable rejection of ~99.9% for EBT. Additionally, the modified membrane demonstrated enhanced permeability for various salts, including NaCl, $MgCl_2$, Na_2SO_4, and $MgSO_4$. Moreover, the incorporation of the poly-(DADMAC-co-DAMAPS-co-DADA) terpolymer into the diethylenetriamine polyamide active layer improved the hydrophilicity and stability of the membrane, making it suitable for long-term operations. These findings suggest that aliphatic diethylenetriamine membranes have a great potential for desalination applications, and their performance can further be optimized by introducing zwitterionic moieties to enhance salt permeability while maintaining high dye rejection rates, making them highly valuable for textile and environmental applications.

Keywords: Clean water; Polyzwitterions; Cyclopolymerization; Solute selectivity; Antifouling performance

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Learning at scale: Shared knowledge and lessons from mega desalination projects

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The global desalination sector is experiencing a rapid increase in mega projects, typically ranging from 600 to over 1,000 MLD, driven by economies of scale and growing water scarcity. While these plants promise lower unit costs and higher supply security, they also magnify technical, financial, and organizational risks. In practice, similar mistakes are frequently repeated across projects, often due to fragmented experience, limited consolidation of lessons learned, and insufficient education beyond traditional engineering silos. This work addresses the need to transform dispersed industry experience into accessible, shared knowledge that supports better decision-making in large-scale desalination.

The proposed approach is based on a global, community-driven knowledge platform developed through The Water MBA. Instead of relying solely on academic literature or isolated project reports, this model enables continuous interaction among professionals across geographies and disciplines. Real project experience is transformed into shared knowledge through courses, interviews, discussions, and curated case-based learning. This contribution focuses on identifying the most recurrent questions and concerns raised by the community regarding mega desalination plants and presenting practical lessons learned from large projects. By openly discussing challenges encountered in projects, the work introduces a collective learning framework that complements conventional technical approaches.

The analysis highlights recurring gaps in areas such as project governance, risk management, procurement strategies, operational readiness, and long-term performance expectations. The key result is the identification of common pitfalls that, if better understood early by professionals, could significantly improve project outcomes. Increasing awareness of these issues can enhance competitiveness, reduce costly redesigns or delays, and improve the overall reliability of mega desalination plants. The findings suggest that structured knowledge sharing and continuous professional education are critical enablers for the sustainable scaling of desalination worldwide.

Keywords: Desalination; Mega desalination plants; Knowledge sharing; Large-scale infrastructure; Water education; Risk management

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Thermoplastic piping systems for SWRO: Enhancing reliability, durability, and lifecycle performance

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Seawater reverse osmosis (SWRO) has become the dominant desalination technology worldwide, driven by growing water scarcity and increasing demand for reliable freshwater supply. While membrane efficiency and energy recovery systems have advanced significantly, piping infrastructure remains a critical yet often underestimated component affecting plant reliability, safety, and lifecycle cost. Conventional materials such as steel and glass-reinforced plastics (GRP) are prone to corrosion, joint failures, and complex installation requirements, particularly in aggressive marine environments. AGRU presents a comprehensive evaluation of thermoplastic piping systems—primarily high-density polyethylene (HDPE) and polypropylene (PP)—as applied to the full scope of SWRO desalination plants, including seawater intake pipelines, outfall systems, intake and distribution manifolds, low-pressure permeate piping, and internal process networks as well as concrete protective systems for basains. Drawing on extensive project experience from AGRU Kunststofftechnik GmbH, the study highlights how material properties, advanced production technology, and fully welded joint concepts contribute to long-term system integrity. Key technical aspects addressed include chemical and biological resistance to seawater, chlorine, and cleaning agents; mechanical behavior under pressure, temperature fluctuations, and cyclic loading; and hydraulic performance enabled by smooth internal pipe surfaces. Special attention is given to large-diameter piping solutions and prefabrication strategies that enable efficient installation in onshore, offshore, and near-shore applications. The results demonstrate that thermoplastic piping systems offer a significantly extended service life with minimal maintenance requirements, reduced leakage risk due to homogeneous welded joints, and faster installation compared to traditional materials. Furthermore, their corrosion-free nature and recyclability support sustainability goals and reduce environmental impact over the plant lifecycle. Conclusion: thermoplastics represent not merely an alternative but a technically and economically superior solution for modern SWRO desalination plants. Their integration enables more resilient, cost-efficient, and future-proof water infrastructure, particularly in regions with harsh climatic and marine conditions such as the Middle East, North Africa, and coastal regions worldwide.

Keywords: Seawater desalination; SWRO (seawater reverse osmosis); Thermoplastic piping systems; HDPE pipelines; Polypropylene (PP); Seawater intake & outfall; Desalination plant infrastructure;Corrosion-free materials; Large-diameter pipes; Lifecycle cost optimization; Welded piping systems; Sustainable water infrastructure

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Optimization of SWRO performance through single- and multi-OEM membrane hybridization

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Hybrid membrane configurations are increasingly applied in seawater reverse osmosis (SWRO) systems to achieve target permeate quality while preserving system efficiency and recovery. By combining membrane elements from multiple OEMs with differing salt rejection characteristics, operators can optimize water quality, productivity, and energy use. This study presents a systematic, simulation-driven framework for configuring multi-OEM hybrid membranes within a single pressure vessel, demonstrating how element selection and placement can be tailored to meet varying product salinity requirements without additional energy demand or operational penalties. The methodology ensures hydraulic compatibility and stable operation while delivering economic benefits. The approach is validated using real operating data from a large-scale commercially operating SWRO plant, highlighting its potential to reshape conventional industry practices.

Keywords: Membrane hybridization; Seawater reverse osmosis; Energy consumption; Multi-OEM membrane configuration; Product water quality

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Why FEED design of seawater intakes is the key to prevent future head loss

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Critical to the production capacity of a coastal utility (SWRO plant) is a seawater intake system operating according to design specifications. One of the biggest threats for seawater intake systems is the headloss along the marine intake pipelines. Head loss is a result of increased wall roughness of the pipeline, mostly caused by aging and marine biofouling attachment. Increased roughness disrupts the smooth flow of seawater, creating more turbulence and friction resulting in increased head loss, reducing the water levels available at the pumping station and decreasing operational efficiency of the intake system. Even after physical cleaning, some fouling organisms remain on the pipe internal surface, leading to irreversible increases in head loss and decreases the seawater flow to the utility. Seawater intake pipes provide optimal conditions for marine biofouling to attach and grow. The velocities inside the intake pipes are generally within a range which provide optimal circumstances for the larvae to attach to the surface. Due to the continuous flow of seawater, an abundance of nutrients and oxygen is continuously provided to give them the ability to grow fast into hard-shell organisms. Once the organisms grow, they change the wall roughness of the pipe surface. Biofouling species can grow on top of each other and can form a layer of marine biofouling species of several tenths of centimeters thick. This significantly impacts the incoming seawater flow due to a reduction of the pipe diameter and increasing wall roughness. Even prior to operation, seawater intake pipelines are exposed to marine biofouling risks during installation. It is common to identify biofouling accumulation during construction (unprotected pipelines are exposed to seawater) resulting in pre-existing head loss at the commissioning stage, immediately impacting the production of the utility from the start. Once a system is operational, remedial actions to recover head loss are often costly and technically difficult to execute. To avoid the risk of increased head loss it is important to consider the favorable conditions for biofouling at the early stages of design (FEED stage) of a seawater intake system. A consideration of the fouling risks during the design stages of the intake system in combination with a proper marine biofouling prevention method and (bio) monitoring plan is key to secure seawater flow capacity and provide production guarantee of the utility. Chlorine production capacity should be tailored to local specific requirements considering the life cycle and spawning periods of local marine biofouling species. In addition, a proper design of the chlorine dosing and dosing dispersion structure is key to secure an effective prevention of marine fouling and to prevent future problems with blockages due to scale buildup in pipes and dozing nozzles. This paper provides insight into preliminary actions which should be taken during the FEED design stage of seawater

Keywords: Seawater intake; Head loss; FEED design; Marine biofouling; Ecodosing

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Next generation high efficiency energy recovery device

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Seawater desalination is the process of turning seawater into fresh water for domestic, industrial, power, and irrigation purposes. With over 21,000 desalination plants operating worldwide, a number that is growing due to increasing water scarcity, desalination has become a well-established water utility, serving more than 300 million people. The invention isobaric ERDs substantially increased energy recovery efficiency and completely disconnected the ERD from the high-pressure pump. With efficiencies of more than 95%, SWRO specific energy consumption reduced to less than 3 kWh/m^3 in the RO section. This improvement helped make desalination affordable, leading to enormous growth of SWRO plant size and number over the last 20 years. More than 40,000 isobaric ERDs are operating around the world today. Nevertheless, the largest contributor to SWRO operating cost is energy consumption, comprising up to 60% of total costs to desalinate. Therefore, further reductions in energy consumption provided by increased ERD efficiency are desired. Increasing ERD efficiency requires understanding device inefficiencies and addressing them with design changes. In isobaric ERDs, like Energy Recovery's PX Pressure Exchanger device, pressure losses in the high- and low-pressure streams, volumetric losses to lubrication flow, and mixing between the brine and feedwater in the device are the primary losses. Reducing pressure losses requires redesign of flow paths to increase cross sectional flow area and reduce bends, expansions, and reductions to the greatest extent possible. Reducing lubrication flow requires tightening of seals by reducing clearances between moving and stationary parts. Mixing is reduced primarily by reducing turbulence in the streams flowing through the device. The purpose of this paper is to quantify the benefit of isobaric ERD improvements on specific energy consumption (SEC) of SWRO. It focuses on the Next Generation PX device, the most efficient ERD ever produced. In addition to energy recovery efficiency, other important attributes of ERD performance are considered, including maximizing operability, reliability, flexibility, and minimizing footprint. The authors present this information in the context of large scale SWRO plants due to their impact on energy consumption and CO_2 generation and the potential contributions of performance improvements toward more sustainable water supply.

Keywords: ERD; Isobaric; Pressure exchanger; Efficiency; Energy savings; Energy consumption; SWRO

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Energy recovery in low, high, and ultra high-pressure reverse osmosis systems

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There is no doubt that the implementation and optimization of energy recovery devices in seawater reverse osmosis (SWRO) desalination have been important in reducing costs, enabling the wide acceptance and application of SWRO for production of water for human consumption worldwide. The rapid growth of desalination and the construction of mega-plants would not have been possible without the achievement of significant milestones in reliable energy efficiency, driven by the development of modern isobaric energy recovery devices. In recent years, water conservation has become a key priority worldwide, leading to increased constraints on water extraction and wastewater discharge, and encouraging water recycling in both municipal and industrial sectors. Regulations and operating permit requirements limiting discharge volumes are driving the development and employment of minimum- and zero-liquid discharge (MLD and ZLD) treatment trains. These processes can be complex and expensive, involving multiple unit operations. Reverse osmosis (RO) is playing an important role in emerging water treatment and conservation processes, providing relatively low cost, high reliability, high effectiveness, and ease of operability compared to alternative technologies. These attributes have led to wide adoption of RO processes globally. Although local variations in seawater salinity and temperature can influence SWRO operation, the process itself has standardized, with limited variations in configurations. These systems are comprised of a high-pressure pump, a single stage of SWRO membranes, and an energy recovery device. However, the diverse properties of other natural water sources, industrial water, and wastewater, together with differing treatment requirements, necessitate new membrane types and custom process designs. This has stimulated a new era of RO innovation. Membranes able to operate effectively at low pressure, very high pressure, in water laden with foulants, and/or in water with extremely high levels of dissolved salts are necessary. Low-pressure RO including brackish water RO (BWRO), multi-stage, batch- and semi-batch RO systems, and ultrahigh pressure RO (UHPRO), and osmotically assisted RO (OARO) are processes that have been recently developed and have gained significant traction. The goal of this presentation is to show how innovative RO membrane systems can benefit from the energy savings offered by energy recovery technologies. Different process configurations and case studies will be presented using isobaric energy recovery devices, centrifugal devices, or a combination of both device types. Operating enhancements, such as increased flexibility, maximum process uptime, and ease of implementation, will be discussed. Recommendations that will help plant designers and operators achieve optimal balance between capital expenditure (CAPEX) and operating expenses (OPEX) will be provided.

Keywords: High recovery; Energy consumption; SWRO; UHPRO; OARO; NF; Semi-batch RO; Batch RO; Isobaric; Centrifugal; Energy recovery devices

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Selective magnesium recovery from seawater-derived solutions through recyclable metal-organic framework glass-based adsorbents

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Magnesium is essential across sectors ranging from biomedicine to advanced materials manufacturing and water treatment. Growing concerns about supply instability, driven in part by declining land based deposits, have led the European Union to designate magnesium as a Critical Raw Material, increasing the urgency for alternative and sustainable recovery strategies. Seawater and industrial waste streams, such as desalination brines, have recently gained attention as abundant secondary sources that align with circular economy principles. Yet, recovering magnesium from these chemically complex water systems remains challenging, as ions such as calcium, sulfate, and bicarbonate compete with Mg^{2+} and compromise separation efficiency. Conventional approaches, including polymer based membranes and ion exchange resins, often fall short due to limited selectivity and insufficient thermal and chemical robustness. To overcome these constraints, we present a newly engineered metal-organic framework (MOF) glass composite resin specifically designed for targeted magnesium recovery from seawater and brine. This hybrid material merges the durability and processability of inorganic glasses with the tailored ion selective properties of MOF, enabling highly efficient discrimination between divalent cations. The composite exhibits superior Mg^{2+} uptake compared with commercial adsorbents, demonstrating strong selectivity over calcium and other co existing ions. Its performance has been validated using real seawater samples from the Red Sea (Saudi Arabia), the Mediterranean Sea (Spain), and the Baltic Sea (Denmark), confirming its robustness across diverse salinity and ionic profiles. Building on these results, we are developing a self supporting membrane derived from the same hybrid system, offering a scalable and resilient platform for resource recovery in desalination and water reuse operations. This work contributes to emerging strategies for sustainable magnesium extraction from seawater and brines and supports the broader transition toward circular resource management in water treatment technologies.

Keywords: Magnesium; Resource recovery; Seawater mining; Brine valorisation; MOF glass; Novel adsorbents; Circular economy

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A global outlook of the desalination industry and state-of-the-art technologies for brine valorisation

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Desalination has become a cornerstone for addressing global water scarcity, yet its rapid expansion generates vast volumes of concentrated brine, often discharged despite containing valuable resources. We provide a comprehensive, data-driven analysis of the global desalination industry and the emerging paradigm of brine valorisation within circular economy frameworks. Leveraging the GWI DesalData inventory, we map over 2,000 large-scale plants, revealing seawater reverse osmosis as the dominant technology and an estimated brine output of ~121 million m^3/day, with more than 60% concentrated in the Middle East. Using region-specific seawater composition data, we quantify the theoretical recovery potential of water and multiple minerals, identifying elements such as magnesium, sodium, and calcium whose recoverable quantities could meet or exceed current global production when integrated into advanced treatment schemes. Our review analysis synthesizes over a decade of research on brine management strategies, highlighting approaches that combine fractionation, staged concentration, and selective separation to minimize energy use and scaling risks. It examines the role of systems designed to recover multiple resources—freshwater, salts, chemicals, and even energy—while addressing technical and economic barriers such as material durability, purity standards, and operational costs. Industrial case studies demonstrate that large-scale implementations currently focus on water and sodium chloride recovery, whereas multi-element extraction remains confined to pilot-scale projects due to challenges in selectivity and market integration. Overall, our work translates fragmented laboratory evidence into actionable insights for policy makers and practitioners. Key recommendations include co-locating processes with renewable energy and waste heat sources to decarbonize operations, prioritizing magnesium-first recovery schemes to unlock high-value pathways, and establishing standardized purity metrics to accelerate commercialization. By providing a global outlook and a roadmap for scaling up resource recovery, this review positions brine valorisation as a transformative strategy to shift desalination from a waste-generating process to a resilient, circular solution—particularly relevant for EUROMED regions seeking sustainable water and resource security.

Keywords: Brine valorisation; Circular economy; Critical raw materials; Desalination; Minimum liquid discharge; Resource recovery; Zero liquid discharge

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Optimization methodology for design and performance of SWRO desalination plants

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In this publication we describe an optional methodology for optimizing the design and/or performance of sea water reverse osmosis (hereinafter SWRO) desalination plants. In a nutshell, the optimization of the energy consumption parameters such as so-called the specific energy consumption (hereinafter SEC) to minimize water production costs. In general, a minimized SEC is an indicator of optimum operation and maintenance practices, thus this method shall allow also plant operators to optimize their facilities. We have identified the main variables involved in this optimization procedure, proposing a methodology based on the graphical representation of the same. This methodology illustrates that the optimized SEC depends on the permeate quality criteria and allows the designer to have a flexible threshold depending on local or project regulations. Certain strategies are introduced to evaluate the equipment efficiencies as key parameters for the calculation of SEC; not just on the design phase but also when operating the plant. This methodology stresses the access to operational data in order to predict water cost in an annual basis and how these costs shall be minimized accordingly. Lastly this methodology is able to correlate the local electricity rate with process variables such as the flux in the RO system. This tool shall give the designer an accurate outlook how process variables affect the cash flow of the project.

Keywords: SWRO optimization; Specific energy consumption (SEC); ROPTIMAX methodology; Desalination efficiency; Energy optimization; Parameter correlation; Permeate quality; Payback calculation; Operational expenditure; System-wide optimization; Recovery rate; Flux optimization; Temperature influence; Equipment efficiency

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Evaluation of optimal operational conditions of a multimedia filter for seawater pretreatment

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Reverse osmosis (RO) desalination is a leading solution to water scarcity, but membrane (bio) fouling remains a major challenge, making effective pretreatment critical. Granular media filtration is widely used but often inadequate for microbial control, while conventional indicators such as turbidity and silt density index (SDI) overlook submicron and microbial particles. Therefore, this study evaluated a novel four-layer multimedia filter (MMF; anthracite, silica, alumina, magnetite) at pilot scale treating real seawater under variable hydraulic loads (up to 40 m/h) and shock chlorination (10 ppm NaOCl, 30 min/d). Performance was assessed using conventional metrics (turbidity, SDI) and advanced tools (high-resolution particle counting, flow cytometry, dissolved organic carbon (DOC)), while considering the influence of flow rate, backwash interval, and chlorination regime. The MMF achieved 94–99% particle removal (0.5–20 µm) across phases, with improved stability following bed conditioning and lower hydraulic loading (30 m/h). Most residual particles were 1 µm. Microbial removal ranged from 20–50%, improving over operational phases. Peak removal occurred during initial chlorination, but prolonged exposure at high flow reduced retention, suggesting possible media aging or microbial detachment. DOC removal was minimal and seasonally variable alongside microbial counts. SDI remained 3 in most cases and correlated with particle and microbial counts during specific phases. Particle counts aligned with turbidity in the feed but not in the filtrate, while microbial counts showed no correlation with turbidity at all, highlighting the need for direct monitoring. Backwash recovery was rapid for particles (~15 min) but slower for microbes (~48 h), with optimal performance 8–11 days post-backwash. Economic analysis indicated ~30% lifecycle cost savings over DMF due to reduced CAPEX and chemical use. These findings demonstrate the MMF's robust and scalable performance, and provide a framework for optimizing RO pretreatment through flow, chlorination, and backwash management.

Keywords: Pretreatment; Seawater reverse osmosis; Biofouling; Multimedia filter

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Gravitational vapor compression desalination (GVCD) — a breakthrough for this millennia

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Seawater desalination is an energy-intensive process and gravitational vapor compression desalination (GVCD) opens the possibility to bring about a paradigm shift in the industry and significantly reduce the energy consumption for desalination to unprecedented low levels. GVCD is a phase change TRL 6 technology based on compressing primary vapor using liquid water injectors and proprietary double fluted tubes with micro-groves. Classified as "green" technology, GVCD is considered as an environmentally friendly option in desalination as chemical treatment of water is not required and the brine released is entirely green, less concentrated and at ambient temperature. Additionally, the GVCD energy consumption is substantially lower than that required by commercialized seawater desalinization technologies and its thermodynamic principles have been proven in a prototype unit. Recent computational fluid dynamics (CFD) modelling has successfully confirmed that the technology allows for the desalination of 42,000-ppm seawater with a specific energy consumption (SEC) of approximately 2.2 kWh/m^3—nearly a third lower than recently commissioned optimized SWRO projects. GVCD recycles 100% of the latent heat and just requires electricity as input; works at ambient temperature and does not require external heat input; it just requires macro-filtration as the only pretreatment. GVCD has the potential to jump from current incremental innovations in desalination to newer heights. It is robust seawater desalination technology with low maintenance costs and minimal environmental impact, capable of transforming the freshwater paradigm. ACWA Power, the largest private developer for desalination projects entered into an industrial development agreement with WGA Water Global Access to further mature the technology to TRL9 level, including testing at a full-scale pilot plant, providing real data for technology validation.

Keywords: Specific energy consumption; Green desalination; Seawater desalination; Phase change; Latent heat

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Subsea desalination plant brine discharge and environmental impact

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Seawater reverse osmosis (SWRO) desalination is a critical solution for global water scarcity but faces major sustainability challenges. Conventional land-based plants operate at high recovery rates (45–47%), producing brine with salinity up to 1.7× feedwater (~70,610 mg/L TDS) and discharging into shallow coastal zones, causing localized salinity spikes, thermal anomalies, and chemical contamination from pretreatment additives. These factors increase ecological risk to benthic organisms and marine biodiversity while driving high energy demand (3.2–3.9 kWh/m³) and greenhouse gas emissions. This study evaluates Waterise's subsea desalination technology, which introduces a disruptive design leveraging deep-sea hydrostatic pressure and low-recovery operation to minimize environmental footprint and operational complexity. The system operates at ~23% recovery using two RO elements per pressure vessel, producing brine at ~53,328 mg/L TDS (1.3× feedwater salinity). Brine discharge occurs at depths >500 m through multiple inclined nozzles, ensuring rapid dilution and compliance with environmental standards without reliance on strong currents. Chemical dosing is eliminated via DeepGuard biostatic pretreatment, exploiting naturally clean, cold, low-biofouling deep-sea water. This approach extends membrane life from three to five years, reduces cleaning frequency, and removes chemical pollutants entirely. Energy efficiency is achieved by utilizing ambient hydrostatic pressure, eliminating high-pressure pumps and energy recovery devices, reducing specific energy consumption to 2.3–2.5 kWh/m³—30–40% lower than terrestrial systems. Comparative analysis confirms superior performance across key metrics: zero chemical usage, reduced brine salinity, improved permeate quality (177.5 mg/L TDS vs. 359.8 mg/L), and minimized ecological impact. Environmental assessments indicate negligible effects on marine sediments and fauna due to deep-water intake and controlled dispersion, while physical footprint is reduced by >80% compared to land-based facilities. The subsea configuration also enables integration with renewable energy sources, further lowering carbon emissions and enhancing ESG compliance. These findings establish subsea desalination as a scalable, environmentally responsible alternative to conventional SWRO. By addressing critical challenges of brine management, chemical pollution, and energy intensity, this technology supports global water security objectives while mitigating climate and biodiversity risks. Its deployment potential in remote or arid regions underscores its role as a next-generation desalination paradigm.

Keywords: Subsea desalination; Brine discharge; Environmental impact; ESG; Marine ecosystem protection

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Eco-friendly kaolinite–alginate beads adsorbents for advanced water treatment applications

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The elimination of hazardous substances, such as cationic dyes, from wastewater has emerged as a significant global challenge. Therefore, a crucial environmental objective is the creation of innovative materials that are economical, efficient, and ecologically benign. In this work, a novel porous biocomposite based on Kaolinite/Alginate was successfully prepared using spheronization, a straightforward, controlled process that requires minimal chemical reagents. A variety of characterization methods, such as Fourier-transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), scanning electron microscopy (SEM), energy-dispersive spectroscopy (EDS), thermogravimetric analysis (TGA), particle size distribution, and pH stability tests, were used to examine the structural and physicochemical characteristics of the Kaolinite/Alginate beads. The developed composite was subsequently utilized to remove methylene blue (MB), a persistent dye commonly found in industrial effluent. The results showed that the porous architecture produced by spheronization and its advantageous interactions with methylene blue combine to give the composite a remarkable adsorption capacity. According to the Langmuir isotherm model, the maximal monolayer adsorption capacity was found to be 112.12 mg/g. The pseudo-first order and Elovich models best represent the adsorption behavior, according to kinetic and isotherm investigations. Five cycles of regeneration and reuse were carried out to assess the reusability of the material, and thermodynamic characteristics verified that the process is both exothermic and spontaneous. The regeneration effectiveness decreased from 80.20% in the first cycle to 62.5% in the last cycle, but it remained comparatively high. As a result, this investigation highlights the spheronized Kaolinite/Alginate composite's great potential as a long-lasting and effective adsorbent for dye removal from aqueous media.

Keywords: Adsorption; Kaolinite; Alginate; Spheronization; Methylene blue

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Electrospun PVDF@MIL-53(Fe) metal organic framework: membranes for potential water treatment

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Wastewater presents considerable environmental concerns due to the presence of various organic and inorganic contaminants, necessitating the development of efficient and long-lasting separation technologies. Membrane filtration has emerged as a possible alternative to traditional treatment methods; nevertheless, designing cost-effective membranes with high separation efficiency, durability, and fouling resistance remains a significant issue. Electrospun PVDF membranes have been developed and filled with MIL-53(Fe) metal organic framework at varying percentages (1% to 5%). The properties of the PVDF polymer and the integration of MOF at various percentages were confirmed using XRD, FTIR, SEM, and TGA techniques, as well as contact angle for all of the latter membranes. In addition to their robust properties, the produced membranes displayed exceptionally high mechanical strength and hydrophobicity, as validated by swelling tests and water uptake capacity. The PVDF@MIL-53(Fe) membranes demonstrated a high membrane permeability.

Keywords: Electrospinning; Filtration; Membrane; Metal organic frameworks

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Subsea desalination energy advantage: a comparative analysis with terrestrial RO facilities

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Global freshwater scarcity is accelerating due to population growth, industrialization, and climate-driven droughts, making seawater desalination a critical solution. Conventional terrestrial reverse osmosis (RO) plants dominate the market but remain highly energy-intensive, consuming 3.0–3.5 kWh/m³ even with energy recovery devices, and rely on large high-pressure pumps, extensive pretreatment, and chemical dosing. These factors increase operational costs, carbon emissions, and environmental risks from shallow-water brine discharge. Waterise introduces a subsea desalination concept that leverages natural hydrostatic pressure at depths of 400–600 meters to drive the RO process, reducing energy demand and eliminating the need for large pumping systems. This approach minimizes chemical usage, simplifies pretreatment, and improves permeate quality while reducing ecological impact. The study employs a comparative analysis of energy performance between subsea and terrestrial RO facilities. Results show that Waterise's subsea system achieves specific energy consumption of 2.2–2.5 kWh/m³ — up to 30% lower than conventional plants—by utilizing ambient pressure (~50 bar) and operating at low recovery rates (20–25%). For a 50,000 m³/day facility, annual energy savings range from 16–32 GWh, corresponding to 8–34 kilotons of CO2 emissions avoided. These reductions are significant given that energy accounts for 30–45% of total water production costs in conventional desalination. Additionally, the subsea system produces permeate with lower total dissolved solids (177.5 mg/L vs. 359.8 mg/L) and discharges brine with salinity only 1.3× feedwater, compared to 1.7× in terrestrial systems, minimizing marine impact. Pretreatment requirements are simplified due to the naturally clean, cold, and low-biofouling deep-sea water, reducing chemical dependency and extending membrane life. Beyond energy efficiency, the subsea design offers operational resilience through modular architecture, remote monitoring, and predictive maintenance. Real-time data transmission and analytics enable proactive interventions, reducing downtime and costly deep-water operations. The system's compact footprint and offshore deployment eliminate large land requirements, making it suitable for regions with space constraints or sensitive coastal ecosystems. Collectively, these innovations position subsea desalination as a sustainable, scalable, and economically viable alternative to conventional systems. As global water demand rises, integrating subsea technology with renewable energy and smart process control will be essential for achieving long-term water security while safeguarding marine environments. Waterise's approach exemplifies the future of desalination—where energy efficiency, environmental stewardship, and operational flexibility converge to deliver reliable freshwater for a growing world.

Keywords: Subsea desalination; Energy efficiency; Brine management; Reverse osmosis; Sustainability

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Redefining SWRO pretreatment through ceramic membrane technology

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Seawater reverse osmosis (SWRO) systems increasingly face severe pretreatment challenges due to deteriorating intake water quality. Coastal eutrophication, algal blooms, and elevated concentrations of total suspended solids (TSS) and dissolved organic carbon (DOC) are becoming more frequent, particularly in regions influenced by municipal and industrial wastewater discharges. These conditions result in unstable operation, increased chemical consumption, and frequent fouling of conventional pretreatment systems, limiting the reliability and efficiency of SWRO plants. This study presents operational experience with ceramic ultrafiltration (UF) membranes as pretreatment for SWRO under highly challenging seawater conditions. Performance data are derived from both pilot-scale testing in Spain and full-scale operation in North Africa. In the Spanish pilot plant, extreme raw water conditions were intentionally created by dosing artificially cultivated algae to simulate high chlorophyll-a concentrations and elevated turbidity. This allowed controlled evaluation of ceramic UF performance under severe and repeatable algal bloom scenarios. The ceramic membranes demonstrated stable operation, effective solids and biomass removal, and sustained permeability despite rapid and extreme changes in feed water quality. These findings were confirmed in a full-scale installation in North Africa, where the intake is characterized by poor hydraulic design, shallow depth, and strong seasonal water quality fluctuations. High algae loads, high TSS, and elevated organic matter concentrations are routinely observed. Despite these adverse conditions, ceramic UF provided continuous 24/7 operation throughout the year, effectively decoupling intake variability from RO feed water quality and preventing fouling events typically associated with polymeric pretreatment systems. In addition to conventional coagulation strategies, the use of novel pretreatment concepts such as bentonite dosing was evaluated to further enhance organic and algal removal upstream of ceramic UF. Bentonite acts as a highly efficient adsorbent for biopolymers, algal organic matter, and hydrophobic DOC fractions that are known to drive membrane fouling. The combination of bentonite pretreatment with ceramic UF creates a robust hybrid process that significantly improves filtrate quality and reduces the frequency of chemically enhanced backwash (CEB) and clean-in-place (CIP) cycles under high-TOC and high-algae conditions. The results demonstrate that ceramic ultrafiltration, especially when combined with advanced pretreatment such as bentonite adsorption, offers a highly resilient and future-proof pretreatment solution for SWRO plants exposed to deteriorating seawater quality. This approach enables stable desalination performance even under extreme environmental and intake conditions, supporting the long-term sustainability of coastal desalination facilities

Keywords: Ceramic filtration; Seawater; Pretreatment to SWRO

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Interpretable data-driven modeling for forward osmosis: water flux prediction and parameter interaction analysis

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Water scarcity has become a pressing global challenge over the last decades, and desalination remains one of the most promising solutions. Forward Osmosis (FO) emerged as an attractive membrane-based desalination technology due to its reduced energy consumption, strong adaptability and low fouling tendency. However, FO still requires substantial research to enhance water flux performance by improving our understanding of system behavior and optimizing operating conditions. In this context, machine learning (ML) modeling has shown strong potential for accelerating the development and optimization of desalination processes, and FO is no exception. This work focuses not only on developing a reliable data driven ML model to predict FO performance, but also on upgrading it from a black-box used only for prediction into an interpretable decision-support tool. Specifically, we quantify how key design and operating parameters influence water flux, and we investigate the nonlinear interactions between these parameters to derive actionable conclusions. Four ML models were developed and benchmarked using an experimental dataset assembled from the literature, including a set of input features related to membrane characteristics and operating conditions. The best performing model was then optimized through a rigorous hyperparameters tuning to further enhance its predictive accuracy. Subsequently, an uncertainty analysis was assessed in order to quantify the model's robustness to inputs' uncertainty. Finally, interpretability analyses were conducted to rank feature importance, identify nonlinear interactions and the dominant process drivers, as well as clarifying how variations in key parameters, individually and jointly, affect water flux. Results show that XGBoost algorithm is the best performing in the water flux prediction accuracy. After rigorous hyperparameters tuning, the optimized model achieved an R^2 of 93.67% with an RMSE of 0.19 LMH. Monte Carlo simulations further confirmed the model's accuracy and robustness, with stable predictions and a narrow RMSE spread (the 95th percentile RMSE remained at 0.13 LMH). Interpretability analysis identified key contributors to water flux predictions and quantified the combined influence of interacting features on water flux predictions, as well as the features individual and paired effect on FO water flux, revealing feed solution molarity, as the most dominant driver, followed by draw solution molarity and feed velocity. The results also determined that the model's response to draw solution molarity depends on membrane orientation and draw solution molecular weight. Our findings

contribute to the desalination research and engineering community by demonstrating how ML models can support FO desalination not only through accurate water flux prediction, but also by generating interpretable insights into the governing process parameters, enabling more informed FO process design and optimization.

Keywords: Forward osmosis (FO); Seawater desalination; Data-driven modeling; Machine learning; Water flux prediction; Uncertainty analysis; Parameters interaction effects; Process optimization

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Renewable energy integration and salinity gradient power recovery for sustainable desalination in southern Morocco

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This doctoral research focuses on the development of an integrated desalination system for southern Morocco that couples renewable energy supply with salinity gradient power recovery to reduce both energy demand and environmental impact. The study specifically investigates the recovery of electrochemical energy from desalination brines using reverse electrodialysis , integrated with solar photovoltaic and wind energy sources under local climatic and hydrological conditions. A system-level modeling framework is developed to evaluate energy performance, brine salinity utilization, and operational synergies between desalination units and RED stacks. The results indicate that optimized salinity gradient exploitation can partially offset desalination auxiliary power requirements while decreasing brine discharge intensity. This work demonstrates that combining renewable energy integration with salinity gradient power recovery constitutes a viable pathway toward energy-efficient, low-emission, and circular desalination systems in arid coastal regions.

Keywords: Desalination, Salinity gradient energy, Energy recovery, Renewable energy integration, Brine valorization

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Discrepancy between salinity and pH on Na^+ rejection: Experimental and modelling insights

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Reverse osmosis (RO) is a water purification technology that balances efficiency and cost. The thin-film composite membrane, comprising a polysulfone support layer and a thin polyamide active layer (AL), is responsible for ion separation. pH/salinity effects on ion rejection in RO have been studied; however, consistent conclusions about their impact on AL are difficult to draw due to the limited pH range and salt levels explored (unrealistic pH/salinity ranges for RO operation); moreover, their reproducibility by a mathematical model remains unknown. The most widely accepted description of the charge density relies on three functional groups (FGs, one amine and two carboxylic) and accounts only for proton-binding. Recent evidence indicates that the representation of the charge density should account for only two FGs, incorporating both proton- and sodium-binding effects. Therefore, we experimentally investigate the impact of pH/salinity on the brackish water at the RO system pH. Furthermore, we describe the experimental NaCl and water transport using a 1D solution-friction model with a new mathematical representation of charge density. Free carbonate experiments were performed by adjusting the pH with HCl and NaOH, and N_2 was bubbled through the feed tank and sample points. The pH was varied from 6 to 10 across four salinity levels (1000, 4000, 8000, and 16000 ppm NaCl), using BW30 and SW30 membranes in parallel. A 1D SF numerical model, accounting for diffusion, electromigration, convection, and reactions, was developed to compute the concentrations of Na^+, Cl^-, H^+, and OH^- as functions of feedwater pH and salinity under various conditions. Moreover, we reformulate the charge density model in the active layer, considering only two FGs (amine and carboxylic), and proton- and sodium-binding effects. The Na^+ permeability (BNa) was affected by the H^+ concentration in the feedwater, with BNa decreasing linearly with increasing pH. This effect was most pronounced at low salinity (1000 ppm). As salinity increased, the slope of BNa vs pH feed tended toward zero, showing that at higher salinities (16000 ppm), the BNa remains unchanged from pH 6 to 10. To investigate the effect of salinity, the pH of the feed tank was held constant at an initial salt concentration (1000 ppm), and then salinity was increased. Unexpectedly, increasing the salt concentration raised the feedwater pH. The SF model with the three FGs produces a reasonable fit at a single salinity; however, it overestimates the salinity effect, producing higher BNa than observed experimentally. On the other hand, our representation of the FGs (one amine and one carboxylic) reproduces our observations across different salinities and reproduces the pH/salinity effect. These findings suggest that proton- and sodium-binding effects should be incorporated into the mathematical representation of the active layer to accurately describe salinity effects.

Keywords: RO; Solution-Friction model; pH/salinity effect; 1D - numerical model; Brackish water

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Ladder electrodialysis enables efficient up-cocentration of brines and acids

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Recently, osmotically assisted reverse osmosis (OARO) was intensively investigated since it can up-concentrate brines to >200 $g.L^{-1}$ NaCl by reducing concentration gradient through the membrane. While the system design, operational complexity and energy consumption could be the bottlenecks to implement this technology in practice. Inspired by OARO, we designed a novel electrodialysis stack (ladder electrodialysis, LED) which consisted one or several "ladder" compartment with higher salt concentration to diminish the gradient gap between the diluate and the concentrate. This work demonstrated that the LED stack can easily concentrate NaCl to 300 $g.L^{-1}$ with relatively low energy consumption. Experiments on lithium chloride and sulfuric acid also proved that it is an efficient way for various streams up-concentration. Lithium ion was concentrated to 29 g/L and sulfuric acid was concentrated to 19%. Furthermore, pilot scale experiment was demonstrated and the results showed that the current efficiency was above 80% with the energy consumption 280 kWh/t NaCl. It is believed that the novel designed LED technology can be used in various applications such as saline wastewater zero discharge, lithium salt production from salt lakes and waste acid reclamation.

Keywords: Electrodialysis; Brine; Upconcentration; Concentration gradient

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Efficiency of reverse osmosis plants from a pumping equipment perspective

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Energy consumption is the largest success factor nowadays for investment in privately developed reverse osmosis (RO) plants, as it is what makes it viable from an economical point of view. With centrifugal pumps accounting for up to 90% of the energy consumption of a modern RO plant, but only about a 3% of the total investment required. It is underscored the critical importance of optimizing pumping systems across the entire water treatment chain to improve energy efficiency and reduce both capital expenditure (CAPEX) and operational expenditure (OPEX), which all affect ultimately the delivered water tariff. On this paper, we will make an analysis of the most typical plant designs and its high-pressure RO train concepts to demonstrate that if the right pumps are considered, the energy savings and initial investment will be optimized. A special attention for the high-pressure pump in terms of energy consumption, capital expenditure and operating expenditure will be shown to explain the big influence of the possible alternatives of the largest energy consumer by far. The selection of the right hydraulic (ring-section or double suction axial split single stage or double stage, with or without a HP booster pump) depending on the required individual flow and head, and therefore on the RO train design concept and the plant size, will very much influence on all the mentioned key parameters. Apart from the different above-mentioned designs, on this study will also be demonstrated that selecting the most efficient pumps in at least the most critical equipment is essential to reach the excellence in the plant energy consumption and operating expenditure, even if the initial capital investment is not as low as desired. Comparisons of energy consumption versus CAPEX of the intake system and pumps and an example of just some slight decimals of efficiency in the high-pressure pumps of a real and existing plant will be explained. By integrating hydraulic optimization into early-stage design and procurement decisions with the pump manufacturers partnership, desalination projects can achieve a more favourable energy tariff, improve financial returns, and contribute to global sustainability goals. Pump selection is no longer a secondary decision but a core driver of energy and cost performance in modern desalination infrastructure.

Keywords: Energy efficiency; Pumps; High pressure; Energy consumption

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Data-driven optimization in large-scale RO facility: a comprehensive case study in operational excellence

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Operational efficiency in MEGA RO facilities are often hampered by a reliance on non-representative data and generic chemical treatments. This presentation details a comprehensive optimization process conducted at an 18 million m³/y facility over an 18-month period. The project aimed to transition the plant from a reactive maintenance model to a proactive, stability-focused operation. The methodology and results presented are applicable across all RO configurations, including BW, SW and industrial. The methodology relied on a two-pronged approach: Data integrity and chemical precision. Real-time operational and parameters key performance indicators integrated into a comprehensive data ecosystem. In parallel, multiple analytical rounds conducted and validated using statistical methods to ensure data representativeness. This multi-month data collection phase was essential to establish baseline conditions and identify operational patterns previously obscured by sparse sampling regimes. This data was processed using a proprietary Smart Membrane Management (SMM) algorithm developed in-house. The SMM tool performed deep statistical analysis to detect operational "micro-events" (subtle deviations in system behavior that precede major performance issues). The analytical framework systematically answers three fundamental questions for each identified event ("WWW"): What happened? Why did it happen? What needs to be done? This diagnostic approach enabled the identification of root causes and the prescription of specific corrective actions in real-time, fundamentally shifting the operational philosophy from reactive troubleshooting to proactive optimization. Simultaneously, a comprehensive chemical audit revealed that the chemistry of the existing antiscalant was not the-best fit for the feed water's characteristics. The substitution with a highly concentrated, target-specific antiscalant formulation allowed for a fourfold reduction in dosage while achieving better scale inhibition performance and lower fouling formation rate. This chemical optimization was guided by detailed water chemistry analysis correlated with operational data from the continuous monitoring system. The results following 18 months of operation were substantial and sustained. The facility observed a significant reduction in CIP from monthly to quarterly intervals. This improvement resulted from enhanced scale control and early detection of fouling precursors, directly decreasing chemical consumption, minimizing water waste during cleaning cycles, and significantly reducing operational downtime. Furthermore, membrane replacement rates were halved compared to historical baselines, yielding immediate ROI. This improvement reflects both better chemical treatment and early intervention enabled by continuous monitoring. The extended membrane life directly impacts capital expenditure while reducing operational disruptions associated with membrane changeouts.

Keywords: RO; Optomizarion; OPEX; O&M

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Tunnelling solutions for water intakes and brine outlets in desalination plant construction

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Due to increasing water scarcity, seawater desalination plants are being built all over the globe, and Morocco is at the forefront of this trend. The country faces significant challenges in securing water resources for its growing population and agricultural sector. One of the most ambitious initiatives is the Casablanca Integrated Water Project (IWP), which will become Africa's largest desalination plant, powered entirely by renewable energy. The installation of shore approaches for seawater intake and brine outlet lines is a major component in desalination plant construction. These works in coastal areas can have significant environmental impact and are therefore attracting increasing public attention. To minimize this impact and achieve public acceptance, trenchless solutions have become indispensable for large and medium-sized seawater desalination projects. Microtunnelling technologies, including conventional pipe jacking and Direct Pipe, are the most widespread techniques for constructing tunnels or installing pipelines from onshore to offshore, followed by subsea recovery of the tunnel boring machine. These methods have been significantly advanced in recent years, enabling longer drives and safer installations while reducing offshore operations to a minimum. Morocco's projects, such as Casablanca IWP, are adopting these tunnelling solutions to protect sensitive coastal ecosystems and meet sustainability goals. By combining renewable energy with environmentally friendly construction techniques, Morocco is setting a benchmark for integrated water management. This paper will share the latest trends of slurry microtunnelling in desalination plant construction. Successful references around the globe create trust with clients and planners, positively impacting planning opportunities and subsequent project execution.

Keywords: Tunnelling; Water intakes; Brine outfall lines

efficiency and purity of the powders produced.

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Development and experimental testing of a sorption-based desalination + cooling system

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Adsorption desalination (AD) integrated with cooling represents an innovative technology that can help in increasing overall energy efficiency in several fields (e.g. industrial, residential, shipping sectors). It can supply high-quality freshwater and cooling at the same time or autonomously. Sorption materials are the core components, they extract the water vapor from the fed brine inside the evaporator during the adsorption process, and release the adsorbed water in the form of water vapor which is then condensed in the condenser to get the portable water during the desorption process. The aim of the current study is to present the development of a sorption-based desalination system which employs silica gel as adsorbent material. The prototype consists of two modules, each one containing one heat exchanger with finned pipes and epoxy coated fins tested at CNR before. The overall layout is based on the design of the chillers that Sorption Technologies has in its portfolio. This means that each module contains the heat exchanger with the adsorbent and two lateral sections, devoted to evaporation and condensation of the refrigerant. To this aim, these two sections contain a porous structure on which liquid refrigerant, i.e. salted water, is dropped. The refrigerant is stored in two vacuum vessels, called “tank evaporator” and “tank condenser”. Each tank is connected to the two modules. Refrigerant flow is achieved by means of submersible pumps, which can also work in the operating conditions of a closed thermochemical storage, i.e. under liquid-vapor equilibrium. Under desalination operation, salt water is pumped in the evaporator tank and, after the sorption cycle is condensed in the desalination tank. After some cycles, the condenser tank is emptied, thus getting the freshwater, whereas the evaporator tank is discharged and the concentrated brine is removed. Experimental tests on the prototype were carried out at Sorption Technologies facilities under cooling mode. The results showed that up to 6 kW cooling power could be achieved, with COP up to 0.45. Starting from experimental results, a dynamic model was realized in Modelica/Dymola, to evaluate the operation of the system under different operating conditions and to calculated the theoretical specific daily water production (SDWP). Considering an adsorption temperature of 30°C, evaporation temperature of 20°C and regeneration temperature of 60°C, the prototype is able to produce up to 25 m^3 water/ton sorbent.

Keywords: Adsorption desalination; Thermal desalination; Prototype testing

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Optimizing calcite contactor remineralization process: a techno-economic framework for desalinated drinking water

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Desalinated water requires remineralization before distribution for human consumption. The process aims for three main objectives: supporting public health by adding essential minerals such as calcium and magnesium, achieving chemical stability by adjusting pH and alkalinity, and protecting the infrastructure from corrosion. Among available methods, bed calcite contactors using calcium carbonate ($CaCO_3$) and carbon dioxide (CO_2) offer a low-carbon alternative to calcium hydroxide ($Ca(OH)_2$) and carbon dioxide (CO_2). However, design and cost optimization remain challenging because performance depends on multiple interacting parameters. This presentation introduces a techno-economic optimization framework for remineralization in calcite contactors. The approach combines a dissolution kinetics model with a cost model to evaluate how treated water flow, empty bed contact time (EBCT), and regional chemical pricing (CO_2, $CaCO_3$, $Ca(OH)_2$) influence both water quality, CAPEX and OPEX. The framework ensures compliance with stability indices and hardness targets while minimizing unit treatment cost. Scenario and sensitivity analyses reveal that EBCT and chemical price variability are the dominant drivers of cost. Short EBCT reduces contactor size but may increase CO_2 demand, while longer EBCT improves dissolution efficiency at a higher capital cost. Regional benchmarking shows significant cost shifts based on local CO_2 and lime prices, highlighting the need for location-specific design rather than generic solutions. By integrating process performance with economic analysis, this methodology enables utilities to select cost-effective, compliance-ready remineralization strategies tailored to their market conditions. The work supports sustainable desalination practices by balancing technical efficiency, economic feasibility, and carbon footprint reduction.

Keywords: Desalination; Remineralization; Calcite contactors; Calcium carbonate ($CaCO_3$); Carbon dioxide (CO_2); Calcium hydroxide ($Ca(OH)_2$); Empty bed contact time (EBCT); Techno-economic optimization; Water quality compliance; Cost analysis; Sustainable water treatment

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Maintaining intake flow: Cleaning and inspection of seawater intake pipelines for desalination plants

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Seawater intake pipelines play a critical role in the reliable operation of desalination plants, where unrestricted flow is essential to achieving and sustaining design output. Even relatively small levels of biofouling and marine growth can result in a measurable reduction in effective internal diameter, leading to increased pumping energy, reduced flow assurance and limitations on plant throughput. This paper presents a practical approach to the cleaning and inspection of seawater intake pipelines using mechanical pigging systems, supported by internal inspection to verify pipeline condition and cleaning effectiveness. Reference is made to a recently completed intake pipeline cleaning and inspection project at a desalination facility in Southern Africa, where biofouling was identified as a developing restriction to flow. Controlled pigging operations were undertaken to remove marine growth, restore intake flow assurance and confirm pipeline integrity without extended interruption to plant operations, following a three-day pigging programme, pipeline flow increased from 4,000 to 8,500 cubic metres. The paper also draws on experience from routine intake pipeline inspection and maintenance activities at desalination plants in Saudi Arabia, demonstrating the repeatability and operational value of the approach across different regions and operating conditions. The paper demonstrates how routine, inspection-led pigging strategies allow intake pipelines to be managed as critical assets rather than reactive maintenance items. By maintaining clear pipelines and validating cleaning frequency through inspection data, desalination plant operators can reduce operational risk, control energy costs and ensure consistent water production over the life of the asset. While the primary focus is on seawater intake pipelines for desalination, the methods described draw on experience gained across a range of raw water, wastewater and utility pipeline applications.

Keywords: Seawater intake pipelines; Intake flow assurance; Biofouling removal; Pipeline cleaning; Desalination plant operation; Intake pipeline inspection; Marine growth management; Operational maintenance strategies; Flow assurance

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Influence of concentration polarization on RO membrane service life

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Seawater reverse osmosis (SWRO) has become the leading technology for large-scale desalination, supported by continuous improvements in energy efficiency and system design. While power consumption remains the largest operational expense, membrane replacement has emerged as a rapidly growing cost driver. Industry data show that annual replacement rates have increased from roughly 10% to nearly 33%, making membrane longevity a critical factor in overall plant economics and sustainability. A major contributor to reduced membrane lifetime is concentration polarization (CP), which elevates the risk of biofouling and accelerates performance decline. This study examines the relationship between CP, biofouling, and membrane degradation, and evaluates how controlling membrane-driven pressure can regulate element flux and reduce CP formation. Effective CP management is essential for improving membrane performance, lowering operational costs, and enhancing long-term system reliability. High-recovery operation is increasingly important in regions with limited feedwater availability, such as tourism-dependent coastal areas. However, high recovery intensifies CP, especially in the first membrane element, where low feed salinity combined with high applied pressure produces excessive flux and severe concentration buildup. This paper introduces design guidelines for economically optimized driven-pressure control. The approach ensures that each membrane element receives pressure appropriate to its position in the array. Traditional SWRO designs apply the highest pressure to the first element, resulting in elevated flux, increased CP, and accelerated fouling. A brine-staged array with interstage pressure boosting addresses this issue by dividing the system into front and rear element groups. The front elements operate at lower pressure matched to feed osmotic conditions, while the rear elements receive additional pressure to overcome the higher osmotic pressure of concentrated brine. Comparative design case studies demonstrate that brine staging with interstage boosting significantly reduces CP, lowers biofouling potential, and extends membrane lifetime. This approach decreases chemical consumption, reduces membrane waste, and can lower overall operating costs by more than 6%. It also supports progress toward zero-liquid-discharge applications, contributing to more sustainable desalination practices.

Keywords: Biofouling; Concentration polarization (CP); Desalination cost optimization; Membrane replacement

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Enhanced desalination performance of a metal-organic framework@activated carbon hybrid material

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The global freshwater situation is becoming increasingly critical due to limited availability, uneven geographical distribution, accelerated depletion, and widespread pollution. This freshwater scarcity is now a major challenge hindering the sustainable development of modern societies [1]. Given that seawater represents more than 97% of the planet's water resources, desalination has emerged as a strategic solution capable of sustainably increasing the global water supply [2]. However, conventional desalination processes, whether thermal (distillation) or membrane-based (reverse osmosis), remain limited by high energy costs, significant operating expenses, and technical constraints that impede their widespread deployment. In this context, the adsorption process appears as a promising alternative for water desalination, offering simple implementation, high operational flexibility, and a lower risk of contaminant formation or material fouling [3]. The objective of this study is to design and evaluate a new hybrid material, developed from recovered natural waste and Metal-Organic Frameworks (MOFs), the latter being known for their highly porous structures, large specific surface area, and ability to selectively interact with salt ions. This innovative material opens new perspectives for more efficient, sustainable, and less energy-intensive desalination solutions.

Keywords: Desalination; Water treatment; Activated carbon; Metal–organic framework

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Harnessing light for water: Photothermal membrane distillation for sustainable desalination

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The rapid advancement of effective photo-active materials has positioned photothermal membrane distillation (P-MD) as a highly promising technology for sustainable water treatment. P-MD enables the direct utilization of solar energy to induce localized heating at the feed–membrane interface, thereby enhancing desalination performance. By generating localized heating at the membrane surface, P-MD overcomes key limitations of conventional MD, including high thermal energy consumption and temperature polarization effect. This approach enhances the transmembrane temperature gradient, boosting permeate flux, lowering energy consumption, and advancing sustainable desalination. Recent advances in P-MD incorporate photoactive materials (carbon nanoparticles, plasmonic nanostructures, semiconductor additives) into membrane to enhance light-to-heat conversion and precisely tune membrane properties via material selection and structural design. Our research has explored a range of membrane preparation strategies, including electrospinning and spray coating, to develop P-MD membranes incorporating carbon-based (graphite, carbon black) and semiconductor-based (iron(III) oxide, zinc oxide) photothermal layers. These layers are designed with specific morphology, optical properties (absorbance, reflectance and transmittance), thickness, pore size and porosity, which are key parameters governing heat localization, mass transfer and overall MD desalination performance. As an illustrative example, graphite was employed as a low-cost, visible-light-absorbing photothermal material to prepare dual-layered surface-modified PVDF-HFP nanofibrous membranes via electrospinning, achieving a maximum light absorption efficiency of 86.81% at an optimal graphite loading of 20 wt.%. The resulting permeate flux enhancement was governed by trade-offs among photothermal absorption efficiency, thermal conductivity, and photothermal layer thickness. Experimental and numerical results have demonstrated that optimizing membrane architecture, photothermal additive loading, and operating parameters (i.e. solar irradiation intensity, feed flow rate, ambient temperature) can significantly enhance water permeate flux and thermal efficiency. In addition, our investigations on multi-layered and mesh-gridded solar-driven membrane designs have shown improvements in mechanical stability and internal fluid dynamics within membrane modules, supporting the scalability of P-MD systems. Beyond experimental and modeling studies, the application of machine learning, data mining, and bibliometric analyses to P-MD enables systematic identification of performance-limiting factors, technology-driven improvement strategies, and opportunities for large-scale, decentralized solar desalination.

The financial support of the project PID2022-138389OB-C31, funded by MICIU/AEI/10.13039/501100011033/FEDER, UE, and the grant RED2024-153562-T funded by MICIU/AEI /10.13039/501100011033, are gratefully acknowledged.

Keywords: Photothermal membrane distillation; Solar energy; Desalination; Temperature polarization; Carbon-based materials; Semi-conductors; Membrane surface coating; Electrospinning; Electro-spraying; Modelling

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Carrier-ion interactions in membranes enable efficient nitrate and chloride separation in wastewater

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Nitrate (NO_3^-) contamination often co-occurs with chloride (Cl^-) in natural water and wastewaters, yet the mechanism of their highly selective separation remains unclear. This knowledge gap stems from the neglect of scenarios where separation is governed solely by a single transport stage—independent of the overall transmembrane rate—and from the absence of highly selective membranes. Guided by coordination-chemistry calculations, we engineered an anion-exchange membrane (101M) and benchmarked it against a low-selectivity commercial AEM (AMX). Membranes were characterized by SEM, FTIR, SAXS, CO_2 sorption, surface charge, water volume fraction, and contact angle. Electrical transport measurements employed a four-electrode cell in single-salt (NaCl or $NaNO_3$) and mixed-salt (1:1 NaCl/$NaNO_3$) solutions at 0.1–0.5 mol·L^{-1}. Macroscale conductivity was analysed via the Nernst–Einstein relation to decouple counter-anion concentration from diffusion in the membrane, while Arrhenius analysis quantified apparent activation parameters. To resolve where selectivity originates, we applied the Kinetic Barrier Network (KBN) model to decompose partitioning and diffusion contributions and identify the stage controlling ion preference. Finally, we validated practical separation implications in a flow-electrode capacitive deionization (FCDI) platform. The 101M membrane displayed unprecedented NO_3^-/Cl^- selectivity: FCDI tests achieved up to 95% NO_3^- removal with a minimum specific energy of 0.33 kWh·kg^{-1} NO_3^- and a selectivity factor of 20.7, to our knowledge the highest reported. These results overturn the “faster-ion-migrates-first” paradigm for this separation and establish interfacial preferential permeation as a decisive, designable lever for high NO_3^-/Cl^- selectivity. The mechanistic framework provides actionable targets—tuning interfacial energetics and partitioning—toward membrane architectures enabling energy-efficient nitrate remediation and broader environmentally targeted ion separations.

Keywords: Ion selectivity; Interfacial preferential permeation; Transition state theory; Kinetic barrier network model; Flow electrode capacitive deionization

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Hydrodynamic control of bubble size in flotation-based PFAS removal from drinking water

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The persistence and longevity of poly- and perfluoroalkyl substances (PFAS) represent a major challenge for wastewater treatment and increasingly threaten drinking water resources. Due to their bioaccumulative nature and resistance to degradation, PFAS removal technologies often rely on energy-intensive processes or face significant limitations in scalability. This work investigates flotation, an established and energy-efficient water treatment technique, as a potential separation method for PFAS, with a specific focus on the influence of nozzle and gas disperser geometry on bubble formation and separation performance. In flotation processes, gas bubbles transport surface-active compounds to the liquid surface, where they can be removed as foam. For drinking water applications, altering the chemical environment is undesirable, as it increases downstream treatment effort and energy demand. Consequently, this study focuses on geometrical and hydrodynamic process parameters, particularly bubble size, distribution, and gas holdup, as key levers for process optimization. Venturi nozzles were identified as especially promising due to their self-aspirating operation, eliminating the need for additional gas injection equipment. A range of 3D-printed Venturi nozzles and dispersers were designed and systematically compared with commercially available devices. Experiments were conducted using tap water to closely approximate real-world drinking water treatment scenarios. Bubble formation, size distributions, and gas holdup were quantified using high-speed imaging and image analysis. The results demonstrate that increasing gas flow rates increase both, bubble diameter and bubble number density, while nozzle throat geometry strongly influences bubble formation. In particular, nozzles with smaller minimum cross-sections generate larger bubbles, indicating intensified shear and enhanced coalescence within the nozzle. Flotation performance was evaluated using methylene blue as a tracer in combination with sodium dodecyl sulfate (SDS) as a PFAS surrogate, avoiding contamination risks associated with PFAS handling during early-stage development. Removal rates were determined via time-resolved sampling and spectroscopic analysis, while foam formation dynamics and mass balances were used to assess process efficiency. The results show that higher gas flow rates significantly enhance foam production and that nozzle and disperser designs producing smaller average bubble sizes with narrower size distributions achieve superior removal performance. These findings demonstrate that nozzle and disperser geometry are decisive design parameters for flotation-based PFAS removal. The presented data provide fundamental insight into bubble–hydrodynamic interactions and establish a robust basis for the development of energy-efficient flotation systems. A transfer towards a pilot plant is subject of ongoing research.

Keywords: Flotation; Nozzle design; Bubbles; PFAS; Hydrodynamic; Process development; Water treatment

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Design and testing of a solar desalination unit for emergency conditions

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During emergency scenarios—such as earthquakes, tsunamis, or failures of centralized water supply infrastructures—the lack of safe drinking water rapidly turns into a humanitarian crisis. In arid regions, where freshwater availability is intrinsically limited, this issue is further aggravated, as access to potable water relies on desalination. In this context, a small-scale, stand-alone desalination unit integrating solar-thermal energy and air-gap membrane distillation (AGMD) can provide a decentralized solution to supply the daily drinking water demand of a household (1–5 L/d). This work focuses on the design and optimization of such a desalination unit. The system is conceived as a sandwich-like multilayer structure composed of stacked layers of different materials. The upper layer functions as a solar-thermal collector, directly heating the feed water flowing in the underlying feed channel along the membrane surface. Due to the presence of a colder air gap on the permeate side, a vapor pressure gradient develops across the membrane, inducing a water vapor flux. The air gap temperature is regulated by a cooling plate, beneath which the cooling water flows. The cooling water is exposed to ambient conditions, while the feed and cooling circuits are independent closed loops. Fluid circulation is ensured by two peristaltic pumps powered by a compact photovoltaic system. To meet portability and rapid deployment requirements, a first reduced-scale prototype (300 × 500 mm) was fabricated. A bench-scale setup was assembled, and several full-day field experiments were conducted to evaluate system performance under direct solar power. In all tests, freshwater productivity followed the temporal trend of solar irradiance. Under optimal conditions, a peak permeate flux of 0.4-0.45 $L \cdot m^{-2} \cdot h^{-1}$ was measured, corresponding to a thermal efficiency of 30-40%. In parallel, a two-dimensional, time-dependent numerical model was developed to support the design process. The model simulates the transient behavior of the system over an entire solar day, accounting for variations in solar irradiance, ambient temperature, and wind speed. The coupled heat and mass transfer equations are solved using the finite difference method in a two-dimensional domain. The model is intended to predict the temporal evolution of permeate flux and the internal thermal field within the module, as well as to quantify the impact of environmental variability on system performance. Both the model and the prototype are currently being scaled-up to design a real-scale version of the device and to maximize productivity while preserving portability. A productivity assessment in different coastal zones is being conducted in parallel.

Keywords: Membrane distillation; Solar desalination; Stand-alone; Emergency conditions; Drinking water

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Beating biofouling: How a revised cleaning and pretreatment strategy restored RO performance

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The case study to be presented focuses on a plant in the energy sector treating a source water containing leachate and wastewater generated on-site to produce high-quality water for the plant's steam turbines. Reverse osmosis (RO) cleanings were being performed every 2 to 4 weeks, but results remained consistently unsatisfactory, with differential pressure (dP) remaining elevated and system performance declining shortly after cleaning. Membrane autopsies and cleaning studies were conducted to characterize the fouling and identify the most effective cleaning regimen to restore RO performance. Based on the autopsy results and the subsequent full-element cleaning study, performance was successfully restored and dP reduced using a new biofilm-targeted cleaning chemical, resolving the plant's initial issues with ineffective cleanings. To provide a long-term solution and prevent rapid re-fouling, the feedwater pretreatment was reevaluated. It was found that the chlorination and dechlorination process using sodium bisulfite (SBS) contributed to more severe biofilm formation. A new biofilm disruptor was implemented at full scale in early 2025. Data from autopsies, bench-scale and full-element studies, and full-train RO implementation, along with operational data collected over the subsequent year demonstrate that system performance was fully restored after the clean-in-place (CIP) and remained stable over months of operation. Cleaning frequency was significantly extended from every 2–4 weeks to no cleanings required in 2025 to date resulting in significant cost savings in chemical and energy consumption, and overall plant efficiency. Abstract Disclosure I have presented a portion of this subject matter at IberAqua 2025 in Madrid for a Water Positive-focused presentation.

Keywords: Biofouling; System optimization; Performance restoration; CIP; Pretreatment

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Yearlong field trial of a brine reuse architecture for point-of-use, reverse osmosis systems

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Point-of-use (POU) brackish water desalination is a globally growing market as groundwater quality decreases and health education increases. Reverse osmosis (RO) dominates the market due to its high contaminant removal, ease of maintenance, and affordability. To maintain low costs in a consumer market, POU-RO systems prioritize extending membrane lifetimes by using smaller membrane areas and applying low back pressure on the brine stream. Even though this reduces the risk of fouling, these systems operate at low recoveries, between 10-40%, with the produced brine traditionally plumbed down the drain. In many decentralized communities who need to conserve water, typically due to a combination of factors like water scarcity and cost of pumping or hauling, this high water wastage limits adoption of these systems. Since the feed water in these systems is brackish and the low recoveries result in a brine stream concentration 11-66% higher than the feed concentration, it was hypothesized that the brine could be diluted and reused. This study explores a simple, yet elegant brine reuse architecture for eliminating POU-RO water waste. Commercially-available POU-RO systems were installed in 9 remote households in the arid southwest of the United States with plumbing to enable convenient brine reuse. A third of the homes had pre-existing plumbing with a cistern and septic tank, so a satellite tank was installed to collect the brine for reuse. In the remaining 6 homes, who had no existing water infrastructure, a tank was installed to provide water to a kitchen faucet and the POU-RO system. The brine stream was plumbed to the top of the tank to dilute with the feed water and enable convenient reuse. Sensors were installed to monitor performance and usage from April 2025 to April 2026 and quarterly interviews were conducted to understand user experience. Throughout the yearlong study, a majority of the systems saw marginal salinity increases in-between tank replenishments. Homeowners reported no noticeable effects from reusing the brine, expressed appreciation for the convenience of the system, and noted the significant cost savings from reducing bottled water consumption.

Keywords: Point-of-use; Brackish; Brine reuse

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Optimize and design of photovoltaic materials for high-efficiency on-grid desalination

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In recent years, there has been increasing pressure on freshwater resources, and at the same time, the growing energy demand has also highlighted the urgent need for sustainable water production technologies. In arid and solar-rich regions, photovoltaic-powered desalination has emerged as a promising solution. In our work, an on-grid photovoltaic-desalination framework is investigated with a particular focus on the role of photovoltaic material optimization in maximizing freshwater production. Density functional theory (DFT) is employed to investigate the structural and electronic properties of advanced photovoltaic materials, followed by SCAPS-1D device simulations to examine the effect of the interfacial defect densities on power conversion efficiency (PCE), fill factor (FF), open circuit voltage (VOC), and short circuit current density (JSC). The photovoltaic performance is automatically linked to desalination output through the estimation of the freshwater production capacity of a reverse osmosis (RO) unit operating in an on-grid mode. The results indicate that higher photovoltaic efficiency increases solar energy utilization for desalination, reduces grid dependence, and lowers the specific energy cost of water generation.

Keywords: DFT; SCAPS-1D; On-grid desalination; Photovoltaic materials

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CTA-HF SWRO membrane — establishing a new industry benchmark in operational durability and performance efficiency

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Cellulose tri-acetate (CTA) hollow fiber (HF) reverse osmosis (RO) membranes possess several advantageous characteristics, including a large membrane surface area, strong anti-biofouling properties, high fouling tolerance, superior chlorine resistance, and high salt rejection. CTA HF RO membranes have over 30 years of operational experience in the Middle East (ME) region and have been widely applied in seawater reverse osmosis (SWRO) plants. CTA HF RO membranes manufactured by TOYOBO MC were originally designed in a 10-inch diameter configuration for conventional SWRO plant designs. To enable application in modern SWRO configurations and extend the benefits of CTA HF RO membranes to a wider range of plants and clients, an 8-inch diameter CTA HF RO membrane has been developed. This newly developed membrane maintains the same fundamental performance characteristics as the conventional CTA HF RO membrane and additionally offers interchangeability with other membrane types, allowing direct replacement without system modification. In recent years, ensuring water security through desalination has become a strategic priority in the ME region.water security through desalination has become a critical issue in the ME region. Despite the rapid global expansion of SWRO installations, a significant number of plants operating in semi-enclosed seas such as the ME face operational challenges due to region-specific seawater conditions, resulting in unstable operation and elevated operating costs. The primary causes of these challenges include: 1. difficulty in controlling severe membrane fouling caused by organic and biological matter in RO feed water 2. increased chemical consumption due to frequent membrane cleaning; 3. high energy consumption due to elevated operating pressure 4. higher environmental impact from chemical dosing to mitigate fouling; and higher CO_2 emission due to high energy consumption 5. increased membrane replacement rates due to performance deterioration. A SWRO plant located in Al-Lith, south of Jeddah on the Red Sea coast of the Kingdom of Saudi Arabia, was designed as a conventional SWRO system comprising canal intake, pressurized sand filtration, micro-cartridge filtration, and first-pass RO using polyamide spiral-wound (PASW) RO membranes. Since its commissioning in 2012, the plant has experienced severe operational issues associated with membrane biofouling. To mitigate these issues and improve plant efficiency, one RO train was retrofitted with CTA HF RO membranes in March 2023. Under identical seawater and operating conditions, the plant has operated for more than nine months with different membrane types installed in parallel SWRO units. Throughout the monitoring period, the CTA HF 8-inch RO membrane demonstrated superior performance compared with the PASW RO membrane, including: 1. lower specific power consumption; 2. reduced chemical cleaning frequency; 3. higher water production; and 4. improved product water quality;

Keywords: Cellulose tri-acetate (CTA); Hollow fiber; RO membrane; Anti-biofouling; Fouling tolerance; Chlorine resistance; Energy consumption; CIP frequency; Production availability; 8-inch RO membrane; SWRO; Middle East; Saudi Arabia

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Performance and energy implications of cellulose tri-acetate hollow fiber membranes in seawater reverse osmosis

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The specific energy consumption of seawater reverse osmosis (SWRO) desalination has decreased by more than 50% over recent decades; however, energy demand remains a critical challenge for improving the affordability and sustainability of potable water production from seawater. Further optimization of energy-intensive areas within SWRO plants is therefore required. Cellulose tri-acetate (CTA) hollow fiber (HF) reverse osmosis membranes offer several inherent advantages, including a large effective membrane surface area, strong resistance to biofouling, high tolerance to fouling, superior chlorine resistance, and high salt rejection. CTA HF membranes have more than 30 years of operational experience in the Middle East and have been widely deployed in large-scale SWRO applications. Hollow fiber membranes demonstrate reduced fouling propensity due to several intrinsic characteristics. Biological fouling is minimized because CTA membranes are compatible with continuous or intermittent chlorination. Fouling from inorganic and suspended particulate matter is also reduced due to the relatively large spacing between fibers and the filament-wound array configuration, which enhances flow paths and limits colloidal accumulation. Consequently, CTA HF membranes typically exhibit longer continuous operating periods, lower cleaning-in-place (CIP) frequency, and reduced pressure drop across pressure vessels. Concentration polarization is a key factor limiting membrane performance, as salt accumulation at the membrane surface increases local osmotic pressure, reduces effective driving force, and limits achievable recovery. Owing to their significantly higher membrane surface area and optimized flow distribution, hollow fiber membranes are less susceptible to concentration polarization and can achieve single-element recoveries of up to 30–35%, compared to approximately 15% for conventional seawater polyamide spiral-wound (SWPA) membranes. In SWPA pressure vessels, permeate flux distribution is inherently uneven, with lead elements producing a disproportionate share of total permeate, leading to increased fouling risk, while tail elements experience elevated salinity and scaling potential. In contrast, CTA hollow fiber membranes provide more uniform flux distribution along the pressure vessel, improving energy efficiency, operational stability, and overall membrane utilization. This paper reviews the operational performance of an SWRO system equipped with eight-element pressure vessels and presents a comparative evaluation of CTA hollow fiber and polyamide spiral-wound RO membranes under identical operating conditions.

Keywords: Cellulose tri-acetate (CTA); Hollow fiber (HF); Reverse osmosis (RO) membrane; Anti-biofouling; Fouling tolerance; Chlorine resistance; Energy consumption; CIP frequency; Production availability; 8-inch RO membrane; Seawater reverse osmosis; Middle East; Saudi Arabia

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Use of membrane concentration polarization (CP) to monitor and control membrane biological fouling in SWRO desalination

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Membrane biofouling in SWRO desalination that occurs at the feed-end elements is the greatest impediment to successful operation. In the design of SWRO plants so as to avoid this problem, it is imperative that one be able to predict the biofouling potential. Two of the commonly used indicators for membrane biofouling potential, SDI and MFI, which monitor the effectiveness of pretreatment before the SWRO membranes, have been shown to be ineffective. We, however, have observed that membrane concentration polarization (CP) is the most effective indicator to monitor membrane biofouling potential. There exists a critical or sustainable CP that controls the aggregation of marine bacteria in membrane boundary layer that is responsible for the aggregated bacterial to deposit onto the SWRO membrane. The critical or sustainable CP is dependent on the permeability of the SWRO membrane and the designed recovery. As the critical and sustainable CP decreases, the greater the membrane biofouling potential increases. Thus, one can predict the membrane fouling potential more effectively than the SDI and MFI methods by using the membrane CP method, Most SWRO plants that are designed are single-staged facilities with pressure vessels containing 6-8 elements and operate in the range of 40-50% recovery. Since membrane biofouling issues occur when the critical or sustainable CP is exceeded, it is imperative that to avoid these biofouling issues that the critical or sustainable CP not be exceeded. It has been observed that most single-staged SWRO plants operate in recovery range of greater than 40% and that the critical or sustainable CP is decreased as recovery increases. As recovery increases, more frequent SWRO membrane cleaning occurs as the membrane biofouling potential increases. It appears that the only way to avoid membrane biofouling issues in single-staged SWRO is to limit the recovery to below 40% recovery which keeps the membrane CP below its critical or sustainable CP value. Therefore, in order to control membrane biofouling issues from occurring one must limit its recovery which reduces the efficiency of operation. To achieve a low membrane CP in SWRO desalination and control membrane biofouling issues, one can design the SWRO facility using brine-staging that allows for decreasing the membrane CP and control of membrane fouling potential. In contrast to single-stage SWRO design, brine-staging allows for the membrane CP to stay below its critical and sustainable CP and avoid biofouling issues while operating in recovery range of 50-70%. Not only can membrane biofouling issues be controlled by incorporating brine-staging, but the specific energy consumption (SEC) when using FEDCO bi-turbo technology in brine-staging is lower when compared to using isobaric ERDs along with using booster pumps. It is apparent that the most future innovation in SWRO is brine staging with FEDCO bi-turbo technology.

Keywords: Concentration polarization; Membrane biological fouling; Brine-staging; Fouling index

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Salinity gradient power for a sustainable future: Insights from reverse electrodialysis

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Salinity gradient power (SGP), also known as osmotic energy salinity or blue energy, is an emerging renewable energy source obtained from the controlled mixing of waters with different salinities. This work provides a comprehensive assessment of SGP development by combining global research trend analysis, regional resource evaluation, and experimental validation, with particular emphasis on reverse electrodialysis (RED). Bibliometric analysis supported by machine learning and data analytics is first applied to elucidate the worldwide dynamics of SGP research, identifying scientific progress, dominant topics, collaborative networks, leading research groups, and the most widely adopted technologies by country. Among the various SGP technologies analyzed, reverse electrodialysis and pressure retarded osmosis emerge as the leading approaches, with a clear and growing increase in research activity focused on RED. To illustrate the practical potential of SGP, natural river–sea interfaces suitable for energy harvesting were identified in Spain as a case study. A geospatial assessment was conducted using river gauging stations located within 20 km of the coastline. The maximum theoretical extractable energy at each site was estimated based on the Gibbs free energy of mixing, using temperature, flow, and salinity data obtained from the European Copernicus Marine Service, Spanish river basin authorities, and the Instituto Geográfico Nacional. Analysis of 21 selected river–sea sites yields a total theoretical potential of approximately 6667 GWh/year (under ideal conditions and without taking into account other river´s flow uses), with the Ebro region identified as the most promising natural resource for SGP exploitation in Spain. In parallel, systematic laboratory-scale RED experiments were performed using salinity gradients ranging from 5 to 65 g/L NaCl to assess process feasibility and performance. The RED stack achieved an open-circuit voltage of up to 5.7 V and a maximum power density of 0.42 W/m² under seawater salinity conditions (35 g/L NaCl), demonstrating the technical viability of RED for energy recovery. Overall, this study highlights the significant potential of SGP, particularly through RED technology, as a sustainable and exploitable energy resource when leveraging existing natural and artificial salinity gradients. The financial support of the project PID2022-138389OB-C31, funded by MICIU/AEI/10.13039/501100011033/FEDER, UE, and the grant RED2024-153562-T funded by MICIU/AEI /10.13039/501100011033, are gratefully acknowledged. Abstract Disclosure M. Khayet et al., Elucidating the Dynamics of Salinity Gradient Energy Research, Renewable and Sustainable Energy Reviews, 219 (2025) 115812.

Keywords: Salinity gradient power; Blue energy; Reverse electrodialysis; Natural salinity spots; Bibliometric analysis; Machine learning; Renewable energy

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Comparative evaluation of pressure-exchange and turbine ERDs under varying feed-flow conditions

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Energy recovery devices (ERDs) play a main role in optimizing the specific energy consumption of seawater reverse osmosis (SWRO) systems, there are a different type of Energy recovery devices, but the most important types are the Pressure exchanger (Piston technology) and Turbocharger (Centrifugal technology). There are many studies about which technology is more efficient, reliability, cost efficient and more in general but we need to have a close look at this comparison in different flows. Their performance is strongly influenced by the flow regime and the number of units installed within the energy recovery battery. This study presents a comparative evaluation of ERD technologies—primarily pressure exchange systems and centrifugal/turbine based devices—under varying feed flow conditions. The analysis highlights how pressure exchange ERDs, while highly efficient at nominal design flow, experience a progressive decline in overall system efficiency as additional devices are added to accommodate higher plant capacities or to manage flow imbalance. Each added pressure exchanger introduces incremental hydraulic losses, increased mixing between high pressure brine and low pressure feed, and greater sensitivity to off design flow ratios. These effects compound across the battery, reducing net transfer efficiency and elevating the required high pressure pump load. In contrast, flow driven turbine ERDs exhibit more stable performance across a wider operating envelope, albeit with inherently lower peak efficiency. The comparative results demonstrate that system level efficiency—not device level efficiency—governs the true energy benefit of ERDs, and that improper scaling of pressure exchange systems can erode their theoretical advantages. The findings provide practical guidance for selecting and sizing ERDs in large scale SWRO plants, emphasizing the importance of flow matching, device count optimization, and minimizing internal mixing losses to preserve high energy recovery performance.

Keywords: Energy recovery devices; Pressure exchanger; Turbocharger

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Study of a simultaneous cooling and desalination system using CO_2 as a refrigerant and AGMD

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Climate change is increasing in regions of high water stress, with projections showing exacerbation particularly along the Mediterranean coasts and in the Maghreb countries. Population growth and rising living standards are driving the expansion of desalination and cooling demand for air conditioning and datacenters. This paper investigates the performance of air gap membrane distillation (AGMD) as a solution for using fatal energy lost by cooling systems. The hydrophobic and microporous nature of the PTFE membrane of the AGMD unit requires less pre-treatment and remains effective for feed solutions at high salt concentrations. The paper details an experimental setup and presents the performance of an AGMD unit. A multi-physical model was developed with EES software and validated by the experimental results. The air gap had a thickness of 1 mm. The temperatures of the hot channel ranged from 40 to 90°C, while the cold channel was maintained at 20°C, with salinity varying from 0 to 300 g/L. The AGMD model was coupled to the model of a CO_2 cooling system. Unlike conventional thermodynamic systems, CO_2 can heat water at high temperatures without losing efficiency in a transcritical cycle. The design and the range of operating parameters are primarily discussed. Finally, the performance of the system in terms of permeate flux, recovery rate, rejection factor, gained output ratio, specific thermal and electric energy consumptions and coefficient of performance is compared to the ones of existing cooling and desalination systems.

Keywords: Fatal energy; Air gap membrane distillation (AGMD); CO_2 cooling

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Sustainable scale control and biofouling mitigation in seawater reverse osmosis using aKua® 100 and data-driven dose optimization

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Seawater reverse osmosis (SWRO) desalination plants are required to operate at increasingly high recovery rates while reducing environmental impact, chemical consumption, and biofouling risks. Inorganic scaling caused by carbonates, sulphates, phosphates, silica, and multivalent metal ions such as calcium, magnesium, iron, and manganese remains a major operational limitation. In addition, some conventional antiscalants may contribute assimilable organic matter that can promote bacterial growth and biofouling. This study presents aKua® 100, a high-efficiency antiscalant based on aKuaCop® technology, specifically developed for seawater desalination under high salinity conditions. The optimized neutralization process used in aKuaCop® technology produces a highly stable phosphonate molecular structure with enhanced ion-complexing capability. A single aKua® molecule can bind up to three metal ions simultaneously, enabling effective scale inhibition at significantly lower dosages compared to conventional antiscalants. aKua® 100 exhibits high water solubility (>91 g/L), extremely low volatility (Henry's constant 6×10^{-17} atm·m³/mol), and high stability across a wide pH and temperature range. From an environmental perspective, the product is not classified as hazardous, presents low toxicity to aquatic organisms, and has a low bioaccumulation potential (log Pow -3.5). The low dosage requirement and optimized molecular design minimize the introduction of nutrients into the process, reducing the availability of assimilable organic matter and limiting bacterial growth in dosing systems and membrane surfaces. Dose optimization was performed using KleinScale ROI software, integrating feed water chemistry, operating conditions, and scaling indices. This data-driven approach reduces chemical consumption, lowers operating expenditure, and supports higher recovery rates without compromising membrane integrity. Operational experience in large-scale SWRO plants confirms that aKua® 100 provides robust scale control, improved biological stability, and enhanced sustainability, fully aligned with the EDS Marrakech vision of efficient, safe, and environmentally responsible desalination.

Keywords: Seawater, Reverse osmosis, Desalination, Antiscalant; Biofouling mitigation; Sustainability; Dose optimisation

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Next-generation post-treatment: Driving efficiency and resource recovery

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Remineralization is a critical step in desalination processes, restoring essential minerals and adjusting water chemistry for safe distribution. This abstract presents two innovative technologies that enhance the efficiency and sustainability of remineralization post-treatment systems, improve resource recovery, and provide sustainable operation for modern water treatment facilities. The first innovation involves the use of highly reactive milk-of-lime as a replacement for traditional caustic soda in final pH adjustment. High reactivity milk-of-lime enables precise control of water pH while reducing chemical consumption and operational costs. Being a source of both calcium hardness and hydroxide alkalinity, it has a dual function of increasing the final water hardness and alkalinity, as well as adjusting the pH to ensure a positive LSI. Its application mitigates risks associated with caustic soda handling and introduces a more environmentally friendly approach to remineralization. The second technology focuses on the deployment of Membrane Calcite Reactors to treat the backwash water generated from calcite contactors. This approach effectively recovers and reuses calcite fines, which are typically lost during conventional backwashing. By integrating membrane filtration, the system not only minimizes calcite waste but also improves overall process efficiency, reduces operational downtime, and ensures consistent water quality.

Keywords: Desalination; Remineralization; Calcite contactors; Calcium carbonate ($CaCO_3$); Carbon dioxide (CO_2); Calcium hydroxide ($Ca(OH)_2$); Milk of lime; pH adjustment; Caustic soda; Membrane calcite reactor backwash system; Innovation; Sustainable water treatment

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Nanocarbon-based coating for graphite electrodes: characterization and electrochemical desalination performance for water treatment

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This study presents an in-depth characterization of a nanocarbon material using eight complementary analytical techniques, including Fourier transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), Raman spectroscopy, Brunauer–Emmett–Teller (BET) surface area analysis, transmission electron microscopy (TEM), scanning electron microscopy (SEM), contact angle measurements, and physicochemical evaluations such as electrode electrical conductivity. Electrochemical performance was further assessed through cyclic voltammetry, galvanostatic charge-discharge, electrochemical impedance spectroscopy (EIS), and specific capacitance measurements. The comprehensive characterization results highlight the outstanding properties of the nanocarbon material, notably its high specific surface area, excellent electrical conductivity, and well-developed porous structure. These features demonstrate its strong potential for the fabrication of high-performance electrodes in electrochemical applications. In addition, the fabrication process of graphite-based electrodes incorporating the investigated nanocarbon material was optimized to enhance ion storage capability. Key parameters, including binder selection and drying conditions, were systematically examined to achieve reproducible and mechanically stable electrodes.

Keywords: Electrochemical desalination process; Nanocarbon material; Electrodes fabrication; Water treatment

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Electrocrystallization as a sustainable approach for metal recovery from secondary battery wastewater

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Wastewater from recycling secondary batteries contains high levels of valuable metals, including copper, nickel, cobalt, and manganese. Recovering these metals is essential for sustainable resource management. However, traditional methods such as solvent extraction require large volumes of chemicals and generate secondary waste. These limitations highlight the need for cleaner, simpler ways to recover metals that align with emerging environmental and industrial objectives. Electrocrystallization is a promising alternative, as it allows dissolved metal ions to be directly turned into solid metal crystals. Each metal ion has its own electrochemical properties, including reduction potentials, nucleation behaviour, and crystal growth tendencies, that can be influenced by adjusting operating conditions. In principle, these differences in ion behaviour can be used to recover specific metals selectively while minimizing the use of chemical reagents. This study, therefore, aims to explore how important process variables such as applied electrical conditions, pH, and electrolyte composition influence nucleation and metal crystal formation. By studying these factors in a controlled electrochemical setting, this work aims to support the development of electrocrystallization as a more resource-efficient and environmentally friendly alternative to traditional separation methods.

Keywords: Electrocrystallization, selective recovery, metal ion reduction, secondary battery wastewater, sustainable resource recovery

This work was supported by Korea Environmental Industry & Technology Institute(KEITI) through Digital Desalination and Brine Resource Recovery Technology Development Project, funded by Korea Ministry of Climate, Energy and Environment(MCEE). (RS-2025-02032970/20250402-001)

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Ultrafiltration and nanofiltration for the recovery of phenolic/tannic compounds and water from the cork processing wastewaters

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Cork processing wastewaters are generated in large volumes in the operation of immersion of the cork planks in boiling water for softening and disinfection. These wastewaters are a complex mixture of vegetal extracts with a very high fraction of phenolic/tannic colloidal matter that is responsible for severe environmental problems. The present work investigates an integrated process of ultrafiltration (UF)/ nanofiltration (NF) for the treatment of cork waste waters aiming two goals: 1 - Water reuse, 2 - The recovery of phenolic/tannic compounds to be used in the leather industry for the vegetable tanning of the skins. The UF cellulose acetate laboratory made membranes with molecular weight cut-off (MWCO) ranging from 1.2 to 91 kDa are characterized in terms of rejection coefficients to total organic carbon (TOC) and tannins in total recirculation mode at a transmembrane pressure of 3 bar. The spiral wound modules of NF200 membranes with MWCO of 200 kDa are operated in concentration mode to yield permeate fluxes and rejection coefficients to TOC ,chemical oxygen demand (COD), total phenolic content (TP) and total tannic content (TT) at varying concentration factors. The results show that the tannins present in the boiling water of cork planks when subjected to concentration by NF membranes have the technical feasibility for application in the Tannin industry. In fact the tannins recovered from the cork wastewaters converted the skins to leathers that have a shrinking temperature of 71ºC, well above the shrinking temperature of the skins (38ºC). The shrinking temperature of produced leather is in the range typical of commercial leathers produced with several types of vegetable tannins, from 70 to 85ºC.

Keywords: Cork processing wastewater; Ultrafiltration and nanofiltration; Water reuse; Recovery phenolic/tannic compounds; Leather industry; Vegetable tanning

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Acknowledgements

All authors acknowledge financial support through FCT R&D Unit grant UIDB/04540/2020 (CeFEMA, LaPMET).

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Coupled thermodynamic analysis, process modeling, and DCMD experiments for sustainable water recovery from steel industry effluent

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The steel industry produces large volumes of saline wastewater, creating significant challenges for water recovery and reuse. Conventional treatment technologies often struggle to achieve high recovery rates or enable near zero-liquid-discharge operation. Direct Contact Membrane Distillation (DCMD) is a thermally driven separation process that can utilize low-grade industrial waste heat, offering a promising solution for sustainable water management in steel production. In this study, DCMD was investigated for the treatment of steel industry wastewater using an integrated experimental and modeling framework. Thermodynamic simulations were performed to assess solution properties and scaling risks, while laboratory-scale experiments were conducted using a hollow-fiber polypropylene membrane module. A predictive model was developed and validated to describe mass and heat transfer performance under varying operating conditions. The combined approach enabled evaluation of system performance, recovery limits, and scale-up potential. The results demonstrate that DCMD can achieve high permeate quality, stable operation at high recovery, and strong agreement between experimental and modeled performance. These findings highlight the feasibility of coupling DCMD with industrial waste heat to reduce freshwater consumption and wastewater discharge, supporting circular water management strategies in the steel sector.

Keywords: Direct contact membrane distillation; Steel industry wastewater; Water reuse; Waste heat utilization; Thermodynamic modeling; Zero liquid discharge

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Brine concentration with low salt rejection reverse osmosis membranes

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The increasing demand for freshwater and the challenges associated with brine disposal from seawater desalination processes have led to the development of more efficient and sustainable brine concentration methods. Traditional brine concentration methods, such as thermal evaporation, are energy-intensive and costly. The low salt rejection reverse osmosis (LSRRO) is a promising approach for brine concentration, which is useful for the valorization of salts present in seawater desalination brine and minimizing brine discharge. A new low salt rejection reverse osmosis membrane was developed with the aim of enabling sodium chloride salt concentration up to 220 g/L salinity. This eliminates the need for a thermal evaporator after reverse osmosis (RO) and allows the concentrated brine stream to be fed directly into the crystallizer. The results obtained with a spiral-wound element demonstrated the feasibility of concentrating up to 220 g/L and showed stabilization was reached after 15 days. The experimental results were used to build a membrane model and perform system simulations. A cost of water estimation study concludes that LSRRO with the new solution would require up to 58% lower capital expenses (CAPEX) and up to 52% lower operational expenses (OPEX) than osmotically assisted reverse osmosis (OARO), which is an alternative approach for brine concentration.

Keywords: LSRRO; Brine valorization; Desalination; Reverse osmosis; Salt; OARO

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New seawater fouling resistant low-energy reverse osmosis element: Introducing FILMTEC™ SW30XLE-400/34 membrane element

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Biofouling in reverse osmosis (RO) systems significantly increase operational costs and reduce efficiency. This issue arises from bacterial biofilm formation on membrane surfaces, leading to higher pressure drops and more frequent chemical cleanings, which in turn escalate energy consumption and maintenance expenses. This study evaluates the biofouling resistance properties of the newly developed FilmTec™ SW30XLE-400/34 seawater fouling-resistant membrane element. Extensive validation experiments at the Global Water Technology Center (GWTC) in Tarragona demonstrated the element's excellent performance under typical Mediterranean seawater conditions. The FilmTec™ SW30XLE-400/34 element exhibits a 25% lower initial pressure drop and a potential 10% reduction in the annual frequency of chemical cleanings (CIP) due to biofouling compared to previous membrane element generations featuring 28 mil feed spacers. These significant improvements are achieved maintaining permeate throughput and quality, helping ensure the element keeps high efficiency and reliability over time.

Keywords: Biofouling; Fouling; Reverse osmosis; Desalination

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Data-driven optimization of ultrafiltration operations using DuPont's ultrafiltration operations advisor

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Efficient operation of ultrafiltration (UF) systems is critical for sustainable water treatment processes. This study presents the application of DuPont's Ultrafiltration Operations Advisor tool to analyze operational datasets and optimize cleaning protocols. The methodology involves automated identification of CEBs (chemically enhanced backwashes), CIPs (clean-in-place), and system shutdowns, providing actionable insights into membrane performance. Temporal trends of transmembrane pressure (TMP) and normalized filtrate flow were evaluated to assess fouling dynamics and cleaning effectiveness. Furthermore, predictive algorithms were employed to compare forecasted cleaning events against recommended interventions, enabling significant reductions in operational downtime and chemical consumption. The final functionality of the tool, is a cost-benefit analysis that demonstrates potential savings when upgrading to DuPont™ ultrafiltration modules, highlighting the economic and environmental advantages of advanced membrane technologies. These findings underscore the role of data-driven decision-making in enhancing reliability and efficiency in UF-based water treatment systems.

Keywords: Ultrafiltration; Optimization; Machine learning; Savings; Software

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The limitation of saturation indices in antiscalant projection software

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Antiscalants are critical for stable performance and membrane protection in RO systems. But each plant around the world operates under unique conditions which means there always exists a balance between operating with sufficient antiscalant to maintain operation, while minimizing chemical consumption. Modern software platforms developed by specialty chemical manufacturers are tasked with accurately predicting antiscalant doses based on process and water quality inputs. The core method employed by such software is herein discussed; along with acknowledgement of complicating factors which must be accounted for in complex feed waters. Key feed water parameters such as ionic composition, alkalinity, temperature, and pH; combined with some system information, determines the concentration of ions in the brine: calcium, alkalinity, sulfate, phosphate, silica, and others. With this information, it is possible to calculate the scaling index for sparingly soluble salts in the brine. This usually includes indices related to calcium carbonate, calcium sulfate, barium sulfate, calcium phosphate, silica, and other common scales found in RO systems. These indices quantify the degree of supersaturation and consequential scaling risk under the projected operating conditions. The calculated brine scaling index is then compared against known antiscalant performance data which reflects laboratory testing, field validation, and proprietary knowledge of specific antiscalant formulations. Based on this comparison, the software identifies the antiscalant concentration required in the brine to effectively inhibit scale formation in the brine. The final step is to convert the required dose in the brine to a practical feed dose, based on the system recovery and concentration factor. This approach ensures that sufficient antiscalant is present at the most critical location in the RO system without excessive overdosing, thereby balancing membrane protection with chemical cost control. While the approach outlined above is useful to understand the principles behind antiscalant dose evaluation, since the first software platforms were developed in the 1990s the authors have observed several complicating factors which should be accounted for by software evaluating antiscalant dose rates. The remainder of this presentation shall provide insight into exceptions, where scaling index alone is not sufficient to accurately predict antiscalant dose rate.

Keywords: Reverse osmosis; Antiscalant

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Lessons learned from the operation of the world's largest reversal electrodialisys (EDR)

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Water sources are becoming scarcer and more variable due to factors such as population growth, climate change, diversification of water usage, and the presence of diffuse sources of contamination. These factors directly affect water bodies, influencing their suitability for drinking water treatment purposes. The aim of water supply companies is to guarantee the quality, quantity, and continuity of the drinking water service while ensuring the sanitary standards and complying with the regulatory framework. ATL is the public-run company under the Government of Catalonia responsible for treating and supplying drinking water to over 5 million people in Barcelona (Spain) and its metropolitan area. The Ter-Llobregat system consists of three drinking water treatment plants (DWTP): Llobregat, Ter, and Cardener, along with two seawater reverse osmosis plants (SWRO) located in Blanes and El Prat del Llobregat. The interconnected distribution network comprises more than 1.000 km of pipelines with diameters of up to 3 m, covering a territory of more than 2,400 km^2. Llobregat DWTP catchment takes water from Llobregat River which has a low and irregular flow. Additionally, surface water contains high concentrations of organic matter and salinity, particularly due to the natural bromide content. After conventional treatment, part of the carbon filtered water is treated by reversal electrodialysis (EDR) with the aim of reducing salinity and organic compounds but also improving organoleptic quality of treated water. Treated volume by EDR is daily determined according to raw water quality and distribution system demands. EDR treated water is remineralized through a lime dosing system and mixed with the carbon filtered water fraction to neutrally maintain Langelier saturation index. The EDR at the Llobregat DWTP was commissioned in 2009 and, throughout the past 16 years, it has produced more than 376 hm^3 of water. Its maximum capacity is 2.3 m^3/s, and it consists of 576 stacks with 600 cell pairs arranged in a 9-racked configuration operating in a double stage process. EDR uses direct current as driving force to transfer ionic compounds through anionic and cationic membranes. The current hydraulic efficiency is around 91.5% and the process energy consumption is 0.58 kWh/m^3. The average removal of main parameters is as follows: electrical conductivity 69±8%, chloride 75±7%, bromide 77±6%, nitrate 75±6%, sulphate 74±7%, calcium 83±6%, magnesium 79±7%, potassium 71±9% and total organic carbon (TOC) 35±9%. Because of bromide and TOC reduction, disinfection by-products formation is highly decreased in treated water. Source water quality is affected by climate change. Intense and long drought periods alternate with heavy rains which make more difficult to produce drinking water. The Llobregat EDR is an example of a success case on technological application that enable ATL to ensure drinking water quality and to comply with regulatory requirements.

Keywords: Drought; EDR; Brackish water; Potable; Supply

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Integrating desalination and indirect potable reuse for urban water resilience in Mediterranean cities

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Catalonia experienced a drought of exceptional severity between 2021 and early 2025. A prolonged lack of rainfall, compounded by record-high temperatures, led to a 56-month drought during which flows in major rivers fell to around 50% of their long-term average. Reservoir storage consequently dropped to critically low levels—below 15% of total capacity—prompting the declaration of an emergency situation. During the most acute phase of this extreme drought, an indirect potable reuse (IPR) scheme was implemented in the metropolitan area of Barcelona for a 28-month period (from mid-December 2022 to mid-April 2025) through the operation of the El Prat Water Reclamation Plant. Reclaimed water was discharged into the Llobregat River approximately eight kilometres upstream of the main drinking water treatment plant, where it mixed with the natural river flow at an approximate 1:1 ratio. Throughout this prolonged drought, drinking water supply was maintained through a combination of demand management measures and non-conventional resources. Desalination and IPR together accounted for around 30% of total water consumption for the five million inhabitants of the Greater Barcelona area, allowing significant savings of reservoir water and preventing their depletion. Without this contribution of "manufactured water", stored water reserves would have collapsed, with reservoirs reaching absolute zero for extended periods. This experience has generated broad political consensus on the need to strengthen urban water supply systems and to undertake a genuine water transition towards a less climate-dependent model. At the same time, it has produced valuable operational knowledge on managing the health and environmental risks associated with indirect potable reuse, in a context where regulatory frameworks were not yet fully developed and Catalan authorities had to establish their own precautionary protocols. The current strategy of the Government of Catalonia is to further consolidate this integrated approach—combining desalination, water savings, and indirect potable reuse—by expanding and replicating existing infrastructure, with the objective of manufactured water resources providing up to 70% of urban supply during drought periods. This three-pillar solution offers a replicable model for other Mediterranean cities, which share both the challenge of an increasingly variable climate and the opportunity to harness seawater desalination and reclaimed wastewater currently discharged to the sea. This combination of measures has proven to be both safe and sustainable.

Keywords: Desalination; Indirect potable reuse; Manufactured water; Urban water resilience

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An integrated RO–NF process for the concentration of volatile fatty acid mixtures: modeling and simulation

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An integrated membrane process combining reverse osmosis (RO) followed by nanofiltration (NF) is proposed for the concentration of volatile fatty acids (VFAs) mixtures derived from anaerobic bio-fermentation, specifically acetic, propionic, butyric, valeric, and hexanoic acids. The process leverages the complementary characteristics of the two membrane technologies. The RO unit provides high solute rejection, generating a pre-concentrated VFAs retentate while producing high-purity permeate water that can be efficiently reused throughout the overall production process, fully aligned with circular economy principles. The RO retentate is directed to the NF unit, which sustains relatively high permeate fluxes even at elevated VFAs concentrations, achieving the final enrichment of the retentate. The permeate from NF is then recirculated to the RO unit, maximizing the overall concentration factor while minimizing VFAs losses from the integrated process. To support rigorous design, evaluation, and optimization, a physically grounded, user-friendly model was developed. The model provides a mechanistic description of VFAs mass transport across RO and NF polyamide membranes, incorporating acids speciation, concentration polarization, interfacial partitioning, and in-membrane mass transfer. The focus was on capturing the effects of pH, temperature, and total VFAs concentration on membrane rejection, with particular emphasis on the impact of elevated solute loads on NF rejection. Model parameterization was performed using prior semi-pilot-scale experimental data obtained from spiral-wound industrial modules, covering VFAs concentrations of 20–70 g/L, pH 6–9, and applied pressures of 30 bar. The model accurately reproduces experimental rejections and overall fluxes for both RO and NF, confirming its robustness for process optimization. Within this framework, the model was applied for preliminary design, identifying the pressure and VFAs concentration in the RO retentate as the main design quantities. Specifically, the latter governs the load distribution between the RO and NF units. As an indicative example, at 50 bar, a stream from the anaerobic fermenter containing 20 g/L VFAs can be concentrated to 60 g/L in the RO unit and subsequently enriched from 60 to 100 g/L in the NF step, ensuring an overall volume concentration factor of 5 and total VFAs losses in the permeate of the RO unit below 0.6 g/L. This configuration requires a total membrane area of approximately 400–450 m^2 per m^3 of NF retentate, with an associated energy consumption of 12–17 kWh per m^3 of NF retentate. Detailed process analysis is currently ongoing to support scale-up considerations and assess the applicability of the integrated RO–NF process at industrial scale.

Keywords: Reverse osmosis; Nanofiltrations; Mass transfer; Volatile fatty acids; Biofermentation; Downstream; Water reuse

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Closing the ion-exchange loop: Regenerating HCl and NaOH from industrial waste eluates using EDBM-based process

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Waste eluates generated during the regeneration of ion exchange (IEX) columns represent a significant source of inorganic load discharged into the environment. These eluates contain high concentrations of dissolved salts (TDS), hardness ions and other species that limit their direct treatment by membrane processes. The aim of this work was to develop and experimentally verify a multi stage treatment concept enabling the recovery of valuable chemicals—HCl and NaOH—from mixed acidic and alkaline eluates, while simultaneously reducing the discharge of dissolved solids. Experimental The feed eluate originates from the regeneration of SAC, SBA and WBA ion exchange columns. The raw eluate is characterized by high conductivity (65–75 mS/cm) and significant concentrations of dissolved salts and multivalent ions, notably Na^+ 13–15 g/L, Cl^- 18–22 g/L, Ca^{2+} 900–1010 mg/L, Mg^{2+} 140–160 mg/L, SO_4^{2-} 500–700 mg/L, NO_3^- 600–800 mg/L, and organic carbon (TOC 200–350 mg/L). Problematic components also include traces of Sr^{2+}, Ba^{2+}, Fe, Al, SiO_2 and F^-, which contribute to scaling and fouling in membrane operations. The experimental process chain consisted of (i) chemical softening and precipitation of Ca/Mg followed by filtration and acidification, (ii) nanofiltration (NF) for separation of monovalent and multivalent ions, (iii) reverse osmosis (RO) for further concentration of NaCl, and (iv) electrodialysis with bipolar membranes (EDBM) for the regeneration of NaOH and HCl. All process steps were tested in lab-scale and now we moved to on-site pilot scale. Results A sequence of operations was tested on real eluates: chemical precipitation, NF, RO and EDBM with homogeneous membranes (EDBM). Pre treatment by pH adjustment with NaOH and Na_2CO_3 reduced Ca^{2+} by >97% and Mg^{2+} by >60%, preventing scaling in downstream membrane processes. NF provided stable operation up to a 3.3 fold concentration factor, generating permeate enriched in monovalent ions with NaCl purity up to 93?wt%. RO was applied to further concentrate NF permeate, increasing conductivity for efficient EDBM operation. Using EDBM, regenerated chemicals were obtained at target concentrations: 2.5 wt% NaOH with molar purity >96% and 3wt% HCl with molar purity >99%. Overall TDS removal from the original eluates reached approx. 55%, and the volume of liquid waste was reduced by ~70%. Conclusions The study confirms that the combined process enables effective valorization of mixed IEX regeneration eluates. Pre treatment is essential to protect membranes and ensure stable operation. NF ensures selective removal of polyvalent ions, while RO improves feed conditions for EDBM. The regenerated NaOH and HCl meet the purity requirements for reuse in IEX column regeneration. The concept demonstrates strong potential for industrial scale up, providing both economic and environmental benefits through reduced waste discharge and circular recovery of reagents.

Keywords: Bipolar electrodialysis; EDBM; Ion-exchange regeneration eluate; HCl and NaOH regeneration; Industrial wastewater treatment

EuroMed 2026
Desalination, Water Reuse and the Environment
22–25 June 2026, Marrakech, Morocco

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Use of variable speed drives on main pumps in large SWRO plants: Technical and economical considerations

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Variable speed drives (VSD) provide flexibility to cope efficiently with the duty changes that a seawater desalination plant based on reverse osmosis technology usually faces. It is common practice to drive the High-pressure (HP) pumps via VSD. However, when the SWRO racks become larger, so do the high-pressure pumps that feed them. In those cases, a dedicated booster pump is required to ensure minimum suction pressure at the HP pump. Such booster pumps are usually driven via VSD, but is this really the most efficient way? This paper will explain the technical pros and cons of having the VSD on the booster pumps or on the HP Pumps. and will quantify the specific energy consumption for different capacity and pressure range requirements. Simulation is performed on 4 plant arrangements: independent trains of 22,000, 25,000 and 30,000 m^3/d of production and a pressure center arrangement for 300,000 m^3/d with three booster and HP pumps feeding a common manifold. Two scenarios for pressure range will be estimated: one with narrower range (60–69 bar) and the second with a wider range (60–74 bar). For absorbed power calculations, sea water specific gravity of 1.03 kg/dm^3 has been defined for all cases. Specific power consumption by Booster (where applicable) and HP pumps will be calculated on all eight cases for minimum, rated and maximum pressure conditions. Motors and VSDs efficiency variations at different speeds are not being considered. In case of Booster pump, the differential pressure split between booster and high-pressure pump is defined to ensure an optimal booster pump selection providing a minimum pressure for the high-pressure pump. Pump selection and efficiency have been based on Sulzer's portfolio for SWRO applications, namely Sulzer A-RO end-suction overhung pump as booster pump and Sulzer MSD and HPDM axial split-casing pump ranges as high-pressure pumps. In all cases, efficiency at best efficiency point reaches between 87% to 91% depending on the duty conditions. The results achieved are somewhat expected. For rated pressure, the achieved specific power consumption is similar no matter where the VSD is located. However, when we go to the higher and lower pressures, we see a significant difference. For the extreme cases, especially for the higher pressures, we can observe up to 10.28% specific power consumption reduction when installing the VSD on the high-pressure pump. Operating HP pumps at variable speed will always improve SEC throughout the entire operation range and will avoid having a booster pump running close to minimum and maximum flow conditions. But it will not come for free: Higher power ratings, medium voltage VSDs are expensive. Higher CAPEX might be paid back in case of longer and more frequent operation in extreme conditions, could this be a way to keep on improving the affordability of the desalted water?

Keywords: Sulzer; Efficiency; Pumps; Specific power consumption; Variable speed drive

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Seawater desalination in Eastern Scheldt, The Netherlands: a challenge in a cold climate and Natura2000 waterbody

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In the Netherlands, like many other countries, climate change is amplifying extremes of water surplus and scarcity. Traditional sources for drinking water production are sweet groundwater (60%) and sweet surface water (40%). Due to climate change these traditional sources are insufficient or becoming unreliable for long-term supply security. All ten Dutch drinking water companies are therefore developing new sources for drinking water. Brabant Water has adopted, as a first in the Netherlands, large scale seawater desalination in addition to traditional sources as a strategic mid-term solution to ensure independence and resilience in public drinking water provision, and as a long-term investment in organizational capability to cope with future climate volatility. Our approach focuses on low-temperature desalination, acknowledging its inherent operational challenges such as seasonal variability in source water quality and efficiency. In addition, local conditions create a challenge. The water body itself is a Natura2000 water body (Eastern Scheldt), requiring low impact of the (pre)treatment for the water body. Therefore three pretreatment are compared: 1. Indirect intake via subsurface/ beach wells 2. Direct intake with submerged ceramic filtration 3. Direct intake with conventional multimedia filtration Indirect intake as well as submerged ceramic filtration might offer benefits over conventional mediafiltration in chemical usage (antiscalants and/or desinfectants) as well as solid residues (due to coagulant dosing). Due to a large dam in the Eastern Scheldt (Oosterscheldekering) the water body has limited tidal effects and therefore refreshment rates. Especially brine discharge is therefore a potential issue with increased salinity in the entire Eastern Scheldt as a consequence. Potential brine treatment towards valorization or minimum liquid discharge is therefore likely needed. Brabant Water is in an early stage of development: a strategic resource analysis has been completed and a new strategic, adaptive multi-source route for the company has been selected. Next steps wil incorporate a small-scale pilot to test technical, environmental, economic, and social parameters. Special focus is on low-impact treatment as well as brine treatment routes. We invite other companies and utilities, research institutes, and policymakers to co-create a new framework and technological approach for adaptive long-term desalination.

Keywords: Low-temperature seawater desalination; Low chemical usage; Pretreatment comparison; Ceramic membranes; Brine treatment; Natura2000

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Brackish water with arsenic: comparing aerobic and anaerobic treatment

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Due to increasing water demand and pressure on groundwater resources, Brabant Water is exploring alternative sources for drinking water production. A new source must be outside the existing freshwater system, sustainable for generations, expandable, and not impact other drinking water companies. This led to investigating brackish groundwater as a potential source. In Drongelen (the Netherlands), a pilot launched in early 2025 examines brackish groundwater at depths of 200–260 m. Using reverse osmosis (RO), the project aims to produce 20 m³/h of drinking water, comparing aerobic and anaerobic purification methods. The pilot includes subsurface monitoring and digital groundwater modeling to assess long-term feasibility, supported by 11 monitoring wells. Concentrate treatment is also tested, with a focus on heavy metal removal. If successful, full-scale production of 5 million m³/year could start by 2030. The aerobic method involves aeration and filtration. Aeration supplies oxygen to anaerobic groundwater and removes gases such as methane and hydrogen sulfide. Filtration captures oxidized metals like iron, manganese, and arsenic, and enables biological conversion of ammonium to nitrate. Pretreatment results show complete ammonium removal and significant arsenic oxidation. Both aerobic and anaerobic groundwater streams are treated by RO membranes with 80% recovery and 20 LMH flux. RO effectively removes most dissolved species, including salts. Differences occur in ammonium, arsenic, and nitrate concentrations: aerobic RO introduces nitrate from ammonium oxidation, while anaerobic RO retains arsenic above threshold values and ammonium near the limit. For anaerobic RO permeate, post-treatment is required to meet drinking water standards. Several options were tested: ion exchange, iron oxide adsorption, and a second RO step with pH adjustment. Ion exchange reduced arsenic to below 1 µg/L for ~10,000 bed volumes, while iron-based adsorbents treated larger volumes (~50,000 bed volumes). A second RO step achieved arsenic removal when feed water pH exceeded 10.5. In conclusion, two treatment approaches for brackish water with high arsenic concentrations are evaluated. Aerobic pretreatment combined with RO produces water suitable for drinking applications. Anaerobic RO requires additional post-treatment to remove arsenic and ammonium. Post-treatment options include ion exchange, adsorption, and secondary membrane filtration. These findings provide valuable insights for drinking water professionals facing similar challenges with brackish water and arsenic contamination.

Keywords: Brackish water; Desalination; Aerobic; Anaerobic; Arsenic; Ammonium

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Using boron as indicator for arsenite removal in BWRO

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Arsenic contamination in groundwater poses a serious health risk, linked to cancer and cardiovascular diseases. In groundwater, arsenic primarily occurs as arsenite (As(III)) and arsenate (As(V)), with arsenite being more toxic and commonly present. In Noord Brabant, the Netherlands, a brackish groundwater source has been identified for future drinking water supply due to the scarcity of fresh groundwater. This source contains an average arsenic concentration of 30 µg/L, far exceeding the WHO guideline of =10 µg/L. Local water authorities aim for an even stricter target of =1 µg/L, requiring removal efficiencies above 98%. Brackish water reverse osmosis (BWRO) is considered a promising technology for arsenic removal under these conditions. BWRO uses pressure-driven membranes to separate dissolved species but generally achieves lower ion rejection compared to seawater reverse osmosis (SWRO). To minimize fouling, BWRO often operates under anaerobic conditions. Reported arsenite removal efficiencies vary widely, influenced by pH, ionic strength, and competing ions. Increasing pH improves arsenic retention but raises scaling risks, making it more suitable for a second-pass RO system with proper pretreatment. This study investigates the relationship between arsenite and boron retention under varying operational conditions, including recovery, flux, and pH. Both arsenite and boron exhibit similar pKa's, with species becoming (negatively) charged above pH 9.2, significantly improving retention. At higher pH values, retentions exceed 90% for both species. Under typical groundwater application conditions, arsenite retention is generally higher than boron retention at pH below 9.2. This suggests boron can serve as a conservative indicator for arsenite retention in projection software, enabling more accurate predictions of water quality without direct arsenic modeling. Pilot-scale tests confirm that higher flux improves retention, while higher recovery reduces it. These findings are relevant for practical design and optimization of BWRO systems treating brackish groundwater with elevated arsenic levels. Using boron as a tracer offers a cost-effective and operationally simple approach to predict arsenite removal performance. Future work should validate this correlation across different sites and explore mathematical models or correction factors to refine arsenite predictions based on boron data, with particular attention to pH effects.

Keywords: Arsenic removal; Brackish water reverse osmosis; Arsenite; Boron

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Can conventional desalination technologies adapt to recover critical elements from the EoL lithium-ion battery recycling industry?

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The rapid electrification is driving a sharp increase in the deployment of lithium-ion batteries. These batteries, depending on their chemistry, contain valuable and critical elements such as lithium (Li), cobalt (Co), manganese (Mn), and nickel (Ni), whose primary extraction is associated with significant environmental impacts and constrained availability, especially within EU. Although recycling cannot gap the growing demand for these materials, their recovery from end-of-life batteries is essential to reduce environmental burdens, improve resource security, and support circular economy. In addition, the EU has introduced the new Batteries Regulation (EU 2023/1542), which establishes recycling rates targets of minimum 50% by 2027 and 80% by 2031 for lithium, and over 90–95% for cobalt, nickel, lead and copper. Meeting these targets demands innovative separation and concentration technologies capable of treating complex and highly concentrated streams. This research, performed within the context of the EU project BeyondBattRec, explores the transfer of knowledge and technologies from the desalination sector to advanced battery recycling applications. Hydrometallurgical leaching processes used for metals solubilization generate highly acidic metal-rich aqueous streams, that show similarities to desalination brines. This parallel enables the application of membrane-based processes such as nanofiltration (NF) and membrane distillation (MD), whose integration was evaluated through mass balance–based process analysis, to selectively concentrate, separate, and ultimately crystallize the valuable mineral phases. Real matrix leachate streams from EoL batteries were characterized, revealing negative pH values and high concentrations of Li, Al, Mn, Co, Ni, Cu, F, and SO_4 (exceeding 10 g/L for Co, Ni, Mn, exceeding 3 g/L for Li, and exceeding 400 for SO_4), highlighting the significant resource recovery potential of these streams. Thermodynamic modeling (PHREEQC), with recompilation and validation of thermodynamic databases, was used to assess the possibility of selective mineral precipitation through water recovery by MD, and to investigate process treatment alternatives, including the need for NF pretreatments aimed at multivalent–monovalent ion separation. Experimental campaigns of Vacuum MD and direct contact MD were initially conducted to up-concentrate the leaching agent only, demonstrating average permeate fluxes of approximately 12 LMH at 60°C (VMD) and approximately 5 LMH at 60-15°C (DMCD), with near-complete rejection values at feed streams concentrations exceeding 2 M, resulting in effective acidity up-concentration and pure water recovery. Overall, this study explores the possibility that desalination-derived membrane technologies could play a role in critical mineral recovery from spent lithium-ion batteries, with the broader goal of fostering cross-sector innovation and more sustainable and resilient material supply chains.

Keywords: Membrane separation; Critical metals recovery; Water recovery; Hypersaline streams

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Floating power/water barges for remote islands

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Greece's non-interconnected islands face persistent challenges in meeting energy and water demand due to geographic isolation, strong seasonal variability, and reliance on carbon-intensive power generation. This paper presents an integrated and scalable solution based on floating power barges that simultaneously provide low-carbon electricity and potable water without requiring new subsea grid infrastructure. Each barge delivers 80–120 MW of firm power using medium-speed gas engines fueled by LNG, Bio-LNG, and up to 10% hydrogen blends, while onboard multi-effect distillation (MED) units utilize engine waste heat to produce approximately 1,000 m³ of freshwater per day. The proposed system offers rapid deployment, modularity, and operational flexibility, enabling full coverage of island energy demand while enhancing water autonomy. Compared to conventional diesel-based systems, the solution achieves CO_2 emission reductions of 20–25% with LNG, up to 65–85% with Bio-LNG, and additional reductions through hydrogen blending. Economic analysis indicates significant cost savings, with electricity generation costs reduced to €100–120/MWh and desalinated water produced at €0.90–1.20/m³, substantially lower than current alternatives. Initial deployment targets 4 Greek islands where regulatory approvals are underway and environmental impact assessments have been submitted. However, this integrated solution can also be applied or deployed in remote areas, or used to cover electricity and water demands in emergency situations, such as in the aftermath of floods, earthquakes, or armed conflicts. By integrating energy decarbonization with circular water production, floating power barges represent a practical pathway toward resilient, sustainable infrastructure for island communities, supporting EU climate objectives while minimizing environmental footprint and public sector subsidy requirements.

Keywords: Bio-LNG; Desalination; Floating power barge; Hydrogen; LNG

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A holistic approach to planning, design, and lifecycle management of large-scale water networks: A case study from Dubai

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This paper presents a comprehensive case study of the planning, design, construction, and lifecycle management of Dubai's water network. Through this integrated approach Dubai Electricity and Water Authority (DEWA) has achieved a non-revenue water (NRW) level of approximately 4.6%, significantly lower than the global average reported for most countries. The paper demonstrates how the combination of system-level planning, optimized material selection, advanced construction methodologies, digital monitoring, and predictive maintenance has enhanced network reliability, resilience, and long-term sustainability. Particular emphasis is placed on the deployment of advanced materials, smart sensing technologies, and data-driven asset management to reduce losses, extend asset lifetime, and improve operational performance. The findings provide transferable insights for large-scale utility networks in arid and rapidly growing regions.

Keywords: DEWA; Dubai; Non-revenue water

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Production of water of high purity by membrane distillation for renewable hydrogen production

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Approximately 2.2 billion m³ of freshwater are withdrawn annually for global H_2 production, representing 0.6% of the total water withdrawn in the energy sector. Considering proton exchange membrane (PEM) electrolysis, which operates with the lowest water consumption, the value is kept around 17.5 L/kg of H_2, being 20.3% less water withdrawal and 21.4% less water consumption compared to alkaline electrolysis. Currently, renewable H_2 production requires high-quality water with low conductivity and minimal organic carbon, such as deionized water, which reduces electrical resistance and improves energy efficiency. The quality of the original freshwater directly impacts the amount of water needed. The lower the quality of the water withdrawn from a source, the more water must be extracted and treated to produce the same amount of H_2. Recovery rates in the pre-treatment step range from 66% for tap water to 58% for river or groundwater, and 35% for seawater. Reverse osmosis (RO) is the most widely used desalination technology worldwide. However, in the context of renewable H_2, this technology has several limitations when it comes to producing the required water. The main limitation is that the quality of water is not enough and additional purification steps beyond RO, such as deionization or distillation, are necessary to meet the stringent requirements of advanced electrolysers. Therefore, it is crucial to explore alternative approaches for the sustainable use of seawater in H_2 production and membrane distillation (MD) is a technology that has demonstrated significantly higher water qualities. This work evaluated two different commercial membranes, one based on polytetrafluoroethylene (PTFE) and the other on polyethylene (PE), in a MD system under two different configurations; i) air-gap membrane distillation configuration; and ii) vacuum-enhanced air gap membrane distillation (V-AGMD), using synthetic seawater containing 35 g/L of marine salts. The MD system is composed of a plate and frame module with an active surface membrane area of 375 cm^2. Three different levels of each operating condition was considered. Hot and cold flow rates were varied between 100 L/h and 200 L/h, hot temperature between 70ºC and 80ºC, and cold temperature between 20ºC and 30ºC. When vacuum was applied, a constant absolute pressure of 500 mbar was kept in the air gap. Both membranes exhibited excellent resistance to scaling and negligible pore wetting, with permeate conductivity values of 2 µS/cm under all tested operating conditions, increasing to 4 µS/cm when vacuum was applied. These preliminary results are promising in the field of renewable hydrogen, not only for the production of high-quality water through membrane distillation, but also for the potential utilization of waste heat generated during hydrogen production as a heat source for the MD process.

Keywords: Renewable hydrogen; Membrane distillation; High-purity water

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Performance assessment of forward osmosis for brine concentration with multi-effect distillation regeneration stage

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The increasing demand of freshwater resources in zones of the world suffering from water scarcity requires the construction of new seawater desalination plants. However, one of the main drawbacks of these plants is the brine generated as a by-product, which is usually rejected into the sea and can cause environmental impact on marine ecosystems. In this context, emerging osmotically-driven technologies such as forward osmosis can help to minimize this impact, maximizing the water production and reducing the water footprint. The main advantages of forward osmosis are the low energy requirements (it uses only osmotic pressure differences), reduced fouling and wide range of applicability. In particular, this work presents a theoretical evaluation of the performance of forward osmosis in brine concentration using artificial draw solutions regenerated by an optimized multi-effect distillation system able to concentrate brine up to 250 g/L. Different operating conditions and draw solutions are investigated to find optimal operation and to enhance the concentration factor with a purposively developed mathematical model.

Keywords: Forward osmosis; Multi-effect distillation; Brine concentration; Environmental impact; Draw solution

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Flow and evaporation heat transfer characteristics of falling film around non-circular horizontal tubes under MED conditions

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Horizontal-tube falling film evaporation technology is widely applied in thermal seawater desalination due to its high heat transfer efficiency and low temperature difference driving force. The hydrodynamic characteristics of the liquid film flowing over the tube surface directly affect the heat transfer performance. Non-circular tubes have shown considerable potential for improving external film flow behavior. Therefore, investigating the falling film flow characteristics and heat transfer performance outside non-circular tubes is of great significance for the further development and enhancement of horizontal-tube falling film evaporation technology in seawater desalination. In this study, numerical simulations based on the Volume of Fluid (VOF) model were conducted to investigate the falling film flow over circular, elliptical and egg-shaped tubes with the same perimeter. The numerical model was validated using experimental measurements obtained by a confocal chromatic displacement sensor (CCDS), and the three-dimensional distributions of liquid film thickness for different tube geometries were obtained. Furthermore, the distributions of the heat transfer coefficient outside the tubes were investigated. Comparisons with circular tubes were carried out, highlighting the promising application potential of non-circular tubes in horizontal-tube falling film evaporation for seawater desalination.

Keywords: Horizontal tube falling film; Non-circular tube; Film thickness distribution; Heat transfer coefficient

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SeaQual: Using remote sensing and AI to predict SWDP performance

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Efficient operation of desalination plants relies on timely knowledge of seawater quality, which can fluctuate due to environmental events such as algal blooms, turbidity spikes, or jellyfish intrusion. SeaQual is a novel data-driven platform that integrates satellite-based remote sensing, in-situ measurements, and predictive AI models to provide actionable insights for desalination plant operators. Using Copernicus Ocean Marine hind cast and forecast datasets, SeaQual predicts chlorophyll concentrations and other key water quality indicators at the intake. This enables early warnings of potential water quality risks, supporting operational adjustments and energy-efficient pre-treatment strategies. By combining environmental data streams with a digital twin of the desalination plant, SeaQual offers plant plant operators the ability to see what's coming. This approach demonstrates the potential of AI and satellite remote sensing to transform water treatment operations, bridging the gap between environmental monitoring and industrial decision-making. This presentation will focus on the results of our initial work in Oman.

Keywords: Remote sensing; Seawater desalination; AI

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Low-cost graphene oxide composite membranes cross-linked with urea: a sustainable solution for textile dye removal

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Graphene oxide (GO)-based ceramic membranes have attracted growing attention for textile wastewater treatment owing to their laminar structure and selective transport properties. However, their application is hindered by drawbacks, such as swelling in aqueous environments, instability of the layered structure, and restacking of GO nanosheets, which compromise long-term performance. To overcome these limitations, urea (UR) was employed as a crosslinking agent to reinforce hydrogen bonding between adjacent GO sheets, improving structural stability and reducing swelling. In this study, an optimized GO–UR membrane was prepared using a pozzolan support, an abundant, low-cost material that provides a sustainable alternative to conventional ceramic substrates. The optimized crosslinked membrane exhibits enhanced water permeability, strong dye rejection, and superior resistance to fouling compared with that of a pristine GO membrane. Importantly, it maintains stable operation during extended filtration, demonstrating the combined advantages of GO functionalization and the low-cost pozzolan support. These findings underline the potential of the optimized UR-crosslinked GO membrane on natural pozzolan ceramics as a durable, efficient, and economically viable solution for dye removal in textile wastewater treatment.

Keywords: Graphene oxide; Urea crosslinking; Pozzolan ceramic membrane; Dye removal

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Machine learning-enabled digital twin for autonomous optimization of containerized reverse osmosis desalination systems

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The increasing pressure on freshwater resources requires not only new desalination infrastructures, but also intelligent systems capable of optimizing performance, energy consumption, and operational reliability under highly variable conditions. Digitalization and data-driven methodologies are emerging as key enablers for next-generation desalination plants. This work presents a digital twin-based framework applied to containerized seawater reverse osmosis desalination systems designed for decentralized and scalable deployment. The digital twin combines a physical desalination unit with a virtual replica integrating real-time process data, hydraulic behavior, membrane performance models, and operational constraints. Continuous acquisition of key parameters—including pressures, flows, conductivity, temperature, and specific energy consumption—feeds the digital twin, enabling dynamic analysis of system behavior and real-time performance assessment. Machine learning algorithms are leveraged to identify patterns, detect deviations, and predict fouling, scaling, or abnormal operating states before critical performance degradation occurs. Beyond monitoring, the desalination system is conceived as an auto-cognitive asset capable of self-diagnosis and adaptive operation. By learning from historical and real-time data, the system progressively optimizes operational setpoints, enhances process stability, and reduces operator intervention, shifting plant management from reactive to predictive and autonomous control. The integration of digital twins and artificial intelligence transforms containerized desalination systems into intelligent cyber-physical infrastructures. This approach improves energy efficiency, extends membrane lifespan, and strengthens operational resilience, contributing to sustainable water production strategies aligned with climate adaptation and smart water management objectives.

Keywords: Digital twin; Machine learning; Intelligent desalination; Reverse osmosis; Autonomous systems; Mobility monobloc desalination plant

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Eco-friendly TiO_2 for ceramic wastewater membranes

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Titanium dioxide (TiO_2) nanoparticles were synthesized using a green sol–gel approach with titanium tetraisopropoxide (TTIP) as precursor and a plant-based extract as a natural stabilizing agent. The synthesis was carried out under mild and environmentally friendly conditions, avoiding the use of hazardous chemicals. The obtained TiO_2 nanoparticles were deposited onto kaolinite-based ceramic membranes to fabricate TiO_2–kaolinite composite membranes. The prepared membranes were investigated for wastewater treatment applications, where the presence of TiO_2 improved surface properties and enhanced interactions with organic pollutants. This study demonstrates that green synthesis of TiO_2 nanoparticles combined with kaolinite ceramic membranes represents a sustainable and effective strategy for wastewater treatment.

Keywords: Titanium dioxide (TiO_2) ; Green sol–gel synthesis ; Ceramic membranes ; Kaolinite support ; Wastewater treatment.

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Brine valorization using bipolar membrane electrodialysis: magnesium and calcium scaling with monovalent selective membranes

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Bipolar membrane electrodialysis (BMED) enables on-site conversion of brines into acids and bases, making it a promising technology for brine valorization. However, the presence of divalent ions such as magnesium (Mg^{2+}) and calcium (Ca^{2+}) can induce scaling in the alkaline compartments, limiting operational stability and typically requiring softening pre-treatment. Although concentration limits for these ions are often reported in the literature (e.g., Mg^{2+} and Ca^{2+} 10 mg/L as $CaCO_3$ equivalents), they are rarely linked to operating conditions, such as current density and hydrodynamics, or to transport phenomena. In this work, we systematically investigated the impact of magnesium and calcium on BMED performance and scaling behavior under controlled conditions. Baseline experiments were performed using a synthetic seawater reverse osmosis (SWRO) brine (1 M NaCl) and compared with synthetic SWRO brines containing either magnesium or calcium at concentrations of 100 and 1000 mg/L, representing highly scaling-prone conditions. Experiments were performed in a lab-scale BMED stack, using monovalent selective cation exchange membranes (mCEM) to restrict divalent-ion transport into the alkaline compartments. Cell voltage, acid and base production, and specific energy consumption were monitored and compared to the NaCl baseline. The two divalent ions exhibited different effects on the BMED process. Magnesium caused a pronounced increase in cell voltage, particularly at high concentrations, but did not lead to detectable solid precipitation. In contrast, calcium induced the formation of calcium hydroxide deposits without a comparable increase in voltage. Despite these effects, stable acid and base production was maintained in all cases, although magnesium's effect on the cell voltage increased energy consumption. Acid cleaning with 0.5 M HCl restored performance after calcium-induced scaling, confirming that calcium hydroxide deposition was reversible under the investigated conditions. Our findings indicate that mCEM can partially mitigate scaling in synthetic brines, with clear differences between magnesium and calcium. We hypothesized that the contrasting behavior is likely correlated with the mCEM selectivity and precipitation kinetics. To establish the robustness of this approach, further research is needed across more complex synthetic brine compositions and during long-term operation. Our future research will compare mCEM with standard CEM under more realistic brine conditions to define operational limits and determine pretreatment requirements to achieve stable BMED performance.

Keywords: Brine valorization; Bipolar membrane electrodialysis; Scaling; Monovalent selective ion exchange membranes

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Binary LiCl–$CaCl_2$ composite adsorbents for low-temperature adsorption desalination

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Water scarcity is an increasingly critical global challenge driven by climate change, population growth, and rising freshwater demand. In this context, adsorption desalination (AD) has emerged as a promising alternative to conventional desalination technologies due to its ability to operate with low-grade or renewable heat sources, low environmental impact, and suitability for decentralized water production. However, the efficiency of AD systems is strongly limited by the adsorption capacity, kinetics, and stability of the employed materials, particularly under low-temperature operating conditions. This work investigates composite adsorbents based on hygroscopic inorganic salts embedded in a mesoporous silica gel matrix, with specific focus on a binary-salt composite consisting of 12.5 wt.% LiCl and 12.5 wt.% $CaCl_2$ impregnated into mesoporous silica gel. This formulation was selected as a compromise between high water uptake and improved structural stability compared to single-salt LiCl systems, which are prone to deliquescence. A total mass of 62.5 g of composite material was loaded into a heat exchanger, enabling the evaluation of adsorption kinetics and cycle performance under realistic operating conditions. Water adsorption experiments were conducted under controlled temperature jumps, denoted as X–30–Y, where the adsorbent was cooled from an initial temperature X (50–80°C) to 30°C, with evaporation temperatures of 20°C (~23 mbar) and 10°C (12.24 mbar). In all cases, adsorption is characterized by a rapid initial uptake followed by a slower approach to equilibrium, indicating diffusion- and heat-transfer–controlled kinetics. Larger temperature jumps enhance both adsorption rate and equilibrium capacity. At an evaporation temperature of 20°C, equilibrium water uptake increases from approximately 23.2% to 46.6%, resulting in a specific daily water production (SDWP) rising from 27.0 to 59.0 $m^3\ t^{-1}\ d^{-1}$, despite longer cycle times. When the evaporation temperature is reduced to 10°C, shorter adsorption–desorption cycles are observed; however, the lower vapor pressure limits water uptake to a range between 13.7% and 28.1%, with corresponding SDWP values between 22.0 and 43.0 $m^3\ t^{-1}\ d^{-1}$. Compared to high LiCl-loading composites such as 30 wt.% LiCl impregnated into mesoporous silica gel reported in the literature, which typically achieve high productivity at the expense of material stability, the proposed LiCl–$CaCl_2$/silica gel composite provides competitive SDWP values while mitigating deliquescence-related limitations under cyclic operation. Overall, the LiCl–$CaCl_2$/silica gel composite shows promising performance for low-temperature adsorption desalination, as larger temperature jumps enhance adsorption kinetics and productivity while salt blending improves material stability, confirming the suitability of this material for heat-driven desalination systems.

Keywords: Adsorption desalination; LiCl–$CaCl_2$ composite; Silica gel; Water adsorption; Low-temperature

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Pilot scale production of magnesium carbonates from desalination brines

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Seawater desalination is widely adopted in water-stressed regions, leading to the generation of large volumes of brines that are typically discharged back to the sea, despite their high content of valuable dissolved elements [1]. Among them, magnesium has been classified as a Critical Raw Material (CRM) for its supply risk and economic importance for the European Union. In this context, the present work investigates the valorisation of desalination brines through the production of magnesium carbonate compounds at pilot-scale within the framework of the Rewaise Project. Magnesium carbonate species have several applications: nesquehonite ($MgCO_3 \cdot 3H_2O$) is adopted as a green building material [2], hydromagnesite ($Mg5(CO_3)4(OH)_2 \cdot 4H_2O$) is employed as a flame-retardant filler [3], while dypingite ($Mg5(CO_3)4(OH)_2 \cdot 5H_2O$) is an intermediate phase. In the Rewaise process scheme, a RO brine (Mg^{2+} ~0.09 M) is treated by a nanofiltration (NF) unit (Mg^{2+} ~0.14 M) and further sent to evaporative ponds. Calcium sulphate, calcium carbonate and sodium chloride compounds selectively crystallize in the ponds, eventually leading to a highly concentrated saline solution (Mg^{2+} 1M and 2M), called bittern. In the experimental campaign, synthetic sodium carbonate, Na_2CO_3, solutions were the carbonate source; and magnesium carbonate crystallization occurred in a multi-feed plug flow reactor (patented by ResourSEAS). Magnesium was recovered in the form of nesquehonite, when a 2M bittern was employed, while a mixture of nesquehonite and dypingite/hydromagnesite was obtained with 1M bittern. In all cases, the instantaneous magnesium conversion in carbonate was ~60%, reaching approximately 90% after 12 h. Solid-phase characterization by X-Ray Diffraction, (XRD), Fourier-Transform Infrared Spectroscopy, (FTIR), and Scanning Electron Microscope, (SEM), confirmed the formation of magnesium carbonate phases. The study provides a baseline for carbon capture and utilization (CCU) strategies where either CO_2 is directly injected into the reactor or captured by alkaline streams and subsequently converted into magnesium carbonates exploiting desalination brines.

Keywords: Mineral recovery; Brine valorization; Desalination brine; Magnesium carbonate

Acknowledgements

The Authors thank the European Union and the Horizon 2020 Research and Innovation Framework Programme for funding this research under the project REWAISE grant agreement

No. 869496. The Authors are also thankful to Aqualia company for hosting the experimental activities in the Wave Center (Tenerife, Spain).

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A sustainable approach to freshwater production: modelling and simulation of a vacuum barometric desalination unit

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A unique approach of desalination processes that provides more efficient and sustainable desalination process is introduced in this research. The premise of this approach is that fresh water can be distilled from saline water under near vacuum level pressures and at near ambient temperature by exploiting the availability of a passive vacuum using a barometric column which allows the use of solar energy or any other low-grade energy to drive the process. Such pressures can be achieved naturally in the head space of water columns of height equal to the local barometric head. The system consists of solar collectors, an evaporator, a condenser, and three tanks for saline water, brine, and freshwater. These units are connected and controlled via a number of circulation pumps and control valves. Such configuration is inexpensive to build, operate and maintain. It can also be integrated easily with other systems. To assess the feasibility of the proposed configuration, various system components will be designed, modelled, and analysed both theoretically and experimentally. Moreover, several design parameters, that may affect the performance of the system, will be investigated.

Keywords: Desalination; Distillation; Thermal; Membrane; Vacuum; Barometric column; Solar energy; Low grade energy; Solar energy; Energy input; Freshwater; Saline water; brine; System performance; Pressure; Temperature

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Development of polycarbazole-based functional ceramic membranes for water treatment

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This work reports a simple strategy for the functional modification of ceramic membranes using a conducting polymer layer formed in situ. Polycarbazole was deposited directly onto porous ceramic supports via oxidative polymerization, leading to the formation of a stable surface-functionalized membrane without complex fabrication steps. The modified membranes were evaluated under pressure-driven filtration conditions, showing stable permeation behavior and effective removal of organic contaminants from aqueous solutions. The separation performance is attributed to surface functionalization effects, combining physicochemical interactions and modification of the membrane interface. These results highlight the potential of polycarbazole as a versatile functional material for ceramic membrane applications in water treatment, offering a low-cost and easily implementable alternative for membrane surface engineering.

Keywords: Polycarbazole; In situ oxidative polymerization; Surface functionalization; Interfacial modification

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Comparison of standard vs. custom RO plant designs: Advantages and disadvantages

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There are a 3 strategy for reverse osmosis (RO) plants design philosophies: standardized design which design team have a stander design use in all plants with same capacity, Sami- standardized which design team have stander design guidelines but they still doing project by project details design and fully customized configurations when the design team believe that each project has a unique site specific conditions and they should start from scratch for each design point. Standard RO designs rely on fixed layouts, predefined membrane arrays, and uniform component selections. This approach reduces engineering time, simplifies procurement, and lowers capital cost due to repeatable manufacturing practices. Standard systems also benefit from predictable performance and streamlined operation and maintenance procedures, as reflected in general RO design principles and membrane system behavior discussed in industry resources. However, their rigidity limits optimization for unique feedwater characteristics, challenging environments, or specialized performance targets. Custom RO designs, by contrast, allow engineers to tailor membrane selection, staging, pretreatment, energy recovery integration, and control strategies to the exact feedwater quality, recovery goals, and operational constraints of the site. This flexibility enables higher efficiency, improved fouling control, and better long term operating economics—especially in complex industrial or high salinity applications. The trade off is increased engineering effort, longer delivery timelines, and higher upfront cost, along with greater dependence on specialized expertise. Overall, standard RO plants offer speed, simplicity, and cost effectiveness, while custom designs deliver superior optimization and lifecycle performance. The choice between them depends on project scale, feedwater variability, regulatory requirements, and the operator's tolerance for complexity versus the desire for maximum efficiency. In this paper we will go through advantages and disadvantages for each philosophy to help engineering teams to decide which one is better for their application.

Keywords: Desalination plants design

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Public perceptions and social acceptance of seawater desalination for drinking water in Morocco

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As Morocco rapidly expands seawater desalination to address the country's severe water stress, public acceptance of desalinated drinking water has become critical to effective and equitable implementation alongside financial and institutional capacity constraints. This study investigates the factors shaping public perceptions and attitudinal acceptance of desalinated potable water across different regional, socioeconomic, and infrastructural contexts in Morocco. Using a culturally sensitive, place-specific mixed-methods approach, the research combines door-to-door household surveys (n = 250 per city) in Agadir and southern Casablanca with qualitative scoping interviews conducted with subjects local to Casablanca, El Jadida, and Safi. Survey instruments were developed through literature review, pilot testing, and interviews with community members, water users, and industry representatives to capture locally relevant concerns, including water cost, quality, environmental impacts, institutional trust, place attachment, and perceived fairness of distribution. The study is conducted in collaboration with local water providers and supported by the International Water Research Institute (IWRI) at Mohammed VI Polytechnic University. Preliminary findings and prior literature indicate that institutional trust, transparent communication, and perceptions of equitable distribution are stronger predictors of acceptance than technical knowledge of desalination. Communities experiencing greater water stress show higher willingness to adopt desalinated water, while concerns over increased household costs (stronger reliance on purchased bottled water), environmental impacts, and limited public participation reduce support. These findings highlight the importance of culturally informed community engagement and participatory governance in the sustainable expansion of desalination, offering a framework to guide policy design, future capacity/human capital building efforts, and community engagement activities.

Keywords: Desalination; Potable water; Social acceptance; Stakeholder engagement; Morocco

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Development of MXene nanomaterial-based nanofiltration membranes for water and wastewater treatment

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Water and wastewater treatment are major global challenges as the consequence of population increase, industrial activity, and the continuous discharge of organic, inorganic, and biological contaminants into water resources[1]. Membrane-based technologies are typically recognized as practical and sustainable alternatives to water purification due to their high separation efficiency and low energy requirements. However, challenges including fouling, limited permeability, and poor selectivity frequently plague traditional membranes. MXenes are a class of two-dimensional transition metal carbides, nitrides, and carbonitrides that have gained popularity as membrane materials for the treatment of water and wastewater. Improved water permeability and separation performance are facilitated by their high hydrophilicity, large specific surface area, adjustable surface chemistry, and changeable interlayer spacing [2]. MXene-based membranes have shown great promise for dyes removal, heavy metals, salt, and other impurities from wastewater, demonstrating its appropriateness for advanced membrane technology in environmental applications.

Keywords: Water treatment; Wastewater treatment; Membrane separation; MXene; Environmental applications

Acknowledgment

This study was supported by the National Center for Scientific and Technical Research (CNRST) under the “PhD-Associate Scholarship - PASS” program in Morocco.

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Streamlining sustainability: Potential onsite water reuse for data center operations

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Data centers (DCs) in arid regions heavily rely on potable water for cooling systems, which is a stressor for water utility companies aiming to meet the local demands. The gaps surrounding the feasibility of onsite water reuse in DCs are underreported. In this study, a 34.5 MW DC in a hot, arid environment (Phoenix, Arizona), is assessed for quantifying the potential onsite water reuse opportunities. Alternative water sources such as harvested rainwater, captured condensate, reclaimed water, and cooling tower blowdown are treated through membrane-based processes for onsite end use (i.e., humidification, cooling tower makeup, and evaporative cooling water). A water matrix highlights the use of alternative water to treatment system configurations, including ultrafiltration-ultraviolet, reverse osmosis, closed-circuit reverse osmosis, and air-gap membrane distillation (AGMD). A techno-economic assessment of the configured alternative water with treatment system scenarios is performed and compared for energetics and costs. Results indicate modeled systems retain water recoveries between 80.0 and 98.4% with the specific energy consumption ranging between 0.0127 and 1.08 kWh m^{-3} and the levelized cost of water ranging between 0.639 and 3.03 $ m^{-3}. When available, onsite waste heat is harnessed to operate AGMD at high enough temperatures (>80 ºC), the system is considered economically favorable. The findings in this study encourage a circular water economy by reducing potable water consumption and providing a modeling framework for onsite water reuse strategies in DCs. Abstract Disclosure this work has not yet been published. a portion of the technical economic research has been presented at NAMS 2026

Keywords: Onsite water reuse; Data center; Blowdown; Reverse osmosis; Nanofiltration; Membrane distillation; Techno-economic and life-cycle assessment

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Water reuse vs. desalination: Technical feasibility, design and economics of ultra-pure water production for green hydrogen

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The momentum towards green hydrogen as a viable energy source has accelerated, driven by its promise of clean and sustainable energy. Central to its production is the need for ultra-pure water, a prerequisite for the electrolysis process that generates hydrogen. This study addresses the critical question of sourcing this vital input, exploring whether seawater desalination or water reuse from industrial or municipal wastewater offers the most feasible, economical, and sustainable solution. The challenge lies in weighing technological capabilities, environmental impacts, regulations, and cost-effectiveness. The study has three main objectives: first, to evaluate the technical viability of seawater desalination and water reuse processes for ultra-pure water production in Germany. Secondly, to conduct a comparative economic analysis that accounts for both capital expenditures and operational costs. Thirdly, to assess the environmental impacts and regulatory aspects associated with each method, focusing on energy consumption and waste streams such as brine and sludge. The study investigates different reverse osmosis configurations to enhance water recovery to cope with the fluctuating feedwater input from small municipal and industrial wastewater treatment plants and the changing renewable energy load profiles for the reliable production of ultra-pure water and hydrogen. The brine discharge and especially the higher concentration of pollutants due to the treatment of industrial and municipal wastewater are addressed, with technical mitigations as well as regulatory aspects presented. Findings demonstrate that both seawater desalination and water reuse are capable of achieving the desired water purity. Seawater desalination, whilst effective, often leads to higher energy consumption and associated operational costs. Water reuse, in contrast, presents a sustainable alternative by recycling wastewater, yet it demands more significant technological investment to ensure contaminant-free output. As a planning support tool, a decision tree is presented that addresses whether to use seawater or the effluent from industrial/municipal wastewater treatment plants for ultra-pure water production in a highly regulated environment.

Keywords: Green hydrogen; Ultra-pure water; Seawater desalination; Water reuse; Reverse osmosis; Environmental impact; Cost-effectiveness; Electrolysis; Wastewater treatment; Renewable energy; Brine discharge

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Development of a low-cost pozzolan-based ultrafiltration membrane coated with purified red clay for dye removal

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In this study, a low-cost and environmentally friendly ultrafiltration membrane was successfully developed using natural pozzolan as a porous support and purified red clay as the selective top layer. The red clay layer was deposited at an optimized loading of 3 wt%, resulting in the formation of a homogeneous and defect-free membrane surface. The structural, mineralogical, and chemical properties of the fabricated membrane were investigated using scanning electron microscopy (SEM), X-ray diffraction (XRD), X-ray fluorescence (XRF), and Fourier transform infrared spectroscopy (FTIR), confirming the effective purification of the red clay and its successful integration onto the pozzolan support. The membrane performance was evaluated under ultrafiltration conditions for the removal of representative azo dyes, including Direct Red, Congo Red, and Acid Orange. High rejection efficiencies of 90% for Direct Red, 87% for Congo Red, and 70% for Acid Orange were achieved, demonstrating the strong separation capability of the developed membrane toward dye molecules with different structures and molecular weights. In addition, the membrane exhibited a high-water permeability of 78 $L.m^{-2}$ h^{-1} bar^{-1}, indicating a favorable balance between permeability and selectivity. The antifouling behavior of the membrane was also assessed, revealing improved resistance to fouling compared to uncoated supports. Overall, the use of natural pozzolan and purified red clay enables the development of a low-cost and efficient ultrafiltration membrane for the treatment of dye- contaminated wastewater.

Keywords: Ceramic membrane; Purification; Red clay; Dye removal; Wastewater treatment

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Fundamental challenges to solution-diffusion theory of water transport across membrane

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Solution-diffusion model has been the prevailing predominant on water transport across membrane for years. It suggests that there is no pressure gradient and water transport is purely driven by concentration gradient inside the membrane. However, there are serious challenges to this theory from both fundamental principles and experimental observations. This article presents rigorous derivations of mathematical models and discussions on the roles of chemical potential on water transport through porous membranes that allow both water and solutes to pass through and osmotic membranes that only allow water to pass through. It is obvious that solution-diffusion model is not a derivation strictly from basic principles. Furthermore, many observations of water transport driven by chemical potential do not support this theory but the opposite that pressure difference is the true driving force for water transport across membrane.

Keywords: Water transport, Solution-diffusion model, Negative pressure, Fick's law, Mathematical model

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A more effective fouling characterization method for feedwater to reverse osmosis desalination processes

Lianfa Song

The main purpose of fouling characterization is to predict fouling development in full-scale RO processes by a quick laboratory test of the feed water with the intended pretreatment, in lieu of the very costly and prolonged pilot test. However, the currently available silt density index (SDI) and modified fouling index (MFI) are hardly to serve the purpose satisfactorily. There is a lack of fundamental relationship between SDI and fouling in membrane processes while MFI does not have a clearly defined physical meaning and needs a clumsy procedure to determine. A more effective fouling characterization method will be presented for feed water to RO membranes. The characterization method can not only accurately determine the true "fouling strength" with a bench scale device as used for SDI measurement but also can be conveniently used to predict fouling development in the RO processes under the real-world operating conditions, which makes it far superior to the existing SDI and MFI methods.

Keywords: Fouling strength; Characterization method; Silt density index; Modified fouling index; Fouling development in RO processes

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Is it feasible to harvest salinity energy profitably?

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Salinity energy is the energy that exists between two water bodies of different salinities. The origin of salinity energy is the osmotic pressure (chemical potential) difference that drives water from low salinity to high salinity. Salinity energy can be harvested with controlled mixing of waters of different salinities. One of the feasible technologies for controlled mixing is with the osmotic membrane. There are two key parameters for the assessment of feasibility of salinity energy recovery and utilization, which are the specific energy and membrane power density. New concepts and methods are presented in this article about the more accurate quantifications of specific energy and more effective ways to cover salinity energy to mechanical or electrical energy. Unlike the prevailing opinions, the analyses show that salinity energy can be harvested from the most commonly existing pair of seawater and freshwater with the currently available RO membranes.

Keywords: Salinity gradient energy; Pressure-retarded osmosis; Membrane power density; Specific energy; Water flux

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Performance of reverse osmosis desalination is controlled by thermodynamic restriction

Lianfa Song

Permeate flux in a reverse osmosis process are affected by many factors including feed water quality (salinity) , membrane characteristics (permeability, salt rejection rate), and operating conditions (pressure, tangential flow rate). It imposes a difficult and serious challenge to model and predict permeate flux accurately. It becomes even more difficult when concentration polarization and membrane fouling are involved in the membrane process. However, careful examinations of reverse osmosis processes in seawater desalination reveal that the processes are almost always working in the regime of thermodynamic restriction. Therefore, the permeate flux can be predicted confidently with very simple equations. Combined with a generic cost model for seawater desalination, the reverse osmosis seawater desalination processes can be optimized analytically with great confidence.

Keywords: Seawater desalination; Reverse osmosis process; Energy efficiency; Process optimization; Thermodynamic restriction

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Using salinity gradients as an energy source to produce hydrogen

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Membrane-based methods for converting salinity gradient energy have been the most widely developed. These include semipermeable membranes for pressure-slowed osmosis and selective ion-exchange membranes for reverse electrodialysis. The world's first osmotic pilot plant operating on river and sea water was launched by the Norwegian company Statkraft on November 24, 2009, in Tofte, Norway. The design capacity of this prototype is 10 kW. A 50 kW pilot electrodialysis unit was commissioned on November 26, 2014, at the Afsluitdijk Dam in the Netherlands. However, with currently available membranes, the economic efficiency of these pilot plants was low. The performance of the electrodialysis unit we tested was also poor. Specialized osmotic semipermeable and ion-selective membranes with higher performance are needed to improve the economics of salinity energy conversion plants. Improvements to salinity gradient energy conversion plants and reduction of losses are also needed. Reverse electrodialysis uses an electrodialysis battery consisting of alternating compartments containing low- and high-concentration solutions, separated by cation-exchange and anion-exchange membranes. Electrodes are placed in the outer compartments. Our setup used inert electrodes made of platinized titanium. These electrodes experience a voltage drop due to electrode reactions. When the electrode chambers are filled with seawater or sodium chloride solutions, hydrogen gas is released at the cathode and chlorine at the anode. This setup can be used to produce these gases. However, if chlorine is not needed and cannot be discharged into the environment, the electrode chambers are filled with sodium hydroxide solutions. The solutions are recirculated between the electrode chambers to maintain their concentration. Electrolysis of sodium hydroxide solutions produces hydrogen and oxygen. This allows for the generation of not only electrical energy but also hydrogen and oxygen through the direct conversion of salinity gradient energy. Alkaline electrolyzers can use electrodes made of nickel or stainless steel coated with catalysts instead of expensive electrodes made of platinum group metals.

Keywords: Salinity gradient energy; Hydrogen; Electrolysis; Reverse electrodialysis; Solutions

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Self-propelled condensation droplets behavior on Cantor fractal surface

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With substantial application potential in microscale and nanoscale thermal management and energy systems, for example Multi-effect-desalination system, the sequential self-propelled departure of droplets during dropwise condensation is a crucial mechanism for improving phase-change heat transfer efficiency. Yet, at the nanoscale, condensate nanodroplets departure is limited by low energy conversion efficiency and incomplete mechanistic understanding of nucleation, dewetting, and jumping on fractal topology. To address this gap, the whole process was quantitatively documented by molecular dynamics simulations to examine condensation on micropillar surface (MSF), hierarchical surface (HSF), and Cantor fractal surface (CFSF), capturing the entire droplet lifecycle from nucleation to departure. Results reveal that droplet nucleation preferentially occurs within nanoscale fractal gaps, where embryos incubate in confined geometries that lower the nucleation energy barrier to ~1/5 and sustain a renewal rate almost twice that of HSF. The asymmetric Laplace pressure generated by the multiscale topology stimulates dewetting transitions and enables single-droplet jumping, while adjacent droplets subsequently coalesce and trigger cooperative jumping behaviors with broadened effective size ranges. Compared with MSF and HSF, CFSF promotes spontaneous removal of larger droplets and achieves a maximum energy conversion efficiency of 4.5%, significantly higher than 1.0% for HSF and 0.3% for MSF. Furthermore, energy distribution analysis demonstrated that line-tension dissipation dominates the departure dynamics, and that fractal topology effectively minimizes viscous loss. These findings contribute to the understanding of the cascade of nucleation-growth-transition-departure of fractal biomimetic structures in nanoscale condensation processes and provide design insights for the expanded use of fractal biomimetic structures in nanoscale phase-change heat transfer systems.

Keywords: Self-propelled departure; Dropwise condensation; Cantor fractal surface; Energy conversion efficiency

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Roadmap to deploy a digital twin for accelerating brine valorisation: from pilot testing to model-based optimisation and scale-up

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Seawater desalination is expanding worldwide, intensifying the need for sustainable management strategies for concentrated brine streams. Brine valorisation through pilot-scale testing offers a promising pathway to refine processes prior to full-scale deployment. In this context, digital twins can significantly accelerate development by integrating real-time plant data with dynamic process models, enabling predictive operation, optimisation-driven-decision-making, and risk-informed scale-up towards industrial implementation of brine valorisation schemes. The proposed theoretical roadmap is structured into four stages: (1) Pilot experimentation, instrumentation and data governance: definition of experimental design and critical-to-quality variables; selection, calibration and validation of sensors and analytical methods; development of sampling strategies, and implementation of a robust and secure data architecture. (2) Hybrid modelling: development of an integrated digital twin that combines first-principles process models with data-driven surrogate models trained on pilot-scale datasets. (3) Verification, uncertainty and optimisation framework: systematic model validation across operating regimes, identifiability and sensitivity analyses, uncertainty quantification and multi-objective optimisation to define feasible operating envelopes while ensuring safe-by-design performance. (4) Predictive operation for scale-up: integration of forecasting and closed-loop optimisation workflows to anticipate operational risks, identify robust operating windows, and support scale-up strategies with quantified confidence levels, underpinned by cybersecurity-by-design for connected models and data interfaces. The expected outcome is a replicable and transferable implementation pathway supporting the industrial development and deployment of desalination brine valorisation scheme. The roadmap explicitly addresses interoperability with existing plant historians, cybersecurity, model lifecycle management, and validation metrics, providing a practical template for researchers and utilities aiming to transition from experimental pilot data to actionable, predictive digital twins.

This work was supported by the INTERREG MAC 2021-2027 Programme through the IDI-WATER project (1/MAC/1/1.1/0022).

Keywords: Seawater reverse osmosis (SWRO); Brine valorisation; Digital twin; Hybrid process modelling; Pilot-scale experimentation; Predictive optimisation and scale-up

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Numerical investigation of steam condensation and liquid film dynamics in inclined tubes under marine operating conditions

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Horizontal tube falling film evaporators are widely employed in multi-effect distillation (MED) desalination systems installed on ships and offshore platforms. Under practical operating conditions, wave-induced motions and wind loads often cause the evaporator to operate at a certain inclination angle, leading to condensation flow and heat transfer behaviors that deviate markedly from those under perfectly horizontal conditions. Motivated by this practical concern, the present study numerically investigates steam condensation heat transfer inside inclined tubes. Particular attention is paid to the liquid film distribution, film velocity, local heat transfer coefficient, and the key factors governing their variations. The results reveal distinct axial variation trends of liquid film thickness and film velocity between the upper and lower regions separated by the stratified angle along the heat exchange tube. A slight downward inclination is found to reduce the liquid film thickness while increasing the film velocity, thereby enhancing local condensation heat transfer. In addition, increasing the inlet steam velocity and saturation temperature further accelerates film flow and improves condensation efficiency. These findings provide physical insight into the influence of inclination on condensation characteristics and offer guidance for the design and operation of falling film evaporators in marine desalination applications.

Keywords: Condensation; Film thickness; Incline

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Extension of cartridge filter lifespan trough chemical cleaning

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Cartridge filters provide protection for reverse osmosis membranes rather than acting as simple filtration devices. Their main function is to capture particles that were not retained during pretreatment. Their lifespan depends mainly on the quality of the raw water and the type of pretreatment, although it is typically 6–8 weeks. However, at the Southern Seawater Desalination Plant, the replacement frequency was every 27 days, which resulted in high costs and operational risks. The Southern Seawater Desalination Plant, located in Binningup, Western Australia, produces 300,000 m³/d, representing 30% of the water supply for the Perth metropolitan area. The plant is divided into two identical halves (Stage 1 and Stage 2), each with a capacity of 150,000 m³/d, and each stage is further divided into two lines (Bank A and Bank B). The pretreatment process includes rotary screens, mesh filtration, and ultrafiltration membranes, followed by cartridge filters before reverse osmosis. Previous studies done by the operations team identified certain factors contributing to the frequent replacement of filters, including: the quality of water after pretreatment had a significant impact, spring storms affected raw water quality, although they showed no significant correlation with water quality after pretreatment and fouling was biological, with a high presence of bacteria that proliferated on the filter surface. Based on these findings, a pilot test was carried out for one and a half years following the chemical cleaning approach used for membranes, achieving satisfactory results that led to its implementation in the plant. The data analysed between 2020 and 2022 showed an average lifespan of the cartridge filters in Stages 1 and 2 of 27 days or approximately 54,000 m³ of filtered volume. However, this filtration time may vary depending on several factors, and recently, an unexpectedly short lifespan was observed in some of the filters. Following the implementation in 2023 of periodic chemical cleanings approximately every 20 days, the evolution of the main parameters of the cartridge filters has been monitored to assess the effectiveness of these cleanings, analysing both the filtered volume between changes and the time elapsed between replacements. The average lifespan of Stage 1 filters has increased from 28 days to 167 days, reaching a maximum of 374 days, and could be extended even further. On the other hand, the average filtered volume has risen from 55,600 m³ to 2,700,000 m³. It is worth noting that the results obtained for Stage 1 are similar to those of Stage 2.

Keywords: Cartridge filters; Lifespan; Chemical cleanings; Desalination; Efficiency; Sustainability

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Scaling-free gypsum and water recovery from pulp and paper wastewater via membrane crystallization

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Membrane crystallization (MCr) is a thermally driven separation process that combines high water recovery with solute crystallization by exploiting vapor pressure gradients and supersaturation. In the context of the European Horizon CORNERSTONE project, this study investigates the application of MCr for treating and valorizing calcium- and sulfate-rich wastewater from pulp and paper industry, with a focus on gypsum ($CaSO_4 \cdot 2H_2O$) recovery. Industrial wastewater was first pre-concentrated by membrane distillation to achieve water recovery levels of 50%, 75%, and 90%. At a feed inlet temperature of 60°, no crystallization was observed for the 50% and 75% pre-concentrated solutions, indicating that supersaturation was not achieved under these conditions. However, the 90% pre-concentrated solution exhibited continuous gypsum crystallization, confirming the critical role of feed concentration in initiating mineral recovery. Based on this observation, the 90% pre-concentrated solution was selected for further MCr experiments at feed inlet temperatures of 40, 50, and 60° to assess the influence of the thermal driving force on permeate flux, water quality and crystal growth. Stables permeate flux was maintained across all temperatures, with no evidence of membrane scaling. Increasing feed temperature resulted in higher flux due to enhanced vapor transport. Permeate conductivity remained consistently low (6 µS/cm), confirming excellent salt rejection (99.99%) and the production of diluted water. Higher temperatures promoted faster crystallization and more pronounced gypsum crystal formation. Overall, the results demonstrate that membrane crystallization can be stable without scaling, while recovering water and gypsum. The study also shows that feed pre-concentration and temperature are a key factor for controlling crystallization.

Keywords: Membrane crystallization; Wastewater treatment; Gypsum recovery; Water recovery

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Liquid entry pressure testing of hydrophobic membranes and perspectives for ceramic membrane distillation

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Membrane distillation is gaining increasing attention as a desalination technology for supplying high-purity water to green hydrogen production systems, particularly in offshore applications. The integration of thermal desalination processes enables the utilization of waste heat from the electrolyser and provides a synergistic system concept. Membrane distillation is a thermally driven desalination process based on a phase change at a vapour-liquid interface, which is immobilized by a microporous, hydrophobic membrane. Owing to its capability to produce water of very high purity and its compatibility with low-grade waste heat, membrane distillation is particularly attractive for integration into hydrogen production systems. The membrane is therefore a key component of the process. Currently, polymeric membranes made of polypropylene, polytetrafluoroethylene, polyvinylidene fluoride, polyethersulfone, or polyethylene are commonly used due to their low surface energy and hydrophobicity. However, membrane fouling and limited membrane lifetime remain major challenges. Ceramic membranes are therefore considered a promising alternative, as they are expected to provide enhanced durability and reduced maintenance requirements, which are particularly relevant for offshore hydrogen systems operating under demanding conditions. A key parameter for membrane evaluation is the liquid entry pressure (LEP), defined as the minimum transmembrane pressure at which liquid penetrates the membrane pores. Even a single liquid breakthrough can result in pore wetting and contamination of the permeate stream. The liquid entry pressure thus provides a quantitative measure of membrane hydrophobicity and resistance to pore wetting and is a critical parameter for membrane distillation. Consequently, a high LEP is essential to enable increased permeate fluxes while maintaining permeate quality. In this work, LEP measurements are performed using a newly developed test rig. Liquid breakthrough is detected using an electrical conductivity probe, allowing immediate identification of saline water passage. The setup is applied to polymeric membranes, and LEP measurements are conducted under different operating conditions. The study is extended to novel ceramic membranes, including initial LEP measurements, and the potential of ceramic membranes for membrane distillation is outlined with a perspective toward offshore hydrogen production.

Keywords: Liquid entry pressure (LEP); Membrane distillation; Hydrophobic membranes; Ceramic membranes; Green hydrogen production

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Breaking the 200 g/L barrier in membrane distillation: Experimental performance of an integrated solar-driven pilot

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The transition towards zero liquid discharge (ZLD) in desalination is often constrained by the operational limits of membrane processes when dealing with hypersaline brines, particularly when targeting salinities above 200 g/L. Although Membrane Distillation (MD) is widely recognized as a promising technology for high salinity brine concentration, its practical implementation remains limited by inorganic scaling, mainly induced by divalent ions such as Ca^{2+} and Mg^{2+}. Building upon the Sol2H2O pilot (funded by the European Commission through Horizon Europe GA Nr. 101079305), this work reports the experimental performance of an integrated treatment chain, focusing on a chemical-thermal synergy that allows a vacuum-enhanced MD unit operation at concentration levels rarely reported in the literature using real brines. The system integrates a multiple-feed plug flow reactor (MF-PFR) upstream of a vacuum-enhanced MD unit equipped with an Aquastill AS26 module with PTFE membranes, specifically operated under extreme salinity conditions. Central to this approach is a fractionated chemical precipitation process in the MF-PFR, designed to selectively remove calcium and magnesium from the RO brine through hydroxide formation. Beyond enabling divalent-ion recovery, this step conditions the brine composition by producing a monovalent solution with crystallization behavior compatible with high concentration MD. After solid–liquid separation and neutralization, the clarified effluent is fed to the vacuum-enhanced MD system, operated under pilot-scale conditions in batch mode. During experimental campaigns the permeate flux, feed and cooling temperatures, vacuum pressure, and permeate conductivity were monitored as the brine was progressively concentrated. Under the operating conditions of feed temperature 80°C, an absolute vacuum pressure 0.6 bar, and passive cooling at 25°C, the system successfully concentrated the brine up to 250 g/L of total dissolved solids, a concentration range not previously documented in the literature for vacuum-enhanced MD treating real desalination brines. Throughout the final concentration phase permeate flux ranged between 1.52 and 0.58 L/m²h, while the recovered distillate at high brine salinity registered conductivity values lower than 10 mS/cm. A mass balance performed across the integrated RO–MF-PFR–MD treatment chain indicates an overall water recovery of 86.06%. These results demonstrate that conventional MD concentration limits can be significantly expanded when appropriate ion management strategies are implemented upstream. Reaching 250 µg/L possibly implies a reduction load on downstream solar evaporation ponds, improving system compactness and accelerating salt harvesting. Future work will address long-term membrane durability, the influence of post-neutralization pH on MD performance, and heat recovery optimization to support system scalability of the Sol2H2O ZLD concept.

Keywords: Brine concentration; Vacuum-enhanced membrane distillation (MD); Multiple-feed plug flow reactor (MF-PFR); Ion management strategies; Zero liquid discharge desalination (ZLD)

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A fluorescence-based artificial neural network for online control of organic micropollutants during quaternary wastewater treatment

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Organic micropollutants (OMPs) such as pharmaceuticals, personal care products, pesticides, and PFAS are frequently detected in wastewater treatment plant (WWTP) effluents due to the limited removal efficiency of conventional treatments. The revised EU Urban Wastewater Treatment Directive requires quaternary treatment to reduce OMP discharges, with ozone (O3)-based advanced oxidation processes (AOPs) considered among the most effective options. However, cost-effective and reliable monitoring of OMP removal remains challenging. This study investigated the removal of 43 OMPs from real secondary and tertiary WWTP effluents using different pilot-scale O3-based AOPs. Highly O3-reactive compounds showed high to moderate removal regardless of O3 dose, while less reactive OMPs were mainly degraded by hydroxyl radicals (•OH). Wastewater matrix effects were evident, with reduced removal in the presence of scavengers such as nitrite. Fluorescence spectroscopy was explored as a surrogate monitoring tool by evaluating five single fluorescence peaks (Ii, i = 1–5). Principal component analysis and linear regression revealed strong correlations between individual peaks and OMP removal, with R^2 values exceeding 0.90 for some OMP–Ii pairs. Combining humic-, fulvic-, and protein/tryptophan-like peaks (I3–I4–I5) further improved correlations, although performance decreased markedly (R^2 0.40) when data from different wastewaters were pooled. To address this limitation, artificial neural networks (ANNs) using I3–I4–I5 as inputs were developed. ANN-1 accurately predicted the removal of atenolol, carbamazepine, and trimethoprim across different wastewaters and AOPs; ANN-2 estimated fluorescence abatement associated with target OMP removal; and ANN-3 predicted the O3 dose required to reach a desired fluorescence reduction. Together, these models enable real-time control of OMP removal and ozone dosing. Overall, this work presents a novel fluorescence-based ANN framework for real-time monitoring and process control of OMP removal by AOPs. The strong performance across diverse wastewater matrices and treatment conditions highlights the potential for a generalized, sensor-based approach that supports water reuse, optimizes oxidant dosing, and reduces energy and chemical consumption.

Keywords: Machine learning; Real-time monitoring; Advanced oxidation processes; Wastewater reuse

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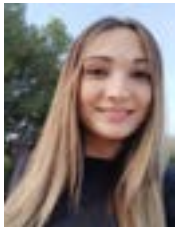
Sustainable concentration of brine from a reverse osmosis plant through the integration of solar membrane distillation



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One of the current challenges in desalination is achieving zero liquid discharge (ZLD). Current desalination technologies, such as reverse osmosis (RO), can reach water recoveries of 45% (with a salinity limit of 75 g/L). Therefore if this residue is properly managed it is possible to increase the water recovery, and reduce the volume of the final brine. One alternative for desalinating this brine is membrane distillation (MD), which can treat highly concentrated solutions and reach a high level of water recovery when operating in recirculation mode, producing a greater volume of freshwater. The best performance in pilot-scale MD to date has been achieved using multi-envelope spiral-wound modules operating in vacuum-assisted air gap (V-AGMD) configuration, being able to treat brines with concentrations of up to 245 g/L. The aim of the project Life-SALTEAU is to produce sustainable drinking and irrigation water from alternative saline water resources. To this end, at the La Caleta desalination plant (Adeje, Tenerife) the RO brine is treated using a spiral-wound nanofiltration system, that splits the saline feed into two streams: one stream is enriched in divalent ions, which are subsequently recovered by precipitation) and the other is concentrated in monovalent ions, whose concentration is approximately 50 g/L. To produce more freshwater from the latter, an MD pilot plant system has been integrated into the process. The chosen V-AGMD module is the most suitable one to operate at high salinity, which has 24 channels (12 for evaporation and 12 for cooling) and a membrane area of 25.92 m^2. As the feed is recirculated into the MD plant, the brine concentration increases during operation. Finally, the concentrated brine resulting from the MD process, which has lower volume and higher concentration, is transferred to evaporation ponds, thus closing the cycle. To analyse the MD technology treating real RO brine, experiments are carried out in two recirculation modes: batch and semi-batch, achieving concentration factors greater than 3.5. The chosen feed flow rate is 1100 L/h to maximise the permeate production and reduce the operating time. Two different evaporation inlet temperatures are tested: 70°C and 80°C, because the required thermal energy is supplied by flat-plate solar collectors, subject to the natural variability of solar radiation. Temperatures lower than 70°C are not considered because the performance is not enough to reach the objective. The cooling inlet temperature varies between 20 and 35°C during the experiment, using the RO brine as cold source. The concentrations of different ions are analysed in the brine and permeate obtained. The results of the experiments will be evaluated and discussed. Acknowledgements:This research was supported by the Life-SALTEAU project (sustainable drinking and irrigation water production from saline alternative water resources), which is funded by the European Commission as part of the Life Programme.

Keywords: Membrane distillation; Pilot plant; Vacuum-assisted AGMD; Zero liquid discharge; Brine concentration

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Annual assessment of a hybrid CAES–PV–RO system with brine re-use

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Water scarcity affects more than one-third of the global population, with desalination based on Reverse Osmosis (RO) being the predominant technology to meet growing freshwater demand. However, conventional RO desalination is energy-intensive and still largely dependent on fossil-based energy sources, which constrains its sustainability and increases its environmental footprint. Solar energy represents one of the most promising renewable alternatives, particularly in water-scarce regions, but its inherent intermittency limits the continuous and reliable operation of RO systems. In addition, the discharge of concentrated brine poses environmental challenges to marine ecosystems. In this context, a hybrid desalination system integrating renewable energy generation, energy storage, and brine recovery is proposed under the framework of the Spanish national project SOLDESALBIO to improve operational flexibility and reduce the environmental footprint of RO desalination. The scheme proposed in the project includes an RO plant integrated into a Central Receiver Concentrating Solar Power (CSP) and Photovoltaic (PV) Plants, complemented by thermal energy storage and compressed air energy storage (CAES). In addition, the scheme considers the re-use of brine from the RO for macroalgae cultivation, supporting circular economy principles and reducing the environmental impacts associated with brine disposal. The CAES–PV system supplies the RO unit, CSP operation, and macroalgae cultivation. During daytime hours, PV is mainly used to compress air in the CAES system, while surplus energy is utilized for RO and macroalgae cultivation. Stored compressed air is subsequently expanded to supply the RO unit after sunset and to support CSP power generation, whereas macroalgae cultivation units rely on grid power as a backup when renewable generation is unavailable. The integrated CAES-RO system will be assessed at pilot scale at the Plataforma Solar de Almería at a new facility to be implemented in mid-2026, within the framework of the European project ASTERIx-CAESar. This work presents an annual simulation of the CAES-PV-RO-B system based on Typical Meteorological Year (TMY) data, considering different operating points of a static model of an RO plant composed of four membranes in series with brine recirculation. For the coupling between CAES and CSP, a discharge strategy representative of commercial-scale operation is assumed to support evening electricity demand. The performance indicators include the PV and grid electricity consumption ratios of the individual energy-consuming components within the system, CAES coverage, and the annual production of permeate and macroalgae. The authors acknowledge funding support from the Spanish Ministry of Science, Innovation and Universities and ERDF under the National R&D Project PID2024-159543OB-C31 and the European Union's Horizon Europe research and innovation program under the grant agreement No 101122231.

Keywords: CAES; Sustainable desalination; Brine re-use; Renewable energy; Net zero

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Correlating pressure drop in spacer-filled RO channels with membrane deformation

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In spiral-wound membrane elements, an envelope consists of two flat sheet membranes which are separated by a porous mesh named permeate spacer, defining the permeate channel and enabling the transport of the produced water. On the feed side, membranes are separated from each other by a feed spacer, promoting mixing and providing structural integrity for the geometry of feed channel. Saline water is pumped into the feed channels to generate a trans-membrane pressure (TMP) that overcomes the osmotic pressure of the feed solution and allows the water transport through the membrane into the permeate channel. For brackish water desalination the TMP is about 10-30 bar, for seawater 50-60 bar, but there are also ultra-high pressure RO processes with TMP up to 120 bar. Several studies reported that the applied pressure leads to membrane deformation, which can be attributed to membrane compaction and intrusion into the permeate channel. Therefore, it is expected that membrane deformation in pressurized operation can impact the geometry of both channels, causing an expansion of the feed channel and reduction of permeate channel volume. Hereby, any change in geometrical characteristics of the feed and permeate channels results in changing hydraulic conditions. For example, a variation in porosity of the permeate channel will impact on the pressure loss along the channel, thus affecting the TMP, which affect the performance of the spiral wound elements [1,2]. To this extent, the characterization of membrane deformation assumes a fundamental role for the process design. Direct observations of membrane deformation in RO modules can be obtained ex-situ (i.e., membrane autopsies). Because, the deformations can be higher during operation, ex-situ analysis (i.e., Scanning Electronic Microscope) is expected to underestimate the change of geometry, showing mainly the plastic effects. To this aim, optical coherence tomography (OCT, applied before as a non-invasive technique to monitor membrane fouling) has been introduced to investigate in-situ membrane deformation [3]. The advantage of using OCT is that reversible and irreversible deformations are in-situ measured assessed along with the deformation pattern [3]. In order to investigate the link between membrane deformation (in-situ) and pressure drop in spacer-filled channels (feed and permeate), three-dimensional membrane deformations were measured in-situ by microscopy (OCT) in MFS-like flow cells, measuring the feed/permeate pressure drops at different TMP (5 bar to 40 bar). The results showed that pressure drops depend on TMP and its history. High TMP correlated with decreased pressure drop in the feed side and increased in the permeate side and generated a permanent effect in relaxed conditions. Characteristic relations were developed considering pressure drop, TMP and membrane deformation (i.e., reversible and irreversible) for both feed and permeate channels.

Keywords: Desalination; Reverse osmosis; In-situ monitoring; Membrane deformation; Pressure drop

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Amphoteric chitosan/PVA beads with lignin nanotriangles for enhanced water desalination

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Faced with a growing global population and increasing demand for desalinated water, it is essential to develop efficient, sustainable, and environmentally friendly desalination solutions. Biopolymers such as chitosan and polyvinyl alcohol (PVA) are promising matrices for adsorption materials due to their abundance, environmental compatibility, and ability to interact with ions in solution [1]. Simultaneously, the incorporation of functional nanostructures into polymeric composites improves porosity, specific surface area, and ion capture performance, as demonstrated by recent developments in nanocomposites for water treatment [2]. In this study, we propose a bio-based desalination platform based on porous chitosan/PVA beads (CP) loaded with carboxylated lignin nanotriangles. Nanotriangles were synthesized using a sustainable process combining solvent exchange and dialysis, resulting in stable nanostructures with a high specific surface area. These hybrid beads, obtained by incorporating the nanotriangles into the CP matrix followed by alkaline crosslinking, exhibit a porous spherical structure and amphoteric adsorption sites. Characterization studies (SEM, BET, FTIR, zeta potential) confirmed their morphology and homogeneous distribution. Batch and continuous column tests demonstrated efficient desalination under various salinities and pH levels, as well as good regeneration and reuse capacity over multiple cycles.

Keywords: Lignin nanotriangles; Chitosan; Polyvinyl alcohol; Desalination; Amphoteric adsorbent; Sustainable water treatment

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Integrating geopolitical risk into desalination planning for Mediterranean water security

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Desalination is becoming a strategic pillar of water security across the Mediterranean, yet project performance depends less on technology than on the territorial and political contexts in which investments are made. Climate stress, uneven governance, and competing sectoral demands shape operational continuity and long-term returns. In a region where water scarcity increasingly intersects with economic vulnerability and social pressure, sound planning reduces not only project risk but also broader instabilities that water insecurity can trigger. This paper applies a geopolitical perspective to examine desalination as critical infrastructure embedded in territorial dynamics operating at multiple scales. Rather than focusing exclusively on engineering performance, it analyses how governance arrangements, demand pressures, and infrastructure interdependencies create conditions that affect project feasibility, cost structures, and operational stability. The study proposes a diagnostic framework that translates territorial complexity into practical risk indicators. The framework complements technical and economic assessments by identifying context-specific vulnerabilities and opportunities that standard appraisals often overlook. For governments, it supports the design of resilient national water strategies aligned with territorial realities and wider stability concerns. For operators and investors, it provides a structured approach to anticipate regulatory, political, and operational risks before committing capital, and to identify leverage points that improve project viability. Integrating territorial analysis into desalination planning is a practical requirement for deploying capacity effectively in the Mediterranean's increasingly complex operating environments.

Keywords: Mediterranean; Desalination; Water security; Geopolitical risk; National water strategies

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Concentration of saline water in a hybrid membrane system

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Concentration of coal mine saline water by evaporation to produce brine nearly saturated with sodium chloride and then its further concentration coupled with the production of evaporated salt is a very energy-intensive process. In the proposed solution, the saline water is pretreated by nanofiltration to decrease the concentration of calcium, magnesium and sulfate ions. The permeate from nanofiltration is then concentrated in a hybrid system: reverse osmosis - electrodialysis. Nanofiltration was tested in a pilot plant operating at a recovery of 88.2%. NF permeate was next concentrated in a laboratory RO-ED system. The RO-ED system showed an energy consumption of 12 kWh per 1 m3 of RO permeate, which is significantly less than the 44 kWh per 1 m3 of distillate in the industrially used MVR evaporator. Energy consumption per 1 t of evaporated salt was estimated at 650 kWh, compared to 1,350 kWh in the industrial plant.

Keywords: Coal mine saline water; Evaporated salt production; Nanofiltration; Reverse osmosis; Electrodialysis

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Ultrafiltration and microfiltration: Going beyond the standard operation and maintenance solutions to extend membrane life

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Polymeric ultrafiltration and microfiltration membranes offer energy-efficient, high quality pre-treatment for reverse osmosis desalination schemes. These membranes are typically chemically and physically robust and, in principle, this allows for simple inexpensive maintenance procedures, often utilising low-cost but aggressive generic chemicals. In practice however, experience has shown that many of these systems encounter fouling problems that provide significant operational challenges and often limit membrane life-span. These issues, often the result of complex mixed matrix foulants, are characterised by a gradual reduction in permeability which traditional backwashing procedures and cleaning cannot completely reverse. In this paper we discuss the limitations of existing maintenance procedures and show how specialist treatments may be incorporated to provide more efficient operation and extend membrane life. Case studies are provided demonstrating the benefits of selecting targeted formulated solutions in terms of savings in cost and waste. These experiences lead us to propose logical next steps for continuous operational improvements.

Keywords: Microfiltration; Ultrafiltration; Membrane life extension; Operating practices; Membrane foulant; Cleaning; CIP; Chemically enhanced backwashing; Waste reduction; Water efficiency

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Counter-current cascades of RO membranes: A tool to enhance performance and overcome membrane aging in desalination

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This study addressed sustainability in reverse osmosis (RO) desalination through performance optimization, water recovery and quality, with recommendations for further multi-criteria assessments to balance performance gains with economic and operational trade-offs. The enhancement of RO performances would be obtained by arranging several membranes in cascade. Besides the single feed stage (0), 3 cascades were considered denoted (+1,0), (0, –1), (+1,0,–1). +1 and –1 indicate, respectively, an additional stage retreating the retentate or permeate from stage 0. Internal recycling resulted in a single permeate and retentate at the cascade outlet. Simulations of cascade performances applied to desalination of NaCl (25–34g.L^{-1}) were carried out aiming at finding the best combination design/permeate recovery. First set of simulations was based on experimental results acquired with a pristine membrane (SW30, 2540, 2.5 m^2, Filmtech) fed with NaCl containing 0.5 mmol.L^{-1} of Tropaeolin O (TO, 263 g.mol^{-1}) or Brilliant Blue G (BBG, 831 g.mol^{-1}), two dyes used as model pollutants. Rejections at 55 bar were 99.4%, 99.6% and 99.9% for NaCl, TO and BBG, respectively. The second set of simulation was achieved assuming NaCl rejection decrease down to 94% in good accordance with literature data for aged membranes. For pristine membrane, simulations showed that water recovery was little affected by the cascade design, while (0,–1) and (+1,0,–1) significantly improved the permeate quality compared to the single stage, reducing NaCl from 250 to 5 ppm, TO from 850 to 11 ppb, and BBG from 581 to 1 ppb, with an increase in membrane filtering area and energy consumption following the number of stages, that can still be optimised. (0,–1) was found to be the best option. Interestingly, simulations exploring the potential of membrane-cascades to mitigate membrane degradation realised with variable NaCl rejections corresponding to a different level of degraded membranes, the cascades had different effects compared to pristine membrane. The water recovery increased with (+1,0,–1) design as membrane degradation is superior. Furthermore, implementing (0,–1) configuration significantly improved the permeate quality for aged membranes up to 96% NaCl degradation, bringing them into the World Health Organization excellent category and even outperforming the new membrane in single-stage. Moreover, the (0,–1) cascade improved the permeate quality of the extremely aged membranes (NaCl rejetion of 95 and 94%), keeping them within the World Health Organization good category. This study was supported by PHC Toubkal.

Keywords: Desalination; Membrane cascade; Simulation; Reverse osmosis; Micropollutants; Membrane lifespan; Energy consumption

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Effect of sintering temperature on the characteristics of microfiltration membranes based on a mixture of perlite and micronized

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This work focuses on developing and the optimizing low-cost ceramic microfiltration membranes based on Moroccan geomaterials, specifically perlite and micronized phosphate. The primary objective is to prepare membranes with appropriate porosity, high permeability, and sufficient mechanical strength for wastewater treatment applications. A series of membranes was prepared by varying the micronized phosphate content and the sintering temperature. The resulting membranes were systematically characterized using structural and morphological analyses, as well as porosity, linear shrinkage, permeability, and mechanical strength measurements. The optimized microfiltration membrane was subsequently applied to clarify industrial wastewater, demonstrating its potential for practical use. Overall, this work contributes to sustainable development by valorizing locally available natural resources and promoting environmentally friendly membrane fabrication technologies.

Keywords: Ceramic membranes; Microfiltration; Perlite; Micronized phosphate; Wastewater treatment

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Zeolite X/polystyrene mixed matrix membrane layer deposited on pyrophyllite support for efficient dye removal

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Membrane-based separation is a highly promising technique for water purification. While ceramic membranes offer excellent stability and antifouling properties, they are expensive. In contrast, polymer membranes are more affordable and easier to process. To combine the advantages of both, Mixed Matrix Membranes (MMMs) are developed by incorporating inorganic particles into polymer matrices. This enhances membrane strength, hydrophilicity and fouling resistance. This study aims to develop an ultrafiltration membrane by incorporating zeolite X into a polystyrene (PS) matrix deposited on a pyrophyllite ceramic support. Zeolite X was synthesized and characterized using SEM, XRD, FTIR and Zeta potential analyses. Different amounts of the synthesized zeolite-X (0-5 wt.%) was embedded on PS in order to enhance the structural properties of the membrane. The optimized membrane demonstrates a dye rejection of approximatively 99% for DR80 with a permeability of 40 LMH/bar. Furthermore, the evaluation of the optimized membrane revels that it costs only 81.6/USD/m^{-2}, making it an effective and affordable solution for industrial wastewater treatment.

Keywords: Membrane; Polystyrene; Zeolite; Ultrafiltration; Dye

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Brine valorization through selective nanofiltration and membrane brine concentration: Operational performance evaluation

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Brine valorization is emerging as a key pathway to enhance the sustainability and circularity of seawater desalination by transforming high-salinity waste streams into sources of valuable salts and critical raw materials. Among the most promising approaches are membrane-based separation schemes capable of selectively isolating monovalent and divalent ions while achieving high brine concentration levels. A dual brine concentration concept integrating Nanofiltration (NF), Reverse Osmosis (RO) and Membrane Brine Concentration (MBC) with low-salt-rejection reverse osmosis (LSRO) membranes has previously been validated to produce two value-added concentrate streams: a purified and concentrated monovalent-ion-rich stream, and a divalent-ion-rich stream suitable for targeted recovery. In this work, newly developed NF and brine concentration (BC) membranes were evaluated in a practical pilot system. The NF membrane exhibited stable selectivity across variable operating conditions, including temperature fluctuations (21–32 °C) and recovery levels (75–82 %), consistently maintaining high divalent-ion rejection with sulphate at 99.5–99.7% and Mg^{2}? near 90 percent. Additionally, a three-stage MBC system operating at 70 bar and using a single BC membrane type achieved long-term concentration of SWRO brine to 220 g/L, demonstrating a simplified and robust configuration for high-salinity brine production.

Keywords: Brine valorization; LSSRO; Nanofiltraiton; Membrane brine concentration

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Parameters affecting membrane distillation performance – Effect of temperature and flow rate in DCMD

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Membrane distillation (MD) is currently regarded as a promising technology for the treatment of a wide range of wastewater streams. Research on this technology has increased exponentially over the last decade [1], focusing on different fields of investigation, with the most productive scientific categories being engineering, chemistry, water resources, and environmental sciences [2]. A key attribute of this technology is its high potential for the treatment of industrial wastewater. On the other hand, textile wastewater represents a major challenge due to its high salinity and complex organic composition, often requiring advanced treatment strategies to enable water reuse [3]. In this context, membrane distillation has emerged as a potential alternative for the treatment of this kind of wastewater as it is considered a clean and environmentally friendly technology that does not require chemicals additives and allows the recovery of high quality water from highly contaminated streams, while significantly reducing the volume of the final wastewater generated. In this contribution, MD in the direct contact membrane distillation (DCMD) configuration has been studied for the treatment of a synthetic textile wastewater stream under different operating conditions. The aim of these experiments was gaining a deeper understanding of the influence of key parameters on the overall process performance and fouling behaviour. For this purpose, a direct dye (Sirius yellow K-CF) was used for the preparation of the synthetic wastewater, which contained a dye concentration of 3 g/L and 2.5 g/L of NaCl. The membrane selected for this research was QL217 (polytetrafluoroethylene active layer and polypropylene support layer, average pore size 0.1 µm, Sterlitech). During operation, the main parameters investigated were the feed-side temperature and the flow rate of both the feed and distillate streams. Several feed temperatures within the range of 40ºC and 60ºC were evaluated, as well as several flow rates from 40 L/h to 60 L/h. In all experiments, the distillate temperature was maintained constant, at 10ºC. To evaluate and compare the efficiency of the process under the different conditions, the rejection of the chemical oxygen demand (COD), dye concentration, and conductivity were evaluated. Simultaneously, the fouling index was determined after each experiment in order to identify the operating conditions leading to the lowest degree of membrane fouling. Finally, ongoing efforts to model the operating conditions for the prediction of DCMD operations using a resistance-in-series model will be presented.

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Keywords: Membrane distillation; Textile wastewater; Modelling

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CO_2 recovery from reverse osmosis brines through membrane contactors

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Anthropogenic carbon dioxide (CO_2) emissions are causing the greenhouse effect and climate change. Scientists estimate that the Earth's average temperature will increase by 2-6°C by the end of the 21st century. The Paris Climate Agreement (PCA) aims to limit the global temperature rise and to achieve climate neutrality.(1) Direct ocean carbon capture (DOC) is among the technologies that will be exploited to achieve the PCA goals. DOC can be considered a method to recover CO_2 from the air through the ocean, which absorbs 27% of the atmospheric CO_2.(2) In the climate change scenario, water scarcity and desertification are major concerns. Desalination through reverse osmosis is a process that produces drinking water from seawater. This process also generates a waste called brine that has a high concentration of ions, including bicarbonates, almost twice that of seawater. Previous works have reported the use of membrane technology for carbon dioxide absorption from gas streams or seawater.(3,4) In this work, the recovery of carbon dioxide from reverse osmosis brines was investigated. Both synthetic and real brines were used. Real brines streams were taken from a seawater reverse osmosis plant located in Valencian Community (Spain). This work aims to recover CO_2 to use it in permeate remineralization, focusing on the separation and absorption in the alkaline solution. Brines (HCO_3^- concentration of 0.21 g/L) were treated in different types of membrane contactors: a polytetrafluoroethylene (PTFE) flat membrane (effective area of 0.0042 m^2) module (CF042, Sterlitech), a Polypropylene (PP) hollow fiber unit of 0.2 m^2 of active area and a bigger one of 1.4 m^2 (Degasmem 1X5.5 and 2.5X8, KIKMO). On the permeate side, alkaline solutions were used to absorb carbon dioxide. Specifically, sodium and magnesium hydroxide solutions were tested but using also sweeping gas and vacuum strategy. Tests were performed in batch mode; turbulence in the device (which depends on the flow rates and the geometry), inorganic carbon concentration, hydroxyl ions concentration, brine pH and system temperature were the process variables. Variables strongly affected the CO_2 and CO_3^{2-} concentration in the solutions. CO_2 recovery%, absorption% and CO_2 flux through the membrane were obtained and compared with literature data and with a mathematical model developed.

Keywords: Brine valorization; Carbon dioxide; Membrane contactor; Mass transport; Carbon capture

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Machine learning–based modeling and performance analysis of multi-effect distillation under CSP variability

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The integration of Multi-Effect Distillation with Thermal Vapor Compression (MED-TVC) plants with variable renewable energy sources, such as solar energy Concentrated Solar Power (CSP), requires advanced modeling tools capable of predicting system performance under fluctuating operating conditions. The Spanish national project SOLDESALBIO, led by CIEMAT-PSA, proposes the optimization for the integration of MED-TVC with a Concentrating Solar Power (CSP) and Photovoltaic (PV) plant, complemented by thermal and compressed air energy storage (CAES). In this scheme, the MED-TVC is driven by the exhaust gases from the CSP plant, consisting in a mini-tower plant with micro-gas turbine. This work proposes the development of a data-driven surrogate model (type Gaussian Process Regression (GPR)) for the MED-TVC unit using a rigorously validated process model previously developed by Ortega-Delgado et al. [1, 2] This model has been simulated to generate a comprehensive synthetic dataset. Then, the GPR model has been trained to provide a fast and accurate surrogate of the desalination process. Numerical simulations cover a wide operational envelope, focusing on variations in motive steam pressure and mass flow rate according to the variation of the exhaust gases from the CSP power block, and evaluating their impact on key performance indicators, including Gain Output Ratio (GOR) and distillate production. This machine learning-based model offers a computationally efficient tool for real-time performance assessment and establishes a foundation for future optimization and control studies, enabling resilient and efficient operation of hybrid CSP–MED-TVC desalination systems under variable thermal energy supply.

Keywords: Multi-effect distillation; Thermal vapor compression; Concentrated solar power; Renewable energy integration; Desalination; Gaussian process regression; Surrogate modeling; Machine learning; Hybrid energy systems; Performance prediction

Acknowledgment This work is part of the project PID2024-159543OB-C31 funded by MICIU/AEI/10.13039/501100011033 and by "ERFD A way of making Europe".

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State-of-the-art nanofiltration and electrodialysis technologies for direct lithium extraction from SWRO brine

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Desalination brine is a chemically complex system containing high concentrations of major salts together with strategic elements of high economical value, such as lithium [1]. Brine generated from seawater reverse osmosis (SWRO) desalination is increasingly being addressed through integrated brine management approaches, including the reduction of brine volumes via minimal or zero liquid discharge (MLD/ZLD) strategies, as well as brine mining initiatives. In the case lithium mining from SWRO brine, conventional lithium recovery routes based on evaporation remain poorly suited to these complex matrices [2]. These processes are slow (1–2 years), highly water-intensive, and generate large volumes of waste. In addition, they are affected by co-precipitation phenomena and high reagent consumption, which collectively limit product purity and overall process efficiency. In this context, this review provides a critical and process-oriented assessment of membrane-based direct lithium extraction (DLE) technologies, with a particular emphasis on nanofiltration (NF) and electrodialysis (ED). The analysis systematically addresses recent advances in DLE from SWRO brine, through advanced membrane-based approaches. Special attention is given to the role of water quality and salinity in governing process performance, with a focus on key challenges such as Li?/Mg²? selectivity, ion and water flux optimization, and overall energy efficiency [3]. Lithium recovery mechanisms, recent progress in membrane design and development, and performance enhancement strategies are critically discussed from a process engineering perspective, highlighting the potential of hybrid configurations such as NF–ED coupling. Beyond separation performance, this review discusses the contribution of data-driven approaches, including artificial intelligence, for predicting lithium recovery and selectivity, as well as issues related to environmental footprint and sustainability. In light of the expected depletion of conventional lithium resources by around 2035, membrane-based DLE technologies appear as a key pathway for sustainable lithium recovery from complex brine systems while preserving aquatic ecosystems and water quality.

Keywords: Desalination; Brine mining; Direct lithium extraction; Selectivity; Membrane separation

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Energetic evaluation of advanced pressure-driven desalination technologies for efficient industrial brine concentration

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To reduce industrial wastewater emissions and support a circular economy, the energy-efficient treatment of high-salinity brines is essential. In addition to selective ion separation, a central objective is the viable concentration of saline solutions, which is critical for minimizing waste volumes and enabling resource recovery. Pressure-driven desalination technologies offer significant energy advantages in this context, but current technical limitations must be addressed to fully realize their potential. This work explores key challenges in industrial brine valorization and presents emerging strategies, with a focus on implementing novel membrane processes at a relevant scale. A core approach involves the combined application of innovative ultra-high-pressure membrane processes to enhance efficiency in brine concentration across different industrial applications. An advanced brine concentration process is introduced that synergistically integrates ultra-high-pressure reverse osmosis (UHPRO), ultra-high-pressure low-salt rejection reverse osmosis (UHP-LSRRO), and ultra-high-pressure extra-low salt rejection reverse osmosis (UHP-ELSRRO), leveraging state-of-the-art membrane technologies and high-efficiency energy recovery systems. Prototype tests using 4-inch spiral-wound membrane elements demonstrated stable operation at pressures of up to 120 bar. Sodium chloride concentrations near saturation were achieved in the concentrate while maintaining favorable permeate quality and recovery, confirming the feasibility of the approach for industrial implementation. The integration of a high-performance energy recovery device (ERD) significantly improved process economics, reducing energy demand by up to 60%, depending on the system configuration. Despite some performance losses caused by irreversible membrane deformation under extreme operating pressures, the combined application of UHPRO, UHP-LSRRO, and UHP-ELSRRO, supported by advanced energy recovery, represents a substantial advancement toward large-scale brine management. This approach directly supports key sustainability objectives, including resource recovery, water reuse, and minimal liquid discharge (MLD). The ultra-high-pressure concept was energetically evaluated based on relevant pilot-scale data and benchmarked against competing pressure-driven processes operated at lower pressures (70–80 bar) under identical boundary conditions. This comparative assessment addresses ongoing uncertainties regarding the energetic performance of ultra-high-pressure membrane processes and provides a transparent framework for evaluating their advantages, limitations, and application potential. Overall, the results highlight both the opportunities and the remaining challenges of ultra-high-pressure membrane technologies and emphasize the need for continued development. The findings provide a robust basis for positioning ultra-high-pressure membrane processes within the existing technology landscape.

Keywords: Industrial brine concentration; Specific energy consumption; Low-salt rejection reverse osmosis; Ultra-high-pressure processes; Energy recovery

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Conventional and emerging membrane technologies for defective treatment of textile finishing wastewater: Differences and advantages

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Water scarcity represents a major concern within the scientific community. This global challenge, which affects societies worldwide, requires innovative solutions that enable sustainable future scenarios [1]. In this context, not only must water consumption be reduced, but wastewater generated in industrial and urban applications must also be effectively treated to maximize water recovery and reuse. One of the major contributors to industrial wastewater generation is the textile industry [2]. Moreover, textile wastewater contains a wide variety of contaminants making the treatment of this wastewater particularly challenging. Under these requirements, membrane technologies emerge as a suitable solution for this paradigm, since their application enables water recovery from different wastewater streams, including textile effluents. Conventional and emerging membrane technologies have been tested, obtaining promising results that encourage further research in this field [3]. Thus, in this contribution, three different scenarios were assessed for textile finishing wastewater treatment: nanofiltration (NF), membrane distillation (MD) and osmotic membrane distillation (OMD). For the NF process , a commercial polymeric membrane (NF270, polypiperazine-amide, molecular weight cut-of ranging from 200 to 400 Da, Dow Chemical) was tested. During the NF operation, the cross flow velocity was set to 1 m/s and the evaluated transmembrane pressures were 5, 10, 15 and 20 bar, reaching, under these conditions values of permeate flux in the range of 20–80 $L{\cdot}h^{-1}{\cdot}m^{-2}$. When NF was performed without any pretreatment, a drastic deposition of solutes on the membrane surface was observed, leading to a severe fouling. Simultaneously, two emerging membrane technologies (MD and OMD) were tested for the treatment of the same effluent. As part of the MD process, a commercial polymeric membrane, QL816 (polytetrafluoroethylene and polypropylene, 0.2 µm, Sterlitech), was evaluated under different temperatures differences between the feed and distillate streams, ranging from 15ºC to 40ºC. The flow rate applied to both the feed and distillate streams was fixed at 35 $L{\cdot}h^{-1}$, and the permeate flux obtained varied between 3 to 7 $L{\cdot}h^{-1}{\cdot}m^{-2}$ Similarly, OMD was performed under the same conditions, using a solution of NaCl as draw solution. To assess and compare the efficiency of each proposed configuration, the rejection of colour, chemical oxygen demand (COD), conductivity and total solids were evaluated . Colour rejection exceeded 95% in all the studied cases, however, COD and total solids rejection differed between conventional and emerging technologies, with higher rejection values obtained for MD and OMD . These results set the emergent membrane technologies as excellent alternatives to recover clean water from textile effluents.

Keywords: Membrane distillation; Textile wastewater; Membrane technologies

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Polymeric antiscalants in desalination: Characterization and biofouling potential in seawater

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Seawater desalination is a key solution to global freshwater scarcity, with reverse osmosis (RO) being the most energy-efficient technology. Inorganic scaling remains a major operational challenge and is commonly controlled through chemical antiscalants, which are typically selected based on cost and scale inhibition efficiency. However, growing evidence indicates that antiscalant chemical composition, impurities, and molecular weight (MW) distribution can significantly influence biofouling and environmental performance, factors often overlooked in conventional selection practices. Phosphonate-based antiscalants are highly effective scale inhibitors but raise environmental concerns due to their phosphorus content and potential contribution to eutrophication. Consequently, polymeric and phosphorus-free alternatives, such as polyacrylic and polycarboxylic acids, have been increasingly adopted. Despite their effectiveness, both phosphonate and polymeric antiscalants have been reported to promote microbial growth, potentially through assimilable organic carbon or altered surface interactions, particularly for low-MW polymer fractions. In this study, a range of polymeric antiscalants with different chemistries and MW distributions was systematically evaluated for microbial growth potential and long-term biodegradability. Microbiological growth assays were combined with one-year incubation experiments to assess short-term biological activity and environmental persistence. The evaluated formulations included synthetic polymers, biopolymers, and phosphonate–polymer blends. The results demonstrate that both antiscalant chemistry and MW distribution strongly influence bacterial growth potential. Significant variability was observed among formulations with similar nominal compositions, highlighting the role of manufacturing processes and impurities. Differences in long-term biodegradability further revealed contrasting environmental persistence among antiscalant classes. These findings emphasize the need for a performance-based antiscalant selection framework that integrates scaling control, biofouling risk, and environmental sustainability, supporting more reliable and sustainable RO desalination operations.

Keywords: Reverse osmosis desalination; Polymeric antiscalants; Bacterial growth potential; Biodegradability

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Integration of a continuous electrodeionisation process with a desalination plant for UPW production

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In the context of the energy transition, the growing interest in green hydrogen production raises new challenges, particularly the limited availability of freshwater, which is a key resource for electrolysis. Industrial-scale electrolysers require ultra-pure water with electrical resistivity between 0.5 and 18 MO·cm [1]. Given its abundance, seawater can be desalinated and post-treated to produce low-conductivity water without exacerbating existing water scarcity issues. In recent decades, continuous electrodeionisation (EDI) has emerged as a water-polishing technology for the production of ultrapure water suitable for electrolysers [2]. EDI combines the principles of electrodialysis and ion exchange, eliminating the need for chemical regeneration. In this work, the integration of an EDI process with a conventional desalination plant was studied, with particular focus on investigating the optimal operating conditions for minimising the energy consumption of the EDI process while maintaining high water recoveries. For the experimental campaign, a pilot-scale EDI stack (MK-3MiniHT) was employed. The stack comprises 10 repetitive units (cell pairs), each composed of cation and anion exchange membranes (CEMs and AEMs) separated by a mixed bed of strong Ion exchange resins (IERs). Electrical power is supplied to the stack via a DC power supply, enabling ion transport across the membranes toward the oppositely charged electrodes, thus generating a highly deionised (dilute) stream and a corresponding concentrate stream. The experimental campaign was designed to explore the role of current density in determining the main feature of the produced ultrapure water and energy consumption, while also analysing its influence on current efficiency. In particular, the feed conductivity was 12 µS cm^{-1} and the flowrates of the dilute, concentrate, and electrode rinse solution (ERS) were set at 600, 50 and 70 Lh^{-1}, respectively. The applied current density ranged between 12 and 57 A m^{-2}. Observing the resulting trends of outlet conductivities, two different operating regimes can be recognised. Working at low current densities, the results show an accumulation of ions in the system, suggesting that the stack is operating in an adsorption regime (namely, enhanced transfer regime). Conversely, increasing the current density, a critical current can be identified, above which the stack works in an electro-regeneration regime. This study identifies an optimal combination of flowrates and current density that minimises the economic impact of the EDI step when integrated with the upstream desalination plant, while ensuring the water quality required for electrolyser operation.

Keywords: Green hydrogen; Electrodeionisation (EDI); Ultra-pure water

Acknowledgements

This work was funded by the MUR, PRIN 2022, within the project SEA-H2, Nr. 2022CX89Y. This work was partially financed by the project PUSH2Green (RSH2A_000019)

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Active batch reverse osmosis: Next-generation membrane desalination for high-efficiency produced water reuse

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Produced water treatment and reuse are increasingly recognized as essential components of sustainable oil and gas production, particularly in regions facing water scarcity such as California. The oil and gas industry is confronted with significant challenges related to the treatment and disposal of produced water, which is typically characterized by high salinity, complex mixtures of dissolved solids, organic contaminants, and scaling minerals. Conventional treatment methods often require extensive pretreatment, result in limited freshwater recovery, and generate large volumes of brine concentrate, leading to high operational costs and environmental concerns, restricting potential beneficial reuse, such as irrigation in nearby agricultural zones. Our project is conducting a six-month field demonstration at a produced water site in California. This demonstration integrates two innovative desalination technologies: high-recovery batch reverse osmosis (RO) and active RO membranes—a new class of electrically conductive membranes designed to actively mitigate mineral scaling and organic fouling. The feedwater consists of brackish groundwater with high total dissolved solids (TDS) and significant scaling potential, providing a demanding real-world test for this combined technology. Initial results from the pilot indicate that active RO membranes significantly outperform conventional passive membranes by reducing fouling and scaling without reliance on aggressive chemical pretreatment. When paired with batch RO, which improves energy efficiency by optimizing operating pressure and enabling high recovery rates, the combined system achieves superior freshwater recovery, reduced energy consumption, and a smaller environmental footprint, representing a substantial advancement over conventional systems. By minimizing pre-treatment needs and concentrate volume, the integrated active batch RO solution offers a simplified system architecture with reduced capital and operational expenses, particularly valuable for deployment in remote or resource-limited oilfield locations. Moreover, the improved quality and quantity of recovered freshwater present significant opportunities for reuse, especially in agricultural irrigation near oilfields, contributing to regional water resilience. Ongoing monitoring and analysis during the pilot will further elucidate long-term membrane durability, process optimization, and environmental impacts associated with water reuse and concentrate management. In summary, this project demonstrates a promising, scalable approach to produced water treatment and reuse, addressing key technical and economic challenges while promoting environmental sustainability and supporting California's broader efforts to secure sustainable water supplies under increasing demand and climate pressures.

Keywords: Batch reverse osmosis; Active membranes; Produces water treatment; Water reuse; Oil and gas industry

EuroMed 2026
Desalination, Water Reuse and the Environment
22–25 June 2026, Marrakech, Morocco

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Advanced treatment technologies for microplastic and emerging contaminant removal to enhance wastewater quality

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Increasing pressures on water resources have intensified the need for high-quality treated water suitable for reuse, prompting greater attention to trace pollutants that persist beyond conventional treatment processes. Among these, microplastics (MPs) and emerging contaminants (ECs) have emerged as key challenges due to their persistence, diverse chemical nature, and potential impacts on water quality and environmental safety. Their persistence emphasizes the importance of integrating advanced treatment solutions capable of reinforcing treatment barriers and ensuring stable, high-purity reclaimed water. This work integrates the results of two pilot-scale advanced treatment technologies applied to real secondary effluent and designed to enhance the robustness of reuse-oriented water treatment. The first technology—a continuous magnetic-agglomeration system—selectively captures MPs by promoting their aggregation with an inorganic agent and subsequent removal under an applied magnetic field. A detailed characterization confirmed the presence of diverse polymers, including polypropylene, polyethylene, acrylics, and polyurethane, in fibers, fragments, and pellet forms. Under stable operating conditions, the system achieved a 76% reduction in MPs, significantly improving the particulate profile of the effluent. This significantly improves overall pretreatment performance by reducing fouling potential and enhancing the reliability of downstream treatment stages that are highly sensitive to particulate and organic matter. The second pilot evaluated granular activated carbon (GAC) adsorption as a final barrier for dissolved ECs, using two parallel fixed-bed columns operated at a 10-min empty bed contact time. 30 representative ECs were monitored, and both GAC materials provided high removal efficiencies (=80 %), nearing complete elimination. The slightly superior performance of one of the tested GACs highlights the influence of pore and surface chemistry on adsorption kinetics. Parameters as UVA254 and TOC/DOC provided practical insights for media management and scale-up, reinforcing the role of GAC as a flexible and effective polishing step capable of controlling micropollutants that cannot be reliably addressed by membranes alone. Both tested technologies demonstrated demonstrate a complementary, scalable strategy that markedly improves water quality in effluents intended for reuse. Their combined application strengthens the multi-barrier treatment approach by addressing both particulate and dissolved micropollutants more effectively than conventional steps alone. These results highlight the potential of integrating selective particle capture with high-efficiency adsorption to deliver more reliable, high-quality reclaimed water and to support advanced reuse pathways under increasingly demanding regulatory and operational conditions.

Keywords: Water quality enhancement; Microplastics; Emerging contaminants; Water reuse

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Integrated solar micro gas turbine–driven seawater desalination combining high-recovery SWRO and zero liquid discharge

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This paper presents, for the first time, a comprehensive assessment of the complete technology proposed within the ZERODESOL Project, aimed at producing freshwater from seawater using solar energy sources. This Project is funded by MICIU/AEI/10.13039/501100011033 and by "ERDF a way of making Europe" under grant agreement PID2022-139571OB-I00. The proposed system integrates three main components. The core element is a power conversion unit based on a solar micro gas turbine, which simultaneously generating electricity and heat power. Both electricity and heat power are subsequently utilised by two different desalination subsystems: an electrically driven SWRO system, and a thermally driven unit designed to achieve zero liquid discharge (ZLD). Previous studies by the authors focused on the experimental and modelling analysis of the individual subsystems. In contrast, the present work addresses, for the first time, the integrated behaviour of all components operating together as a fully coupled solar-powered SWRO system. This new evaluation builds upon the insights gained from earlier experimental campaigns and numerical assessments, during which several system-level limitations were identified and addressed. In the proposed configuration, the electrical output of the solar micro gas turbine supplies an optimised high-recovery SWRO system, whose brine stream is subsequently treated in the ZLD subsystem using the available waste heat. To properly characterise the overall system performance, a dedicated modelling framework has been developed. The design optimisation analysis considers different power scales, operating conditions, and climatic scenarios, evaluating both single-unit configurations and arrays of solar micro gas turbines.

Keywords: Brine concentration; Seawater desalination; Energy efficiency; Reverse osmosis; Solar micro gas turbines

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The CARMEn project: A novel circular approach to recover critical raw materials and energy from spent seawater brines

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The increasing demand for water and critical minerals has driven research toward the development of novel circular approaches for the valorization of waste. Desalination and saltworks plants produce fresh water and table salt, respectively, along with highly saline waste streams, which are typically discharged into the sea. However, these streams are rich in valuable components. In this scenario, the Italian-funded CARMEn project introduces a novel circular approach that aims to valorize desalination and saltworks waste streams by producing magnesium hydroxide, freshwater, and energy via an integrated treatment chain. The chain consists of a nanofiltration (NF) unit, a reactive precipitation step, a softening unit, an electrodialysis with bipolar membranes (EDBM) stack, a membrane distillation (MD) unit, and a reverse electrodialysis (RED) stack. The idea was proven at laboratory scale, treating real reverse osmosis (RO) brines and saltworks bitterns. Based on the experimental data, a preliminary techno-economic analysis was conducted to assess the viability of a pilot plant targeting 50 tons/year of $Mg(OH)_2$. The lowest CAPEX and EnEx were found when using bitterns (Mg^{2+} concentration ~20 times higher than that of RO brine). Additionally, the use of bitterns resulted in $Mg(OH)_2$ purity values > 99.7%. On the other hand, the chain required external water input, reducing circularity. RO brine and NF retentate achieved full circular operation, although with higher CAPEX and EnEx and slightly lower product purity (between 85 and 93%). EDBM and MD dominated energy demand, but coupling MD with waste heat lowered the levelized cost of $Mg(OH)_2$ [1].

Keywords: Mineral recovery; Circular approaches; Water treatment; Magnesium hydroxide; Brine valorization

Acknowledgments

This work was supported by the Made in Italy Circolare e Sostenibile (MICS) Extended Partnership (PNRR Project No. PE_00000004) funded by the European Union NextGenerationEU.

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Transition Box remediation: a modular approach to underwater infrastructure renewal

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The Transition Box Remediation project at the Binningup Desalination Plant addresses severe early-life structural degradation and sand ingress within a submerged concrete intake structure essential to Perth's potable water supply. The deterioration that was manifested through cracking, voids, and sediment intrusion, threatened hydraulic performance, increased maintenance risks, and posed potential operational disruptions. Traditional replacement methods were deemed unfeasible due to environmental sensitivities, the complexity of demolition, and the requirement to maintain continuous plant operations. To resolve these challenges, a novel modular internal lining solution was developed. Custom-machined HDPE blocks were engineered to form a wye shaped flow path accommodating the complex geometry of the existing structure. These blocks were reinforced with corrosion-resistant alloys (CRA), fiber-reinforced plastic (FRP) mesh, and structural steel, then installed underwater in nine interlocking levels through rehearsed diver procedures and full-scale mock-ups. Once positioned, the annular space was filled with high-strength grout, creating a sealed, load-bearing composite lining capable of withstanding marine pressures. The design was validated through advanced computational fluid dynamics (CFD) modelling and rigorous dry and wet full-scale testing, ensuring hydraulic efficiency, alignment precision, and structural robustness. Post-installation assessments confirmed elimination of sand ingress, restoration of hydraulic performance, and grout strengths exceeding 43 MPa. Minor alignment deviations were mitigated through dowels and frictional restraints, and all interfaces were secured with redundant sealing systems. A comprehensive risk-based Inspection, Maintenance, and Repair (IMR) Plan was developed, incorporating CVI, photogrammetry, NDT, and air leak monitoring to ensure long-term reliability. The project achieved major sustainability benefits by preserving the existing asset, reducing environmental impact, and minimising diver exposure and operational downtime. This work demonstrates a replicable, scalable model for underwater infrastructure renewal in desalination systems. By integrating modular engineering, advanced materials, and lifecycle driven planning, the project sets a new benchmark for sustainable remediation of critical marine assets.

Keywords: Desalination; Remediation; HDPE; Modular; CFD; Intake infrastructure; Underwater

EuroMed 2026
Desalination, Water Reuse and the Environment
22–25 June 2026, Marrakech, Morocco

High-pressure pumps – Total cost of ownership analysis

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I. Introduction: Reverse osmosis (RO) is the predominant technology for seawater desalination, yet its significant energy demands present ongoing operational challenges. Among these, the high-pressure pump is the largest energy consumer, responsible for up to 80% of the facility's specific energy consumption (SEC). Optimizing high-pressure pump efficiency is therefore essential to achieve meaningful reductions in SEC, with even small improvements delivering substantial payback and operational savings.

II. Research Conducted: Desalination facilities conventionally employ two categories of high-pressure pumps: centrifugal pumps (CF pumps) and axial piston pumps (APP). CF pumps offer variable efficiency depending on flow rates and pressure lifts, while APPs maintain consistent efficiency under varying operational demands. Historically, CF pumps have dominated the market, but the modularity and energy efficiency of APPs have led to their adoption in larger-scale systems. This research conducted a comparative life cycle cost evaluation of modular APP arrays versus conventional CF pump systems in SWRO plants, focusing on train capacities ranging from 1,000 to 10,000 m^3/d. The study included leading manufacturers and realistic system configurations to ensure a comprehensive performance benchmark.

III. Analysis The analysis involved a 20-year life cycle comparison of capital and operating expenditures between APP and CF pump systems, considering not just pump acquisition but also installation components such as VFDs, electric service cabling, couplings, and other infrastructure. Key metrics included return on investment (ROI), payback period, and net present value. Special consideration was given to evaluating system efficiency under various operational modes and plant sizes to capture the full spectrum of performance scenarios.

IV. Results Review of life cycle costs indicates that energy expenditures dominate plant operating costs, accounting for more than 96% of total costs in both pump systems over two decades. Specifically, the energy used by high-pressure pumps alone can reach up to 50% of total SWRO operating costs. This finding underscores the central importance of pump selection, as improvements in pump efficiency directly translate into optimized operational expenditure (OPEX) and reduced SEC.

V. Conclusions The study validates that investment in energy-efficient pump technologies is essential not only for cost savings but also for environmental sustainability in SWRO systems. High-pressure pumps are the critical drivers of plant OPEX, with energy use representing over 96% of total life cycle costs. APP systems, in all evaluated scenarios, provide annual savings with payback periods averaging just 1.1 years, making them a financially attractive solution. The analysis demonstrates that transitioning to APPs is both technically viable and economically compelling, marking a strategic shift toward more sustainable and cost-effective desalination.

Keywords: Reverse osmosis; SWRO; Axial piston pumps; Energy efficiency; Desalination; APP; Operational performance; Energy savings

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Non-conventional water resources in agriculture: advances, challenges and practical recommendations

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Food security is one of the major global challenges in the coming decades. Projections from the United Nations indicate that food production must double in the coming years to meet the demands of population growth, which will result in a significant increase in water requirements. Consequently, the sustainable management of water resources will increasingly depend on the use of non-conventional water sources, particularly desalinated water and reclaimed wastewater. These alternative resources are becoming essential to ensure water availability in regions affected by water scarcity and climate change. Globally, the use of desalinated water in agriculture remains relatively limited, representing approximately 3% of total desalinated water production. However, certain countries provide clear evidence of its potential when applied under appropriate agronomic and technological conditions. Spain represents a noteworthy example, where desalination has been successfully integrated into agricultural systems focused on high-value crops and advanced irrigation technologies. Currently, more than 21% of the national desalination capacity is used for agricultural supply, a proportion that continues to grow as water scarcity intensifies and competition for conventional water resources increases. In addition to the extensive integration of desalinated water into irrigation systems, Spain is one of the European countries with the highest level of wastewater reuse, reusing a significant share of treated effluents every year. More than 70% of reclaimed water in Spain is allocated to agricultural irrigation, mainly in water stressed Mediterranean basins, where it constitutes a strategic resource to reduce pressure on conventional surface and groundwater sources. In this context, the removal of emerging contaminants and pathogens is a critical challenge to ensure the safety and acceptance of reused water in agriculture. Innovation plays a central role in advancing the sustainability of desalination and reuse systems. This paper presents the Innovation project SOS-AGUA-XXI, a project funded by the Spanish Government with support from European Next Generation funds, encompasses 6 research lines, including detailed studies on the effects of boron on different crops and soils, the use of drone-based technologies for monitoring boron-related stress, and the feasibility of on-site boron reduction. The project also addresses advanced treatment processes for water reuse, focusing on the elimination of emerging contaminants to ensure environmental and agricultural safety.

Keywords: Desalination for agriculture; Emerging contaminants; Advanced wastewater treatment for reuse

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Energy and cost optimization in CCRO and FO-RO water reuse systems

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Industrial water reuse has shifted from a cost-based requirement to a strategic goal due to increasing water scarcity, stricter regulations, and environmental performance objectives. Many industries now face zero or near-zero liquid discharge requirements, leading them to treat complex and high-salinity wastewater. Conventional single-pass reverse osmosis (RO) systems often cannot overcome limitations in recovery, energy demands, and operational flexibility, especially with challenging wastewater.

Emerging Solutions: CCRO and FO-RO integration closed circuit reverse osmosis (CCRO) and forward osmosis (FO) technologies address many of these limitations. CCRO operates with a recirculating feed, enabling higher recoveries, reduced chemical use, and better scaling/fouling management. Integrated FO-RO designs use FO for pre-concentration, lowering the load on the final RO stage and allowing higher recoveries with less energy consumption. This study evaluates CCRO and FO-RO system designs from a system-level energy and lifecycle perspective, focusing on how integrated high-pressure pumping and non-mixing energy recovery influence efficiency, controllability, and long-term cost performance.

Methodology: Both system types were evaluated using steady-state and representative variable operating conditions. The methodology includes:

- Energy balance calculations across feed, concentrate, and purge streams
- Evaluation of specific energy consumption and installed power
- Qualitative lifecycle cost assessment considering energy use, operating stability, and maintenance implications

Assumptions related to electricity pricing, operating hours, and recovery targets follow the reference water reuse case studies used in this analysis.

Comparison of System Designs: Key differences between conventional designs and integrated CCRO/FO-RO systems:

- Pressure Variability: Conventional designs handle poorly; integrated systems manage better.
- Specific Energy Consumption: Higher in conventional; reduced in integrated systems.
- Part-Load Efficiency: Moderate in conventional; enhanced in integrated systems.

Energy and Cost Optimization: Advanced configurations achieve higher water recovery and consistent operation, minimizing energy use and chemical costs. This results in a more sustainable, cost-effective approach to industrial wastewater management and water reuse.

Conclusion: This study demonstrates that CCRO and FO-RO systems require purpose-designed energy and pressure management strategies to achieve their full economic and operational potential. Integrating high-efficiency axial piston pumping with non-mixing energy

recovery on concentrate and purge streams significantly reduces specific energy consumption, improves operational stability, and lowers total cost of ownership. The findings confirm that system architecture, rather than membrane selection alone, is the primary determinant of long-term performance in advanced water reuse applications.

Keywords: CCRO; Forward osmosis; Energy recovery; Water reuse; Total cost of ownership

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Potential of $Cs_xK_{1-x}NbO_3$ ferroelectric materials for desalination applications : structural, dielectric, and functional study

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$Cs_xK_{1-x}NbO_3$-based materials, developed using solid-state methods, have been studied for their potential application in desalination. Structural analyses using XRD confirm the formation of a well-crystallized perovskite phase, while Raman and infrared spectroscopy highlight distortions in the NbO_6 octahedra associated with the ferroelectric nature of the material. Scanning electron microscopy observations reveal a morphology favorable to surface-ion interactions. The dielectric properties, characterized over a wide range of frequencies and temperatures, show high permittivity and a marked polarization response, enhanced by Cs doping. These characteristics suggest a strong aptitude for electrostatic interaction with dissolved ions under the effect of an electric field. UV–Visible optical results also indicate stability and absorption compatible with irradiated aqueous environments. Based on these properties, Cs-doped $Cs_xK_{1-x}NbO_3$ materials are proposed as ferroelectric functional fillers for desalination membranes and as active materials for capacitive deionization processes, where dielectric polarization plays a key role in the rejection and adsorption of Na^+ and Cl^- ions. This study highlights the potential of $Cs_xK_{1-x}NbO_3$ as an advanced ceramic material for future applications in water desalination

Keywords: Ferroelectric $Cs_xK_{1-x}NbO_3$; Dielectric properties; Additive membrane; Capacitive deionization (CDI)

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Smart groundwater complete solution up to MLD

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Groundwater desalination increasingly faces a "volume problem": when feedwater quality fluctuates due to seasonality and aquifer dynamics, conventional treatment plants struggle to maintain high recovery without scaling, fouling, unstable output, and downtime. As a result, operators are forced to reduce recovery and discharge large brine volumes, which increases disposal burden, cost, and compliance risk. Achieving Minimum Liquid Discharge (MLD) therefore requires a solution that remains stable under real groundwater variability, not only under fixed design conditions. To address this, we introduce HydroVolta ONE, a fully integrated "Monitor + Treat + Valorize" platform engineered to maximize recovery while minimizing liquid discharge. The system combines continuous water monitoring with adaptive process control and SonixED™ technology (ultrasound-enhanced Electrodialysis Reversal). By linking real-time water quality trends to operational setpoints, the platform proactively adjusts treatment parameters to prevent scaling and fouling, allowing operation at the high concentration factors required for MLD-level recovery. Ultrasound integration further reduces deposition on membrane surfaces, supporting stable performance without the frequent shutdowns typically associated with high-recovery desalination. Pilot testing validates that HydroVolta ONE can sustain water recovery above 95% under variable groundwater conditions, demonstrating consistent MLD-level performance with minimized brine volumes. This improves operational reliability and reduces the penalties associated with instability-driven downtime. Beyond brine minimization, the reduced concentrate volume can be directed toward valorization pathways such as reagent generation and mineral recovery, offering a route to convert waste streams into usable resources. Overall, the results demonstrate that MLD can become a practical operational baseline for groundwater desalination when monitoring, adaptive control, and high-recovery electrochemical treatment are combined into one complete solution.

Keywords: Groundwater; Desalination; Minimum liquid discharge (MLD); Electrodialysis reversal (EDR); Ultrasound; Fouling control; Brine minimization; Adaptive control

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Characterization of nanocarbon nanomaterial based electrodes for enhanced electrochemical degradation of aqueous pollutants

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The development of high-efficiency electrochemical oxidation techniques is necessary due to the persistence of organic micropollutants in industrial effluent. The production of electrode material intended to maximize electron transfer and catalytic activity in water treatment applications is investigated in this work. X-ray diffraction (XRD), Raman spectroscopy, scanning electron microscopy (SEM), transmission electron microscopy (TEM), X-ray photoelectron spectroscopy (XPS), cyclic voltammetry (CV), electrochemical impedance spectroscopy (EIS), etc. were used to characterize the nanocarbon's morphological and structural characteristics. Every characterization performed on the nanocarbon material demonstrated the extraordinary characteristics of this substance: a high specific surface area, an outstanding electrical conductivity as well as a well developed porous structure. It is perfect for producing high-performance electrodes in the context of electrochemical process applications because of these qualities. When a low voltage (about 1.2 V) is supplied during the electrochemical process, the nanomaterial electrodes trap dissolved ions (Na^+ and Cl^-) in the electrical double layer (EDL) that forms at the electrode-electrolyte interface.

Keywords: Electrochemical process; Nanocarbon material; Specific surface area (SSA); Characterization; Water treatment

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Evaluation of low salt rejection RO membranes prepared by controlled oxidation of SWRO membranes

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Desalination is currently undergoing rapid growth and requiring research for more sustainable operation. Brine management is of crucial importance and processes-based membranes like low salt rejection reverse osmosis (LSRRO) demonstrate capability and scalability in terms of energy efficiency and sustainability. This study investigates the performance of the possibility to transform seawater (SW) RO membranes into LSSRRO by contacting SWRO Dupont membrane with different NaOCl concentrations. M1, M2, M3, M4, M5, M6 LSRRO membranes were produced with NaOCl doses respectively of.... ppm.h and were compared with SW30 and nanofiltration NF90 and NF270 membranes. Permeabilities and selectivity's of 9 different membranes were tested [SWRO, NF90, NF270, M1, M2, M3, M4, M5, M6] using divalent ($MgSO_4$) and monovalent (NaCl) salts. All experiments were conducted with 2 g/L and 80 g/L and 15 and 50 bar operating pressure respectively. It was observed that selectivity increased and permeability increase following higher contact time with NaOCl transforming efficiently SWRO membranes into LSRRO ones. The results observed confirm that modified SWRO membranes operate properly under LSRRO mode by enhancing permeability and controlling salt rejection. At the same time, very low flux was recorded when using SWRO at high concentration confirming that this membrane is not suitable unless operated at very high pressure. While high rejection of both monovalent and divalent salts was maintained at low concentration, a significant decrease in rejection was observed at higher salt concentration and operating pressure, consistent with realistic LSRRO operating conditions. In addition, Modified SWRO membranes also could be almost have the same performance as the commercial NF membranes with advantages of controlling the rejection on them. Overall, the key results highlight the potential that membrane modification enables the development of the LSRRO process by controlling the rejection respect to the concentration and type of salt. This approach supports energy-efficient and sustainable brine management by enabling operation at lower pressures while maintaining controlled separation performance.

Keywords: Desalination; Reverse osmosis; Brine management; Low salt rejection reverse osmosis

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A physics-informed hybrid machine learning framework for forward osmosis water-flux prediction under uncertain membrane parameters

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Forward osmosis (FO) is a promising route for low fouling desalination and hybrid desalination systems, yet boarder deployment still requires substantial experimental and modeling effort to enable reliable scale-up. FO process involves strongly coupled and non-linear transport and thermodynamic effects that are difficult to capture with simplified diffusion-based laws. Purely mechanistic models can be biased by limiting assumptions and by uncertainty in nanometric membrane properties; in particular, water permeability coefficient (A), salt permeability coefficient (B), and structural parameter (S). Although these parameters are often treated as constants, many studies report that they vary with operating conditions. Conversely, purely data-driven models can perform well in-domain but struggle to extrapolate and typically provide limited physical insight. This work develops a generalized physics-informed hybrid framework for FO water flux prediction that couples (i) an analytical FO transport model based on diffusion and mass-transfer balances with (ii) a data-driven correction term trained on the residual to learn the influence of non-idealities, hidden experimental variability, membrane type, and thermodynamic properties. A multi-source FO dataset spanning 1150 experimental points was curated from the literature and quality-controlled to ensure consistency and robust preprocessing. Multiple machine learning (ML) algorithms were benchmarked, leading to the selection of a Random Forrest model. The analytical model provides a baseline flux estimate from measurable drivers and membrane properties, and the ML model is trained on the residual to capture systematic gap from idealized transport. The framework is implemented in Python using open-source tools (Reaktoro, PHREEQC) and empirical correlations for thermodynamic calculations; and scikit-learn/TensorFlow for ML. The hybrid model covers both commercial and synthetized membranes and achieves high predictive accuracy when intrinsic membrane parameters are available, with MAE = 3 LMH, RMSE = 4.58 LMH, and R^2 = 0.9. To expand applicability when A, B, and S are missing, empirical correlations were integrated to estimate these intrinsic parameters. Under this correlation-estimated scenario, the hybrid model remains accurate, achieving MAE = 2.75 LMH, RMSE = 4.1 LMH, and R2 = 0.92. Compared to the analytical baseline evaluated under the same conditions, the hybrid approach improves MAE by 37.8%, RMSE by 45.2%, and R2 by 23.5%. Feature-importance analysis consistently ranks membrane properties (A and S), draw and feed osmotic pressures, and membrane orientation among the dominant drivers, highlighting the importance of developing high-permeability and low-structure membranes and operation under sufficiently high driving force. The proposed framework provides an interpretable, generalizable, and practical modeling tool for FO performance prediction and for guiding membrane and process optimization.

Keywords: Forward osmosis (FO); Water flux prediction; Physics-informed hybrid framework; Machine learning (ML); Random Forest; Membrane intrinsic parameters (A; B; S)

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Closing the brine valorisation cycle at DESAL+ Living Lab via an integrated approach to high-purity salt production

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Desalination brines are increasingly recognised as secondary sources of valuable raw materials. In a context of volatile international markets and growing dependency on imported commodities, their recovery offers a strategic opportunity to enhance material resilience, reduce import reliance and support local industrial value chains. Over the past decade, brine valorisation has emerged as a highly active research field, exploring a wide range of technological approaches for resource recovery. Nevertheless, few solutions have progressed beyond laboratory or pilot scale to reach industrial implementation or commercial viability, often due to technical complexity, high energy demand, or unfavourable economics. Addressing this gap requires integrated, site-specific solutions demonstrating both technical robustness and economic relevance under real operating conditions. Within this framework, the Canary Islands Institute of Technology (ITC) is pursuing a strategy to close the brine management cycle through interconnected technological developments. The Brine Valorisation Open Testbed, integrated into the DESAL+ Living Lab platform in Pozo Izquierdo (Gran Canaria, Spain), is a key infrastructure in this strategy. It aims to facilitate the transition from pilot research to market-oriented applications by enabling production of value-added products from desalination brines. In particular, this initiative seeks to complete the valorisation chain to obtain high-purity sodium chloride suitable for local sodium hypochlorite (NaClO) production, thereby strengthening regional supply chains and promoting circular economy approaches. This work presents results from pilot-scale membrane processes applied to desalination brines, including reverse osmosis (RO), nanofiltration (NF) and osmotically assisted reverse osmosis (OARO). In parallel, chemical precipitation studies were performed on the concentrated brine to evaluate impurity removal and identify the most suitable purification strategy prior to salt recovery. The combined analysis supports the definition of quality requirements for the brine feed to the final salt production stage. Based on these findings, technical specifications for the final evaporation–precipitation step are established. Implementation of this last stage, through a public tender, will allow ITC to fully close the valorisation cycle and perform a comprehensive techno-economic assessment. Beyond this case study, the results contribute to understanding practical limitations and opportunities of brine valorisation under real conditions, offering guidance for researchers and industry stakeholders aiming for economically viable and sustainable desalination practices. This work has been co-funded by FEDER funds, INTERREG MAC 2021-2027 programme, within the IDIWATER project (1/MAC/1/1.1/0022).

Keywords: Brine valorisation; Salt recovery; Integrated approach; Circular economy; Open testbed; Pilot plants

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Design and implementation of the DESALRO 2.0® concept: The most energy efficient seawater reverse osmosis desalination plant

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This paper deals with the most energy efficient seawater reverse osmosis (SWRO) desalination plant, referred to as DESALRO 2.0®, which was awarded the Guinness World Record (GWR) with a Specific Energy Consumption (SEC) of 1.794 kWh/m^3 (February 2025) working at 40% of recovery rate and product water quality of TDS 200 mg/L and B 1 mg/L. This plant is the first implementation of the DESALRO 2.0® concept with 2,500 m^3/d of nominal production capacity. It is located at the ITC - DESAL+ LIVING LAB facilities in Pozo Izquierdo (Canary Islands, Spain) – 37 g/L, 22ºC, B 1 mg/L -. The Canary Islands Institute of Technology (ITC) developed the design of the plant whereas the temporary joint venture Canaragua-Elmasa carried out the plant construction. The design has been scaled up to 5,000 m^3/d and eight plants based on the DESALRO 2.0® concept have been implemented for agriculture purpose so far. This paper describes the development of DESALRO 2.0® concept along with existing implementations and projects under construction, specifically:

1. Construction of a SWRO rack with 5,000 m^3/d of nominal capacity to be integrated at the IDAM SURESTE desalination plant, thus enlarging its existing capacity. This plant belongs to the local administration, Mancomunidad del Sureste of Gran Canaria Island.
2. Construction of a 2,500 m^3/d SWRO train for Fuerteventura Island, specifically the plant IDAM GRAN TARAJAL belonging to Agricultura GobCan.
3. Use the expertise by ELMASA-CANARAGUA in their future project to be installed in Estepona (Málaga), consisting in two racks of 4,000 m^3/d.
4. Preliminary project of a new SWRO plant to be installed in La Palma Island, funded by the Consejo Insular de Aguas de La Palma.
5. Eight plants currently in operation focused on agriculture irrigation (EAFRD funds).
6. New scale design in elaboration up to 8,000 m^3/d.

Keywords: Reverse osmosis desalination; Energy diagnosis; Energy efficiency; Seawater desalination

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Assessment of next generation high area ultrafiltration membrane as seawater desalination pretreatment

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Ultrafiltration (UF) is used as seawater desalination pre-treatment due to its capacity to deliver a filtrate of consistent quality. In order to diminish its associated CAPEX, membranes with larger surface area have been developed. In this regard, a multi-channel modified polyether sulphone (PESM) fiber, the DuPont™ inge™ Multibore™ fiber with 7 capillaries resulted in 60 m² (DuPont™ Inge™ MB 60 TR S, here called MB 60), whereas the next generation of DuPont™ inge™ Multibore™ PRO fiber with 19 capillaries results in 82 m^2 (DuPont™ Inge™ MB PRO 82 TR S, here called MB PRO 82) maintaining the same external module size. To compare their performance, both membranes have been tested in parallel at pilot scale, dealing with Mediterranean seawater continuously. Both modules have been equipped with an integrated prefilter, avoiding the need for strainers or ring filters, and hence, further reducing the system footprint. The two full scale membranes have been fed by raw seawater from the Mediterranean Sea, only pre-filtered by 2 mm grids. Both membranes have been able to successfully deal with raw seawater (average influent turbidity 0.52 NTU, pH 8, SDI15 5.32, total suspended solids (TSS) 5.20 mg/L and total organic carbon (TOC) 0.63 mg/L), a natural storm (average influent turbidity, 0.91 NTU, pH 8, SDI15 5.14, TSS 4.03 mg/L, TOC 1.10 mg/L) and spiking 10 ppm of TSS, continuously, working at 80 L/(m^2·h) (LMH), without any coagulant dosage, performing a BW every 40 min and 1 CEB per day. Hydraulic and quality performance of each membrane (MB 60 and MB PRO 82) under each scenario are summarized in Table 1.

Table 1. Main hydraulic and quality performance of MB 60 and MB PRO 82 membranes under different scenarios tested so far. TMP: transmembrane pressure.

	MB 60	MB PRO 82
Raw seawater		
Average TMP (bar)	0.31	0.20
Filtrate turbidity (NTU)	0.09	0.08
Filtrate TSS (ppm)	1.12	1.10
Filtrate SDI15	2.62	2.62
10 ppm spiking		
Average TMP (bar)	0.32	0.24
Filtrate turbidity (NTU)	0.08	0.06
Filtrate TSS (ppm)	1.30	1.06
Filtrate SDI15	2.71	1.85

As can be seen, MB PRO 82 presents a lower TMP vs MB 60, delivering a filtrate of equal or even slightly better quality, not only providing savings in terms of space requirements but also of performance. Under all these scenarios, the water recovery has been 94.3% and the chemical consumption 1.18 mL NaOH 30%/m³, 2.74 mL NaOCl 15%/m^3 and 1.37 mL H_2SO_4 98%/m^3 for both types of membranes. Experiments are on progress further characterizing and comparing both membranes, facing more challenging influent water quality conditions: currently 20 ppm of TSS are being spiked to the raw seawater and subsequently, tests adding algae (up to 20 Mcel/L) will be conducted, to fully determine both systems performances, enabling a subsequent technico-economic analysis.

Keywords: Seawater desalination; Ultrafiltration; Pre-filter; Footprint

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Demonstration of a highly sustainable desalination scheme

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Seawater desalination has become an essential tool for ensuring water supply in regions affected by resource scarcity and the increasing frequency of droughts. In recent years, climate change has heightened both the occurrence and severity of these events, leading to reduced freshwater reserves and putting the water security of many communities—especially in coastal and Mediterranean areas—at risk. Within this context, desalination not only offers a viable alternative to meet demand but also creates opportunities to diversify water sources, reducing reliance on conventional resources and building resilience against climate variability. Moreover, the incorporation of more efficient and sustainable technologies in desalination processes helps to minimize environmental impact and optimize energy use, which is crucial for the long-term viability of this approach. As such, desalination stands out as a key solution within integrated and sustainable water management policies, making a significant contribution to drought adaptation and the socio-economic development of the most vulnerable regions. In this context, the LIFE INDESAL aims to contribute tackling these challenges, developing and demonstrating a new integrated and circular seawater desalination scheme. Specifically, it aims to increase the sustainability of seawater desalination by:

- Reducing seawater desalination consumption by up to 0.2 kWh/m^3 using a low-pressure multi-stage reverse osmosis system (LMS RO).

- Generating up to 0.1 kWh/m^3 of renewable energy from brine using reverse electrodialysis (RED).
- Transforming brine into acid and base that can cover 100% of the demand of the desalination process itself using electrodialysis with bipolar membranes (EDBM).

A pilot plant with a nominal capacity of 8 m^3/h has been designed, built and been in continuous operation in San Pedro del Pinatar (Murcia) for almost 20 months, treating water from the Mediterranean Sea. The hydraulic and quality characterization of each process, both individually and in an integrated way has been determined, enabling the identification of the optimal conditions. Based on the pilot plant results, full scale projections have been conducted, enabling the performance of a Life Cycle Assessment (LCA) and a Life Cycle Costing (LCC) to determine the technico, economic and environmental benefits of the LIFE INDESAL scheme, hence enabling a comparison with a conventional desalination system.

Keywords: Seawater; Desalination; Reverse osmosis; Circularity; Sustainability

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Universal electrified pretreatment system for high recovery of brines

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The global surge in anthropogenic activities has led to a substantial increase in brine production from industries such as desalination, energy, and semiconductor manufacturing. Despite variation in chemical composition, brines are uniformly characterized by elevated levels of total dissolved solids (TDS) and total organic carbon (TOC), posing significant challenges for disposal and limiting reuse opportunities. This bench-scale study explores the efficacy of a novel universal pretreatment system designed for the continuous reclamation of brine. This work integrated six components: an electrolytic cell (EC), an iron reactor (IR), a fluidized bed crystallizer (FBC), granular activated carbon (GAC), a microfilter (MF), and reverse osmosis (RO). A 35g/L NaCl solution was initially utilized as the feed for the EC, which facilitated in-situ water electrolysis to generate the acid and base reagents for the IR and FBC, respectively. Secondary municipal RO concentrate served as feed for IR and FBC. The FBC effectively removed scale-inducing constituents such as calcium and magnesium. Effluents from FBC were blended with anolyte produced by the EC to achieve circumneutral pH. This combined stream served as the feed to the IR to enable in-situ ferric coagulant generation. The IR effectively removed TOC, silica, bicarbonate, and free chlorine, an anodic byproduct of the EC. The IR effluent was then filtered through a 5 µm microfilter before purification via RO. Subsequently, the concentrate generated by the RO was utilized as the EC feed, forming a closed-loop system. The closed-loop configuration gradually increased the salinity in the system, allowing the process to mimic that of seawater desalination. This characteristic offered two advantages: 1) feedwater-agnosticism because different brine sources can be reclaimed by eliminating scaling and fouling constituents, and 2) enhanced EC Faradaic efficiency due to increased conductivity, producing high-quality acid and base reagents. The ability to fine-tune the reagent quality position STREAM competitively, especially in terms of fouling mitigation, since the concentration of ferric coagulant can be readily adjusted by altering the current density provided to the EC. This presentation will introduce the operational mechanisms of each pretreatment component and their synergistic interaction in mitigating membrane fouling and scaling. Key focus areas are: (1) the quality of electrochemically generated acid and base reagents, (2) removal efficiency of pretreatment processes in removing target contaminants, (3) discussion on optimization of configurations targeting brine with different organic loading profiles, and (4) operating cost compared to conventional pretreatment methods.

Keywords: On-site reagents generation; Electrochemically enhanced RO; Universal pretreatment system; Minimal-liquid discharge

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Techno-economic assessment of high-recovery seawater reverse osmosis (SWRO) based on osmotically assisted reverse osmosis (OARO)

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The interest in seawater and brine valorisation along with zero liquid discharge motivates the development of cost-efficient systems of high-recovery seawater desalination. Previous research activities of the authors have quantified the specific energy consumption (SEC) of seawater desalination with high recovery based on the reverse osmosis process coupled to other processes – i.e LSSRO (Low Salt Rejection Reverse Osmosis), OARO (Osmotically Assisted Reverse Osmosis), PRO (Pressure Retarded Osmosis) -. Within this frame, this paper deals with high-recovery seawater desalination based on coupling of conventional seawater reverse osmosis (SWRO) and OARO processes with the main aim of identifying the best design layouts. To this end, a comparative analysis is conducted by combining the assessment of energy efficiency, technical reliability and capital costs. Results highlight the opportunities of developing reliable configurations of high-recovery seawater desalination that exhibit reasonable SEC and capital costs. After dedicated technical discussion, quantitative results of configurations analysed are reported, as a function of recovery rate and plant location, in terms of SEC, capital costs, membrane area economy, product quality and maximum salt concentration.

Keywords: Reverse osmosis desalination; Osmotically assisted reverse osmosis; Energy diagnosis; Energy efficiency; Seawater desalination

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Performance analysis of MSF and MED based desalination plants using exergy and actual data

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Demands for potable water are growing due to the significant increase in social, industrial and economic activities in multiple regions worldwide. Saudi Arabia is one of those countries with severe scarcity in drinkable water. For several decades, the country has relied on reliable thermal and membrane desalination technologies for providing the potable water needed. Even though the recently commissioned and constructed plants in the Kingdom are almost all based on reverse osmosis (RO) process, thermal desalination ones namely multiple effect distillation (MED) and multistage flash (MSF) and their variants are still competitive mainly in cogeneration options. This work presents first a comprehensive update of the status of desalination in the Kingdom followed by a systematic performance investigation of selected operating desalination plants namely Ras-Al khair MSF plant, Yanbu MSF phase III plant and Yanbu MED-TVC phase II plant. The study is based on first and second laws of thermodynamics as well as actual technical specifications of the main components of the plants. In addition, an accurate evaluation of the seawater flow exergy for various levels of temperature, salinity and pressure has been conducted. The results include the impact of operating and weather conditions such as various loads, seawater and top brine temperatures for clean and fouled conditions on the overall performance of the plant as well as the exergy destruction and exergy efficiency of the main components of each plant. The main results show that the highest exergy destruction occurs in the heat recovery stage of the MSF plants. The fouling conditions significantly increase the exergy destruction by more than 10% as compared to clean ones. For the MED based plants, the thermal vacuum compression system (TVC) is responsible for the highest exergy destruction rate. The results obtained in the frame of this study have been discussed and used to develop appropriate recommendations to improve the performance of the selected plants.

Keywords: Cogeneration; MSF; MED-TVC; Energy recovery; Exergy; Actual data

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Performance enhancement of a typical air GT by waste heat recovery to drive a sCO_2 Brayton cycle and membrane distillation unit

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Gas turbines are widely used power generation thanks to their several advantages including their reliability and technological maturity. However, they are known to have a low thermal efficiency level, and then high amounts of hot gases are discharged into the ambience. This work presents a comprehensive thermodynamic and systems-level investigation of a cogeneration power and desalination plant composed of a typical gas turbine, a supercritical CO_2 Brayton cycle and a Membrane distillation unit. The proposed configuration is designed to maximize primary energy utilization through cascaded waste heat recovery, enabling simultaneous production of electrical power and desalinated water. The system is particularly suited for application within the Saudi Arabian power sector, where electricity demand growth and freshwater scarcity present critical challenges. Detailed mass and energy balance formulations are developed for each subsystem, and key performance indicators including overall thermal efficiency, net power output, freshwater production rate, and electrical power produced are evaluated. Comprehensive simulations for various configurations under Saudi weather conditions will be presented and analyzed. In particular, the impact of the recuperator effectiveness on the water and sCO_2 power production as well as the overall performance of the cogeneration plant. The integration of parabolic trough collectors will also be evaluated.

Keywords: Gas turbine; Membrane distillation; Waste heat recovery; Solar parabolic trough collectors; Utilization factor

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Renewable energy and desalination integration as a sustainable approach

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The high energy consumption and environmental impacts associated with the desalination industry are two major concerns limiting the implementation of appropriate measures toward sustainable desalination. Specific studies on energy, water, and the environment are needed to mitigate the above energetic and environmental concerns. The use of renewable energy can solve several environmental and sustainability issues. However, further efforts are needed to master the technology and reduce the total cost of water using renewable energy sources. The path to a higher technological development level is needed using an overall and integrated approach. The development of both RO and thermal-based technologies while using clean energy sources and methods to lower the rejection of concentrated brine and emissions of gases is a principal way toward sustainable desalination. It is worth mentioning that based on the available literature on desalination and related fields, there exists a real lack of quantitative metrics to evaluate the sustainability aspects in desalination. This results in vague, shallow and non-accurate conclusions when comparing desalination systems based on sustainability requirements. This work will discuss various aspects of sustainable desalination by considering few examples of integrated renewable energy and desalination systems through modeling and simulations.

Keywords: Sustainable desalination; Renewable energy; Performance metrics; Environmental impacts; Brine discharge

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From pilot-scale operation to technoeconomic and life cycle assessment for hybrid brackish water desalination

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With increasing demand and declining potable water supply, non-conventional water sources and treatment methods, such as brackish water desalination, offer a promising alternative to expand the water portfolio. Reverse osmosis (RO) is a highly selective pressure-driven membrane process widely used for brackish and seawater desalination. However, RO desalination can face challenges such as high energy requirements and high costs associated with managing residual streams, which can limit implementation in inland regions. Thus, there is a need for low-energy water treatment technologies that are widely accessible and aid in increasing the lifecycle of water. Compared with RO, Nanofiltration (NF) has lower salt rejection; however, NF consumes less energy while maintaining a higher water flux than RO, owing to the selective design of the membrane. This study explores hybrid NF-RO treatment trains where NF is used as a pre-treatment (NF270-RO) or brine recovery and recirculation (RO-NF270) step to mitigate adverse effects on RO membranes. A comparative techno-economic (TEA) and life-cycle analysis (LCA) were performed to evaluate the environmental impacts and costs of hybrid treatment trains across varying recovery and feed concentrations. The results were validated using experimental results from a pilot system located in Yuma, Arizona, United States. The proposed NF270 brine-recovery configuration results in 10% lower energy requirements, 20% higher water recovery, and, consequently, 50% lower operating costs. Additionally, membrane autopsies indicate that NF270 pretreatment results in fewer divalent scaling compounds on the RO membrane, suggesting that hybrid systems have the potential to reduce the costs and impacts associated with scale mitigation in the RO stages. Furthermore, the NF270-RO system reduces scaling, membrane replacement, energy consumption, and chemical use, resulting in lower environmental impact scores compared to conventional RO configurations. Results of the study demonstrate that the application of hybrid NF-RO configurations can reduce overall energy consumption and operating costs and increase membrane lifetime and water recovery.

Keywords: Brackish water desalination; Nanofiltration; Reverse osmosis; Life cycle analysis; Technoeconomic analysis

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Effect of temperature on NaOH production and energy consumption from seawater brines by using bipolar electrodialysis

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Desalination removes salts from seawater, brackish water, and groundwater to produce fresh water. Whether thermal, pressure, or electric, it generates a concentrated saline stream (brine) is generated in addition to pure water. In fact, the major challenge of desalination facilities is brine disposal, as it can harm the environment due to high salinity and additives. Brine can recover salts such as NaCl, KCl and $CaCO_3$, with membrane tech like bipolar electrodialysis (BPED) aiding circular use. In Bipolar Membranes (BM), water dissociates at the junction, producing H^+ and OH^- that form acids and bases from salts. In BPED, several aspects influence the separation of ions, such as applied current density, temperature, electrode washing solution, initial concentrations, and volume affect ion separation. Energy consumption is high due to water splitting at the bipolar junction and ion migration from the salt chamber to acid and base compartments. As the salt solution becomes diluted, resistance rises, increasing energy use, which requires high voltage to maintain stable current density. The initial saline solution concentrations directly affect the final acid and base concentrations. However, a plateau exists for the final concentrations, supported by membrane leakage of H^+ and OH^-, and water transport to the reservoirs via osmosis and electro-osmosis, diluting the solutions. Temperature influences water dissociation in BPM and ionic migration, enhancing kinetics, but high temperatures can destabilize membranes. Our goal is to provide a framework for exploring how temperature affects the temperature and the final concentration of NaOH of different commercial ion exchange membranes, laying the groundwork for future developments. An ED equipment designed for laboratory and pilot studies by PC Cell GMBH (Germany) was used. It operates in a membrane cell with a 64 cm^2 active area and three triplets. Two types of commercial IEMs were used: one from ASTOM membranes (CMX, AMX, BM) and another from Pccell membranes (PC SK, PC SA, BP). Experiments varied temperature (25°C, 25°C, 35°C), current densities (500, 800, 1200 A/m^2), and brine concentrations (2 and 3.5M NaCl). The performance of the BPED test was evaluated by calculating the final NaOH/HCl concentration and energy consumption. Astom membranes demonstrated superior performance, especially in base and acid production, and favorable energy efficiency. Under optimal conditions of 30°C and a current density of 800 A/m^2, the performance and concentration levels were maximized, whereas PCCell membranes showed inferior performance under identical conditions. These findings indicate that Astom membranes are the most efficient, and that temperature significantly impacts process optimization.

Keywords: Performance; Bipolar electrodialysis; Brines; Temperature

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Photo-thermal membrane distillation for desalination

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With the rapid development of efficient photoactive materials, photothermal membrane distillation (P-MD) has emerged as a promising approach for sustainable water treatment, enabling direct utilization of solar energy to heat the membrane feedwater interface and thereby enhancing desalination performance. By generating localized heating at the feed membrane surface, P-MD effectively mitigates key limitations of conventional membrane distillation, particularly high thermal energy consumption and feed-side temperature polarization. This localized photothermal effect increases the effective transmembrane temperature gradient, thereby enhancing vapor transport and permeate flux while reducing the reliance on external thermal energy input, offering a pathway toward more energy-efficient desalination. In this context, the present work focuses on the experimental development and evaluation of photothermal membranes for P-MD desalination. Different membrane fabrication strategies, namely electrospinning and surface spray-coating, were employed to prepare PVDF-based membranes incorporating semiconductor photothermal materials. Zinc oxide (ZnO) and iron(III) oxide (Fe_2O_3) nanoparticles were synthesized and integrated into the membrane structure to promote efficient light-to-heat conversion at the membrane–feed interface. The resulting membranes exhibited controlled surface morphology and enhanced photothermal response, which directly influenced mass and heat transfer during desalination. The desalination performance of the prepared membranes was experimentally investigated in a photothermal-enhanced direct contact membrane distillation (P-DCMD) configuration under simulated solar irradiation. The effects of key operating parameters, including solar irradiation intensity, feed temperature, and feed and permeate flow rates, were systematically examined. The results demonstrated a significant enhancement in permeate flux under photothermal operation, with a maximum increase of 158.7% compared to conventional DCMD conditions, while maintaining salt rejection above 96%. These findings confirm that incorporating semiconductor photothermal materials effectively reduces temperature polarization and improves thermal efficiency in membrane distillation. Overall, this work demonstrates that photothermal membrane engineering, through appropriate material selection and surface modification, is an effective strategy to improve heat and mass transfer in membrane distillation. The results highlight the potential of P-MD as an energy-efficient and solar-driven desalination technology, particularly suited for decentralized and off-grid water treatment applications. The financial support of the project PID2022-138389OB-C31, funded by MICIU/AEI/10.13039/501100011033/FEDER, UE, the grant RED2024-153562-T funded by MICIU/AEI /10.13039/501100011033, and the FINCOME 2025 (CNRST, Centre National pour la Recherche Scientifique et Technique, Morocco) are gratefully acknowledged.

Keywords: Desalination; Solar energy; Photothermal membrane distillation; Oxides; Semiconductor materials; Temperature polarization; Membrane surface coating

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Innovative, online biofilm-control solution for SWRO systems producing potable water: A case study from the Arabian Gulf

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Biofouling is widely recognised as one of the most persistent and costly operational challenges in seawater reverse osmosis desalination systems and the problem is especially severe in the Arabian Gulf, where environmental and operational factors combine to create near ideal conditions for biological fouling. Membrane compatible biocides could be an attractive solution to the problem but, traditionally, these are not suitable for on-line application in potable water systems. An exception to this is Kuriverter IK-220 which is an effective but non-aggressive, low toxicity bio-control treatment that can be applied either continuously or intermittently to the feed of reverse osmosis systems. In this paper we present a case study demonstrating the benefits of this treatment on a large scale SWRO system in the Arabian Gulf. We focus on the operational benefits in terms of reductions in cleaning frequency and energy consumption by showing a side-by-side comparison on two identical systems.

Keywords: Reverse osmosis; SWRO; Biofilm; Bio-fouling; Biocides; Bio-dispersant; Bio-control; Energy savings; Operational benefits; Arabian Gulf

EuroMed 2026
Desalination, Water Reuse and the Environment
22–25 June 2026, Marrakech, Morocco

Maven brine mining plant – world 1st commercial OARO project: HPP and ERD on-site performance results

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Seawater desalination is essential for global freshwater supply and produces brine as a by-product. Ocean brine mining enables recovery of valuable minerals while supporting environmental protection. Transitioning from thermal brine management to advanced membrane technologies, including Zero Liquid Discharge (ZLD), improves energy efficiency and reduces carbon footprint.

Research

Osmotically assisted reverse osmosis (OARO) is designed to concentrate brine without thermal resources. Applicable to salt production, brine concentration, desalination, and industrial wastewater treatment, it surpasses conventional RO limits (80 bar, 85,000 ppm) by reaching 250,000 ppm at 70 bar. This increases water recovery while lowering energy use and environmental impact. Operating at pressures similar to SWRO, OARO integrates with existing infrastructure. A demonstration plant since 2018 confirmed its viability, producing 6 tons of salt and 220 m³ of desalinated water daily.

Results and conclusions

Indonesia's coastline offers salt production potential but has relied on low-tech methods. The first commercial OARO plant, by Hyrec, began operation in 2023–2024, aiming for 220,000 tons of food-grade salt annually and 25,000 m³ of freshwater daily. Testing three membrane designs and setups showed OARO with hollow fiber membranes, axial piston pumps, and active isobaric energy recovery devices achieved the lowest specific energy consumption (3.14 kWh/m³, SWRO + OARO). This configuration reduces operational and capital costs, ensures high availability, and leverages proven technology.

System process and plant key parameters

Seawater is pre-treated to remove impurities, then concentrated via OARO. Saturated brine is crystallized, with optional purification. Key values:

- Overall recovery: 78%
- Power consumption: 9.86 MWh/h (below 10.7 MWh/h design)
- Annual salt output: 220,000 tons
- Daily water output: 25,000 m³
- Specific power consumption: 9.5 kWh/m³

Keywords: OARO; SWRO; Ocean brine mining; Desalination; Energy savings; Membranes; Isobaric ERD; High-pressure pumps; Operational performance

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Can off-grid desalination scale globally? Insights from a techno-economic and life-cycle analysis

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Off-grid water treatment systems offer an opportunity to diversify and strengthen the global water portfolio, particularly for communities without access to centralized infrastructure. Yet, the implementation of global off-grid desalination, even for modular treatment configurations, remains complex. Environmental factors, including geographic location, seasonal variability, and water source characteristics, influence the performance and applicability of standalone systems. These challenges highlight the need to evaluate treatment trains with low or passive energy requirements that are compatible with sustainable energy sources, maintain performance across a wide range of feed salinities, and minimize waste streams. In this study, a techno-economic and life-cycle assessment (TEA–LCA) was performed for a membrane distillation system powered by a hybrid concentrated solar power and photovoltaic configuration (MD–CSP/PV) for inland, off-grid desalination in Tucson, Arizona. The analysis incorporated geographical and temporal variability, with locations ranging from the United States to Australia. Experimental data were used to validate an integrated TEA–LCA of the hybrid system under operating conditions that included feed salinities from 2 to 140 g/L, treatment capacities from 1 to 1,000 m^3/d, and multiple solar configurations (CSP–PV, CSP-only, and PV-only). For the baseline location of Tucson, Arizona, systems with a capacity of 1,000 m^3/d operating under the CSP–PV configuration resulted in water costs between 3.5 and 16 USD/m^3, whereas PV-only scenarios exhibited costs that were 3- to 10-fold higher under comparable conditions. At the smallest capacity of 1 m^3/d, costs for the CSP–PV system ranged from 42 to 61 USD/m^3, which is comparable to hauled water costs. Global warming potential ranged from 1.6 to 15 kg CO2-eq/m^3 depending on solar configuration, and water consumption ranged from 0.1 to 0.3 m^3/m^3. Results indicate that the choice of solar configuration exerts a stronger influence on system cost than on environmental impacts. The feasibility of MD for off-grid desalination is highly location- and season-specific and is governed by the costs and environmental impacts associated with energy storage and module performance. Seasonal variability substantially affects desalination cost and limits continuous operation in many regions, with costs increasing between 1- and 50-fold from summer to winter depending on location. High-latitude regions, cloudy equatorial zones, and locations with short winter days face the highest penalties, whereas high–solar-resource sites remain feasible year-round. Findings highlight the trade-offs between cost and impact across locations, seasons, and solar configurations and suggest that solar-driven MD is not a universal solution for off-grid desalination but can function as a complementary treatment option in select regions, supporting context-specific strategies that aid in achieving a circular water economy.

Keywords: Off-grid desalination; Membrane distillation; Solar-powered desalination; Techno-economic analysis (TEA); Life-cycle assessment (LCA); Circular water economy; Seasonal desalination performance

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Active energy recovery devices to enable lower power consumption - MPE 70 operation results

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Reverse osmosis (RO) remains the leading technology for converting seawater into freshwater, essential for addressing global water scarcity but challenged by high energy demands. SWRO (Seawater Reverse Osmosis) plant operators seek innovations that enhance operational performance across diverse conditions while maximizing energy efficiency. Energy recovery devices (ERDs) are central to this effort, improving sustainability in SWRO processes. Despite high hydraulic efficiency in modern isobaric ERDs, issues such as biofouling, limited controllability, and salinity fluctuations persist, reducing potential energy gains. In 2022, Danfoss introduced the MPE 70—the world's first active isobaric ERD for medium to large desalination plants—drawing on over 15 years of isobaric device experience. This technology integrates a compact electric motor and variable frequency drive (VFD) for precise control, improving flexibility and reducing operational expenses.

Research

Rising energy prices intensify the need to minimize Specific Energy Consumption (SEC) over the plant's lifetime. ERDs influence key SWRO parameters:

- ERD mixing: Increased salinity at the membrane inlet raises HP pump pressure and energy use.
- Biofouling: Can immobilize or damage ERDs, increasing mixing and reducing production.
- Differential pressure (HP/LP): Pressure drops require more output from booster and LP pumps, raising energy consumption.
- Lubrication flow loss: Loss of high-pressure brine increases HPP flow and power needs.

Reducing mixing, pressure losses, and biofouling is essential for further SEC reduction. Isobaric ERDs are either passive (rotor driven by seawater flow, e.g., PX ERD) or active (motor and VFD control, e.g., MPE 70), with active designs offering superior controllability and OPEX benefits. Results: active isobaric ERD (MPE 70)

Operation experience

Field trials of the MPE 70 show strong energy savings and reliability under varied conditions. In one installation, average flow per unit ranged from 54 to 51 m³/h, overflushing decreased from 4.7% to 1.5%, and mixing varied from 1.9% to 3.3%. Installations in Spain, Morocco and UAE demonstrated low salinity increases and high hydraulic efficiency (up to 97.1%), confirming that active isobaric ERDs can significantly reduce plant energy demands, maintain optimal performance, and lower operational costs over the plant's lifecycle.

Keywords: Reverse osmosis; SWRO; Energy recovery devices; Isobaric ERD; Active ERD; Energy efficiency; Desalination; MPE70; Operational performance; Energy savings

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An innovative and sustainable pretreatment design for flexible and robust operation

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Algal blooms, commonly known as red tides, are one of the most dangerous phenomena for the operation of desalination plants, due to their toxicity to humans, but also because of fouling and clogging they caused in the pretreatment systems currently installed. Variations in water quality, especially during episodes of high organic load, causes even shutdowns of desalination plants. During an exponential algae growth episode, currently available pretreatment processes are unable to adapt to these conditions, making it necessary to develop pretreatments capable of adapting to seawater quality. ROWSIP® (reverse osmosis with simple intake pretreatment) process is a single-stage pretreatment conceived to tackle this objective, aiming to develop and design a flexible, robust, and sustainable pretreatment for seawater desalination plants experiencing these episodes of high organic load, but also in line with the most important challenges facing the sector; reducing energy consumption or the environmental impact of the desalination process. The innovation in ROWSIP® process lies in the submerged membrane ultrafiltration system, both in the design of the tank and in the operating conditions. The tank has a sweep flow for flushing effect on the membranes, preventing fouling, clogging and enhancing the operation. The flow conditions inside the tank are the major difference between conventional submerged ultrafiltration processes. ROWSIP® has operated for almost two years in the Ensenada desalination plant, using the same incoming seawater, in order to compare both processes and prove the system in a challenging seawater quality. It was designed using commercial-scale equipment to ensure that the results were conclusive and scalable to full-plants. The fouling of UF membranes was analyzed regarding to the quality of the seawater, and evaluating the process adaptability to events of poor water quality. The results showed that the process adapts the operating parameters to obtain ultrafiltered water with the quality required for RO, measured by SDI (up to 3), and without flow losses. Furthermore, no plant shutdowns due to UF system failures were reported. The experimental results demonstrated a 6% reduction in specific current consumption at the Ensenada SWDP if ROWSIP® were applied as a pretreatment. Furthermore, a reduction in CAPEX should be consider, because the current three-stages pretreatment would be replaced by one. Finally, the possibility of bringing the intake closer to the shoreline due to the system's adaptability to water quality involves a significant reduction in civil works. An environmental positive impact is also highlighted, because pretreatment is a free-chemical process in continuous operation, and the brine discharged are less concentrated because of the dilution effect of sweep flow. Optimize operating parameters to further reduce energy consumption and contribute to the environment are the main objectives for the future of the project.

Keywords: Energy consumption; Flexible; Pretreatment; Ultrafiltration; Robust

EuroMed 2026
Desalination, Water Reuse and the Environment
22–25 June 2026, Marrakech, Morocco

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Assessment of energy efficiency of the DESALRO 2.0® plant installed at the Canary Islands Institute of Technology

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This paper tackles the energy assessment of the most energy efficient desalination plant of seawater reverse osmosis (SWRO) technology, referred to as DESALRO 2.0®. The Canary Islands Institute of Technology (ITC) developed the design of the plant. This plant was awarded the Guinness World Record (GWR) with a Specific Energy Consumption (SEC) of 1.794 kWh/m^3 (February 2025) working at 40% of recovery rate and product water quality of TDS 200 mg/L and B 1 mg/L. Moreover, this paper generally assesses the DESALRO® concept to be implemented at different coastal locations. Given the difficulties of comparing plants installed at different locations and operated with different recovery rates and different product quality targets, this work proposes and applies a dedicated methodology for a thorough diagnosis of the plant SEC. To this end, results quantitatively assess the dedicated design of DESALRO 2.0® plant in terms of efficiencies of main components and the whole plant with the main aim to enable the easy comparison with other plant designs at different locations. Moreover, results identify the best potential improvements based on possible changes in design and working parameters. The first implementation of the DESALRO 2.0® concept initially focused on 2,500 m^3/d of nominal production, however opportunities of improving the energy efficiency by increasing the nominal production up to 10,000 m^3/d is also discussed.

Keywords: Reverse osmosis desalination; Energy diagnosis; Energy efficiency; Seawater desalination

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Nutrients recovery from wastewater centrate via struvite precipitation with brine-derived magnesium hydroxide

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Struvite ($MgNH_4PO_4 \cdot 6H_2O$) crystallization from wastewater streams is an increasing adopted strategy to recover nitrogen and phosphorus to valorize nutrient-rich streams into a slow-release fertilizer product. So far, struvite crystallization has been mainly based on the use of magnesium chloride or sulphate sources, requiring alkaline reagents (e.g., NaOH) to reach the reaction pH [1]. On the other hand, today much effort is focused on the recovery of magnesium hydroxide, $Mg(OH)_2$, solids from Mg^{2+} rich waste brines from desalination plants and saltworks industries. In this context, this work explores an integrated approach that couples the recovery of nutrients from a real centrate (clarified stream from centrifugation of digested sludge) from municipal wastewater treatment, rich in NH^{4+} and PO_4^{3-}, with struvite precipitation via direct addition of magnesium hydroxide extracted from Mg-rich saltworks brines [2]. In particular, $Mg(OH)_2$ suspensions were produced via reactive crystallisation within three different reaction configurations, leading to different particle size distribution and morphology. Batch crystallization experiments were conducted at ambient temperature with continuous monitoring of pH and ion concentrations over time. Emphasis was given to the interplay between $Mg(OH)_2$ characteristics (particle size distribution, specific surface area, morphology) and process variables such as aging time and feeding flow rate. SEM analysis of struvite samples revealed a shift in crystal habit and aggregation based on $Mg(OH)_2$ properties, indicating that struvite features can be tuned through the magnesium precursor source. Thermogravimetric analysis consistently showed struvite purities close to 100%, even when using a real concentrated wastewater centrate feed. Results marked that struvite crystallization using $Mg(OH)_2$ as co-reactant (i) is an effective alternative to conventional magnesium salts, (ii) can lead to high product purity, and (iii) allows morphology and crystal size of the struvite product to be tuned based on the initial characteristics of $Mg(OH)_2$ solids.

Keywords: Wastewater valorisation; Struvite; Mineral recovery; Crystallization; Brine valorisation

Acknowledgments

This work has received funding from the European Union's LIFE 2021-2027 programme under Grant Agreement 101147407 - LIFE23-ENV-IT-MAREMAG LIFE.Opinions expressed are those of the authors only and do not necessarily reflect those of the European Union or CINEA . The authors acknowledge the financial support provided by the Erasmus+ Traineeship Programme, as well as the Universitat Politècnica de València for granting the FPI-UPV scholarship to Samuel Navajas Valiente.

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Survival analysis for the dynamic prediction of gypsum scaling risk in batch reverse osmosis systems

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Gypsum scaling is a significant challenge in high-recovery desalination and brine management, leading to membrane flux decline, increased chemical cleaning, and process shutdowns. When and where scaling occurs is governed by crystallization kinetics, which depend on supersaturation (SI > 0) and sufficient residence time, both captured by the induction time. Using 268 literature datapoints, we previously developed a static gypsum induction time model (R^2 = 0.91) spanning 20–80°C and 0–5 M NaCl. However, this static approach cannot capture dynamic desalination conditions where solute concentrations evolve over time, limiting prediction of nucleation onset under realistic operation. To address this limitation, we propose a survival-analysis-based framework that incorporates both time and concentration history and apply the framework to evaluate operating and control strategies for batch reverse osmosis (RO) systems. Survival analysis quantifies failure probability as a function of elapsed time and evolving conditions. The framework was validated using dynamic experiments in which gypsum solutions were continuously concentrated and monitored by UV–Vis spectrophotometry. Concentration was increased by dosing a supersaturated solution at fixed time intervals. Ten concentration rates (11 to 467 mM·min^{-1}) were tested between starting and ending SIs of 0.27 and 0.48, with 21 replicate experiments per rate. Nucleation onset times were recorded to construct cumulative nucleation probability distributions. Static induction time data obtained at discrete saturation indices were used as inputs to calculate the cumulative hazard and evolving nucleation probability for each dynamic test, which spans a range of saturation indices over time. Predicted nucleation probability and mean dynamic induction times showed strong agreement with experimental observation, with a mean error of 9.8%. Finally, we demonstrate the application of this framework to evaluate nucleation probability in batch reverse osmosis (RO) systems. A numerical model was developed to simulate the spatial and temporal evolution of solute concentrations in the membrane module and feed tank, and the survival analysis framework was used to predict the evolving probability of gypsum nucleation, with emphasis on high-risk terminal elements. The impacts of key design and operating parameters on scaling risk and specific energy consumption were assessed. Results show that permeate flux and flow rate must be optimized to balance energy efficiency and scaling risk, while operating elements in parallel significantly reduces scaling risk with minimal energy penalty compared to series configurations. Reducing pipe volume and spacer thickness further lowers nucleation risk. Overall, this approach bridges static laboratory data and dynamic engineering conditions, providing a practical tool for predicting nucleation onset and informing optimal concentration rates in batch RO systems.

Keywords: Gypsum scaling; Crystallization kinetics; Batch RO; Induction time

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Enhancing RO system design: Integration of arbitrary molecule rejection simulation for PFAS and emerging contaminants

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TORAY is enhancing its RO projection software with a new feature that enables simulation of arbitrary molecule rejection, including PFAS, using basic rejection data. Traditionally, engineers relied on manual calculations to estimate performance, a process that was time-consuming and prone to error. The new functionality automates this task, allowing users to input molecule-specific data and model system performance under various operating conditions such as pressure, recovery, and staging. This innovation supports compliance with increasingly stringent regulations on emerging contaminants like PFAS, while enabling optimized system configurations tailored to user needs. Ultimately, the feature empowers water treatment professionals to design robust, cost-effective RO systems that address evolving environmental and public health challenges.

Keywords: PFAS; Emerging contaminant; RO projection software; Simulation

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Enhancement of microfiltration performances of pozzolan membrane by incorporation of micronized phosphate and its application for microfiltration of aluminum chloride suspension and wastewater of tannery industry

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The present work reports the enhancement of low-cost ceramic microfiltration pozzolan membrane by incorporation of micronized phosphate. The flat membrane was obtained by dry uniaxial pressing process and sintering. The effect of sintering temperature (900–1100°C) and MP addition (10–40 wt.%) on membrane properties such as porosity, microstructure, mechanical strength and permeability were investigated. Experimental results showed that temperature increasing significantly improves microstructure, mechanical strength and permeability of pozzolan membrane until 1050°C. Importantly, the incorporation of micronized phosphate in pozzolan matrix considerably diminishes membrane pore size while the porosity is preserved. Therefore, membrane competitiveness can be enhanced in terms of selectivity and permeability. Referring to results, it was found that the optimized membrane (20 wt.% of micronized phosphate and sintered at 1050°C) has a porosity of 32.07%, an average pore diameter of 1.33 µm and a water permeability of 1732.5 L/h.m^2.bar. As application, the optimized membrane was applied for microfiltration of aluminum chloride suspension and wastewater of tannery industry. Filtration results showed that the membrane could approximately reject the totality of turbidity (99% for aluminum chloride suspension and 97% for tannery effluent). Finally, based on its promising proprieties, its excellent filtration efficiency as well as its low cost, the obtained membrane could be recommended as alternative membrane for clarification of industrial wastewater.

Keywords: Pozzolan; Micronized phosphate; Ceramic membrane; Microfiltration; Wastewater

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Design and engineering of nano-hydroxyapatite-based ceramic membranes for superior wastewater treatment performance

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The design of high-performance membrane materials for wastewater treatment requires the development of selective layers with tailored physicochemical properties. In this context, nano-hydroxyapatite (nano-HAp), a calcium phosphate-based bioceramic, offers compelling advantages due to its large surface area, high ion-exchange capacity, and strong affinity for various pollutants, including heavy metals, dyes, and organic compounds. This study presents a systematic investigation into the synthesis of nano-HAp via different routes primarily hydrothermal and wet chemical methods aiming to control key parameters such as particle size, morphology, crystallinity and surface functionality. The synthesized nano-HAp is subsequently applied as a selective coating on ceramic membrane supports to fabricate advanced composite membranes. Structural and surface characterizations (XRD, SEM, FTIR and BET) confirm the successful formation of nanoscale apatite with desired textural properties. The incorporation of nano-HAp significantly enhances the membrane's hydrophilicity, adsorption capacity, and antifouling behavior, enabling efficient removal of contaminants from complex domestic and industrial wastewater matrices. Preliminary filtration tests demonstrate high rejection rates of toxic ions and persistent organic pollutants, combined with stable permeate flux and mechanical durability under harsh operational conditions. Finally, this work underlines the critical role of synthesis route optimization in tuning the properties of nano-HAp for membrane engineering. The proposed approach offers a sustainable and scalable platform for the development of next-generation ceramic membranes tailored to real-world water treatment challenges.

Keywords: Nano-hydroxyapatite; Synthesis; Ceramic membranes; Wastewater treatment

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Low-cost geomaterial-based membranes in service of seawater desalination

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The water issue is the one that best illustrates the future challenges of sustainable development, namely economic growth to fight against poverty, the preservation of natural ecosystems and biodiversity. Morocco is already suffering from the impacts of climate change through a reduction in water availability. Therefore, the preservation of the existing hydraulic infrastructure, and looking for new water resources are the major challenges to be addressed. Ceramic membranes are highly demanded under harsh filtration conditions compared to polymeric membrane because of their high mechanical strength, excellent chemical stability in concentrated media and high thermal stability even at high temperatures. However, these commercial ceramic membranes are costly because they are prepared from industrial oxides such as titania, zirconia, alumina and their composites beside they require high sintering temperatures (1300-1500 °C). In this project, we are focusing on the development of low-cost microfiltration membranes with different configurations (flat disks and tubes) prepared from abundant and inexpensive geomaterials such as clays, pozzolan, phosphate and perlite. These materials are widely available in Morocco and can be processed by pressing and extrusion followed by sintering under less severe conditions compared to those required for the preparation of commercial alumina membranes. Our approach is to integrate geomaterial-based membranes as the pretreatment in the process of reverse osmosis desalination to remove suspended particles, bacteria and organic compounds.

Keywords: Low-cost membrane; Ceramic membrane; Reverse osmosis; Water supply; Seawater pretreatment

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Impact of renewable-driven intermittent operation on scaling in falling film evaporators: role of tube material selection

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Proposed offshore hydrogen production concepts rely on the direct coupling of wind power generation, seawater desalination, and hydrogen production. Falling film evaporators are particularly attractive in this context because they can utilise low-grade waste heat from the electrolyser. Unlike conventional thermal desalination plants, which typically operate continuously at or near full load, renewable-powered systems are subject to fluctuating energy supply and therefore to intermittent operation. Despite the relevance of such dynamic load profiles, systematic studies on the effects of intermittent operation on crystallization fouling (scaling) in falling film evaporators are still lacking. In this study, these effects were investigated under practice-oriented conditions. Experiments were conducted in a horizontal tube falling film evaporator using artificial seawater, and tests with repeated intermittent operation cycles were compared to reference experiments performed under continuous operation. The impact of intermittent operation was examined on polymer composite tubes with enhanced thermal conductivity based on polypropylene filled with graphite flakes and compared to conventional stainless steel tubes. Scale formation was characterised by measuring deposit mass and determining calcium and magnesium content via inductively coupled plasma optical emission spectroscopy (ICP-OES). Scale layer thickness was quantified using an optical LED micrometer. Surface morphology was examined by scanning electron microscopy (SEM), and local elemental composition was analysed using energy dispersive X-ray spectroscopy (EDX). Adhesion strength was evaluated with a newly developed force-based test rig designed to measure the force required to mechanically remove the fouling layer from the tube surface using a scraper. Results indicate a notable influence of intermittent operation on deposit mass and scale layer thickness. Polymer composite tubes exhibited lower adhesion forces, indicating their potential to reduce scaling severity under fluctuating operating conditions. The findings of this study provide experimentally supported insight into how intermittent operation affects scaling mechanisms in falling film evaporators. The observed lower adhesion strength on polymer composite tubes offers a material-based approach to mitigating scaling in renewable-powered desalination systems. These results support informed material selection and contribute to the design and operation of more resilient and energy-efficient thermal desalination concepts for offshore hydrogen production.

Keywords: Scaling; Falling film evaporator; Tube material selection; Intermittent operation; Offshore green hydrogen production

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Sustainable seawater pretreatment: bioflocculant performance optimized via statistical and AI approaches

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Efficient pretreatment of seawater is essential to reduce fouling in reverse osmosis (RO) desalination systems. In this study, a sustainable bioflocculant extracted from Opuntia ficus-indica cactus cladodes was developed and evaluated for seawater pretreatment. The extraction process was optimized using statistical design of experiments (DOE) combined with machine learning techniques to enhance extraction yield and flocculation efficiency [1]. Key extraction parameters, including pH, temperature, extraction time, and solid–liquid ratio, were optimized using response surface methodology and predictive machine learning models. The optimized cactus-based bioflocculant, mainly composed of natural polysaccharides, showed high stability and effectiveness under high salinity and alkaline conditions typical of seawater [2]. Jar test experiments demonstrated effective removal of turbidity, suspended solids, and algal particles. Compared with conventional synthetic flocculants, the Opuntia ficus-indica bioflocculant produced larger, denser flocs and reduced sludge volume, with improved dewatering properties. These findings highlight the potential of cactus-derived bioflocculants, optimized through statistical and machine learning approaches, as an eco-friendly and effective pretreatment solution for seawater RO desalination.

Keywords: Opuntia ficus-indica; Bioflocculant; Seawater pretreatment; Reverse osmosis desalination; Flocculation optimization

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Sustainable menthol-derived antibacterial compounds for biofouling mitigation in water treatment and desalination systems

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Biofouling and microbial contamination remain critical challenges in water treatment and desalination systems, leading to membrane deterioration, increased operational costs, and excessive use of chemical disinfectants. Conventional antimicrobial agents often present environmental persistence and potential toxicity, motivating the search for sustainable and biodegradable alternatives. Menthol, a naturally occurring monoterpenoid obtained from essential oils of Mentha species, represents a renewable and environmentally benign scaffold with recognized biological activity. Its chemical versatility allows the synthesis of functional derivatives with improved antibacterial and antibiofilm properties. In this study, a combined in silico and experimental approach was employed to investigate menthol-derived organic compounds as potential eco-friendly antibacterial agents for water protection applications. Molecular docking simulations were conducted to predict the interactions between selected menthol derivatives and bacterial target proteins, enabling the preselection of promising candidates prior to synthesis. This computational screening strategy reduced unnecessary chemical synthesis and minimized experimental resource consumption. Selected compounds were subsequently synthesized using organic reactions designed in accordance with green chemistry principles, emphasizing reaction efficiency and waste reduction. The antibacterial activity of the synthesized derivatives was evaluated against representative bacterial strains associated with biofouling in water systems. The results demonstrated favorable binding affinities in silico and confirmed antibacterial activity for several menthol-based derivatives in vitro. These findings highlight the potential of menthol-derived compounds as sustainable agents for mitigating microbial growth and biofouling in water treatment and desalination processes. This work underscores the strategic role of natural product derivatives and computational-guided synthesis in the development of environmentally responsible solutions for water quality protection and sustainable desalination technologies.

Keywords: Menthol derivatives; Biofouling control; Sustainable antibacterial agents; Water treatment; Desalination systems; Molecular docking; Green chemistry; Natural products; Antibacterial activity; Eco-friendly materials

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Design-guided high-entropy alloys for electrochemical PFAS and contaminant removal in desalination

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We present a novel high-entropy liquid metal alloy catalyst for efficient electrochemical removal of critical contaminants, including PFAS, from diverse water sources, relevant to desalination and brine treatment. Combining molecular dynamics, design of experiments, and density functional theory, the alloy exploits entropy-driven stability and dynamic active sites to overcome kinetic limitations, achieving noticeably enhanced reaction rates with near-100% Faradaic efficiency. This work demonstrates a scalable, design-guided approach for advanced water purification, offering a sustainable pathway for pre-treatment, post-treatment, and brine valorization in desalination processes, thereby advancing circular water management strategies.

Keywords: Desalination; PFAS; Water contamination; High-entropy alloys; Electrochemistry; Emerging contaminants; ZLD

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Advancing water, energy, and environmental circularity

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The traditional linear “take-make-dispose” model for water, energy, and waste is unsustainable. This abstract proposes a new paradigm for urban and industrial systems based on circular economy principles, with a specific focus on desalination as a vital solution for water scarcity. It integrates advanced water treatment techniques, including desalination and wastewater recycling, along with resource and energy recovery strategies. Drawing on over 30 years of engineering experience and a non-profit background in lifecycle evaluation, this paper outlines a holistic approach to transforming waste into valuable resources. Through a case study of an innovative desalination system, this work demonstrates how a high-quality water supply can be secured while minimizing environmental impact and maximizing resource efficiency. The abstract will explore the economic viability and investment strategies required to make

desalination projects feasible. Additionally, it will highlight the critical role of novel materials and policy frameworks in overcoming regulatory hurdles to achieve true circularity in water management. The conclusion emphasizes that an integrated, lifecycle-focused approach that includes desalination is not only environmentally necessary but also an economically sound strategy for building resilient and sustainable water cycle cities.

Keywords: Circular economy; Water recycling; Energy recovery; Resource recovery; Anaerobic digestion; Decentralized systems; Policy; Sustainable cities

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Variable-property mass transfer modeling to optimize ultrafiltration pretreatment for high-recovery RO desalination

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Effective ultrafiltration (UF) pretreatment can stabilize reverse osmosis (RO) performance by reducing fouling load, enabling higher recovery, and lowering O&M burdens. This work links concentration polarization (CP) control in UF to downstream RO operability through a mass-transfer framework that explicitly accounts for variable rheology. We measured the rheological behavior of desalination-relevant solutes (dextran, BSA, whey-derived streams) as functions of concentration, shear rate, temperature, and pH, and incorporated these dependencies into a two-dimensional channel model with variable viscosity, diffusivity, and osmotic pressure. Experiments in stirred cell and cross-flow UF showed: (i) viscosity is the dominant driver of CP and flux decline, with thixotropy/rheopexy emerging for protein-rich feeds at high concentration; (ii) each 5°C increase raised flux by ~8%; (iii) a 30% cross-flow velocity increase raised flux by ~10%; and (iv) frictional pressure drop scaled with solute viscosity to the 0.7–0.99 power, aligning with variable-property predictions. Among tested feeds, 90% demineralized whey exhibited the highest UF flux and RWPC the lowest, consistent with measured rheology and size distributions. The model indicates that optimizing UF operating windows to suppress apparent viscosity at the membrane (via temperature, shear, and pH control) curtails CP beyond traditional constant-property expectations. Translating to RO, such UF control reduces particulate/colloid breakthrough and fouling propensity, stabilizes SDI, lowers RO differential pressure rise rates, extends cleaning intervals, and supports higher system recovery without compromising permeate quality. The framework provides a predictive route to co-design UF setpoints and hydrodynamics for RO pretreatment, integrating feed rheology, CP kinetics, and pressure-drop constraints to minimize lifecycle cost and maintenance.

Keywords: Ultrafiltration pretreatment; Concentration polarization; Variable-property modeling; Rheology; Reverse osmosis fouling; Desalination O&M

EuroMed 2026
Desalination, Water Reuse and the Environment
22–25 June 2026, Marrakech, Morocco

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AI optimization of membrane cleaning in desalination and wastewater treatment facilities

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Membrane fouling and the diverse quality of feedwater significantly increase operational costs, downtime, and chemical usage in desalination and wastewater treatment plants, impacting councils, regional water utilities, landfill operators, and industrial sites. Current operations predominantly depend on fixed PLC/SCADA setpoints, conventional cleaning-in-place (CIP) practices, and vendor-specific tools that are largely reactive and tailored for individual sites. We propose an AI-driven smart controller that integrates seamlessly with existing control systems. This innovative solution utilizes plant telemetry to continuously predict fouling and scaling risks, optimizing CIP timing and recipes. It offers operators ranked recommendations on recovery, pressure adjustments, and chemical dosing. Designed as a retrofit for existing systems and as an option for new Osmotec installations, it combines localized edge processing with cloud analytics and features an intuitive dashboard that provides real-time advisories and automated setpoint suggestions, while always ensuring manual override capabilities for safety and compliance. Technically, our solution employs machine learning models trained on historical plant data, incorporating physics-informed features such as flux decline, differential pressure, conductivity, turbidity, temperature, and dosing history. This enables precise estimates of remaining useful runtime, early detection of abnormal operating states, and tailored CIP strategies that minimize chemical consumption and reduce membrane stress. Unlike traditional vendor-specific tools, our system is vendor-agnostic, learning across multiple plants and building a shared library of operational patterns to enhance performance over time, eliminating the need for site-specific manual tuning. Deployment will commence with pilot programs at two operating desalination or leachate treatment plants in NSW, supported by a MobileLab campaign to gather diverse feed condition data and validate models under various constraints. Our objectives include achieving a 20-40% reduction in CIP frequency and chemical use, extending run times between cleanings by 25-50%, and significantly reducing unplanned downtime. The commercial model encompasses hardware retrofitting and subscription tiers for monitoring, optimization, and remote support, targeting councils, regional utilities, landfill operators, and industrial sites across NSW. By reducing operational expenses, energy consumption, and chemical usage while fostering local software and data roles, the AI smart controller offers a distinctly scalable solution to modernize treatment operations in the region.

Keywords: Membrane fouling; Desalination; Wastewater treatment; AI optimization; Cleaning-in-place (CIP); Machine learning; Operational efficiency; Operational costs; Environmental impact

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Enhancing PFAS removal: Innovative plasma-treated TiO_2 photocatalysts on Unisol membranes for advanced water treatment

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Per- and polyfluoroalkyl substances (PFAS) are persistent pollutants that significantly threaten water quality globally. Traditional water treatment methods often fall short in effectively degrading PFAS due to their inherent chemical resistance. This study introduces a groundbreaking strategy to improve PFAS removal by integrating plasma-treated titanium dioxide (TiO2) photocatalysts onto Unisol DT membranes. Unisol DT membranes, recognized for their flexibility and high filtration efficiency, serve as the substrate for TiO_2 deposition. We employ dielectric barrier discharge (DBD) plasma treatment to modify the membrane surface, which enhances functional groups, increases hydrophilicity, and improves the adhesion of TiO_2. This treatment produces a thin, uniform photocatalytic layer while maintaining the membrane's structural integrity and filtration efficacy. The modified membranes are then activated under ultraviolet (UV) light, resulting in the generation of reactive oxygen species (ROS) that effectively decompose PFAS into benign by-products. The synergistic combination of membrane filtration and photocatalysis facilitates efficient PFAS removal, even at low concentrations. Experimental findings indicate that the TiO_2-coated Unisol membranes surpass traditional filtration techniques in PFAS degradation, demonstrating high stability, reusability, and sustained photocatalytic performance over multiple filtration and UV cycles. This innovative approach presents a scalable and sustainable solution for treating PFAS-contaminated water in industrial and environmental applications, aligning with the conference's focus on advanced desalination technologies.

Keywords: PFAS; Titanium dioxide; Photocatalysis; Unisol membranes; Water treatment; Desalination; Environmental pollutants; Membrane filtration; UV light; Sustainability

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The Enerplage system or how to protect beaches against coastal erosion and producing filtered seawater

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The Ecoplage® beach drainage system requires significant civil engineering work, making it more difficult and less economically suitable for very small beaches, often referred to as "pocket beaches." However, the principle of beach drainage is equally well-suited to these beaches as a method of erosion control. Furthermore, another advantage of the system is the production of salt water, which can be used in various applications such as freshwater production through desalination or heat recovery. These two applications can offer an even faster return on investment for beach managers. The objectives of this project, named Enerplage®, were therefore to build a full-scale prototype of a mini-dewateringsystem and to monitor its effectiveness in lowering the water table and sediment transport, to test its combination with a desalination unit for freshwater production, and finally, to test its integration with a heat production unit. ECOPLAGE implemented and monitored this Enerplage® prototype on the beach of Saint Gilles Croix de Vie (French West coast). The experiment provided data on the system's actual capacity to produce filtered seawater to supply a desalination unit and a heat production facility, while also measuring its effectiveness in lowering the beach water table and its effect on the beach's topography.

Keywords: Seawater intake; Beach dewatering; Coastal erosion; Desalination; Sand filtration

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Enhancing SWRO sustainability: Energy optimization and fouling control with TFN high-rejection membranes and LDP feed spacers

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Climate change is reshaping global water management strategies. Prolonged droughts, declining rainfall, and rising seawater temperatures are increasing the dependence on seawater reverse osmosis (SWRO) as a reliable source of potable water. Southern Europe and North Africa are among the regions most affected by these environmental shifts. With over 70 large-scale SWRO plants producing more than 50,000 m³/d, many operating for 20–30 years, these facilities face growing operational challenges linked to global warming. Higher seawater temperatures lead to increased salt passage, requiring membrane solutions with superior rejection to maintain water quality. This often results in higher energy consumption and operational costs. Simultaneously, elevated fouling potential—driven by warmer waters and changing biological activity—causes increased feed pressure, more frequent chemical cleanings, and accelerated membrane degradation. Conventional mitigation strategies, such as lowering membrane flux, can reduce fouling but typically worsen salt passage, creating once again the need to use higher rejection membrane solutions to compensate it. Thin-film nanocomposite (TFN) membranes represent a significant advancement in addressing these challenges. With an industry-leading salt rejection of up to 99.89% under standard test conditions, TFN membranes enable operation at lower fluxes without compromising permeate quality, thereby allowing a larger margin to meet permeate quality requirements at higher temperatures while minimizing energy consumption. Furthermore, recent innovations combining TFN technology with low differential pressure (LDP) feed spacers enhance hydraulic performance and fouling resistance, offering an integrated solution for optimizing SWRO sustainability. This paper presents different case studies from SWRO plants in Southern Europe and North Africa, comparing TFN membranes with conventional RO elements. Results demonstrate that TFN membranes, with or without LDP spacers, deliver measurable improvements in energy efficiency and fouling control, allowing compliance with restricted water quality standards while reducing detrimental effects from membrane contaminants. By integrating advanced membrane technologies and spacer designs, SWRO systems can adapt to the evolving challenges of climate change.

Keywords: SWRO; Climate change; Energy efficiency; Membrane fouling; TFN membranes; LDP feed spacer

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Thin-film nanocomposite reverse osmosis membranes for sustainable seawater desalination: The Dakhla SWRO project in Morocco

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Water scarcity has become a critical challenge for Morocco, as for many regions in North Africa and Southern Europe, due to the combined effects of climate change, population growth, prolonged droughts, and declining reservoir storage. Over the past three decades, these factors have severely impacted water availability for municipal, agricultural, and industrial sectors. In response, Morocco has adopted an ambitious national strategy centered on seawater desalination powered by renewable energy. This plan aims to secure up to 2 billion m^3/year of desalinated water by 2040, ensuring a sustainable water supply and supporting regional development. The Dakhla Seawater Reverse Osmosis (SWRO) project, located approximately 130 km north of Dakhla city in the Dakhla-Oued Eddahab region, is one of the key projects within this strategy. Designed for a production capacity of 112 million liters per day (MLD), the plant allocates 80% of its output for irrigation and 20% for municipal potable water, operating entirely on wind-generated power, reflecting Morocco's commitment to integrating advanced engineering solutions with renewable energy sources. One of the most significant technical challenges in this project was meeting stringent permeate quality requirements for irrigation: chlorides =105 mg/L and boron =1.0 mg/L. These specifications are particularly demanding given the characteristics of the feedwater, which can reach 42 g/L total dissolved solids (TDS), chloride concentrations of almost 24,000 mg/L, and boron levels close to 6 mg/L, with seasonal temperature variations between 10°C and 24°C. Achieving these targets while optimizing operational costs (OPEX) required careful membrane selection and system design. Thin-Film Nanocomposite (TFN) RO membranes from NanoH2O were selected for the Dakhla SWRO plant. TFN membranes offer two critical advantages: exceptional boron rejection, consistently exceeding 95% in multiple sites, and industry-leading salt rejection specification up to 99.89%. These characteristics enable compliance with strict water quality standards while allowing the use of membranes with higher permeability, reducing energy consumption and minimizing chemical dosing requirements. The integration of TFN technology not only ensures operational efficiency but also supports the project's sustainability goals by lowering the carbon footprint associated with desalination. While the plant is currently being commissioned, the startup is scheduled for the second quarter of 2026. This paper will present the design considerations, membrane selection process, and comparative analysis of different reverse osmosis configurations evaluated for the Dakhla SWRO project. It will also highlight how advanced membrane technology, combined with renewable energy, can deliver reliable and cost-effective solutions for water-scarce regions, contributing to long-term resilience and regional development.

Keywords: SWRO; TFN; Boron; Energy savings; Renewable energies

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Decentralized desalination systems for resilience under climate and environmental emergencies

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Water supply is a critical service, and its failure during emergencies can have serious social, economic, and security consequences. In many regions, desalination is the primary source of potable water, yet traditional centralized desalination plants are increasingly vulnerable to climate change, environmental pollution, and conflict-related disruptions. Extreme storms, flooding, oil spills, power outages, and even radioactive contamination can force large, centralized plants to shut down, affecting entire populations at once. This work presents a resilient alternative based on decentralized, modular, and scalable desalination systems, developed through more than 43 years of experience by IDWT Group and continued today under DEW Group. With one of the largest portfolios of decentralized wastewater treatment and desalination solutions operating in over 21 countries, this approach has been proven under a wide range of environmental and operational conditions. Decentralized desalination distributes water production across multiple smaller units located closer to demand centers. This reduces reliance on single intakes, power connections, and long pipelines, significantly lowering the risk of complete system failure. Modular design allows systems to be expanded, repaired, or redeployed quickly, while ensuring that water supply can continue even when individual units are offline. Climate change has intensified extreme weather events, increasing risks to water infrastructure. Decentralized systems offer improved adaptability by limiting the impact of localized damage and enabling operation with renewable or hybrid energy sources during power outages. Excess renewable energy can also be converted into stored freshwater, further strengthening resilience. Environmental emergencies such as oil spills, industrial pollution, and radioactive contamination present additional challenges. In these scenarios, ceramic ultrafiltration pretreatment plays a critical role. DEW Group has developed the largest and most advanced ceramic filtration portfolio worldwide, capable of operating under highly contaminated and variable feedwater conditions. Ceramic membranes provide a robust physical barrier against suspended solids, hydrocarbons, bacteria, and particulate-bound radioactive contaminants, while tolerating aggressive cleaning and harsh operating conditions. This capability has been demonstrated at full scale through the engineering and delivery of the world's first and largest seawater pretreatment system using ceramic ultrafiltration membranes in Morocco, implemented in partnership with CERAFILTEC. The project confirmed the ability of ceramic pretreatment to protect downstream desalination processes and maintain operation under extreme feedwater conditions. In addition to emergency response, decentralized systems can support the modernization of aging desalination plants. Modular units can maintain water supply during shutdowns while enabling upgrades to energy efficiency, chemical dosing, and pretreatment performance.

Overall, decentralized desalination systems equipped with advanced ceramic pretreatment provide a practical, reliable, and future-ready solution for water security. By shifting desalination design toward resilience, flexibility, and redundancy, water infrastructure can better protect populations and critical services in an increasingly uncertain world.

Keywords: Decentralized desalination; Wastewater treatment; Pretreatment; Ceramic membranes

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Independent pilot evaluation of electrochemical feedwater conditioning for energy and fouling reduction in seawater reverse osmosis

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Scaling and fouling remain critical operational challenges in seawater reverse osmosis (SWRO), driving increased energy consumption, chemical usage and membrane degradation. This paper presents results from an independently hosted pilot study evaluating an electrochemical feedwater conditioning approach as a chemical-free pre-treatment strategy for SWRO systems.

Testing was conducted at a fully instrumented SWRO pilot facility operated by an independent desalination research institute, using a structured A/B methodology aligned with international benchmarking protocols. Baseline operation without electrochemical conditioning was compared against optimised conditioned operation under matched hydraulic and water quality conditions. Performance metrics included specific energy consumption (kWh/m³ permeate), permeate flux stability, salt rejection and observed fouling behaviour, with results normalised to standard seawater reference conditions.

The electrochemical conditioning method operates by altering ionic activity in the feedwater, disrupting the conditions under which mineral scale and fouling layers typically adhere to membrane surfaces, without chemical dosing, sacrificial media or forced bulk precipitation.

Results demonstrate measurable reductions in specific energy consumption alongside improved operational stability and reduced fouling-related performance drift. Membrane productivity and selectivity were maintained or improved relative to baseline operation. The findings indicate that electrochemical feedwater conditioning can contribute to lower chemical dependency, improved energy efficiency and enhanced robustness of SWRO operation.

This study provides independent, pilot-scale evidence supporting the role of electrochemical, chemical-free pre-treatment technologies in advancing more sustainable and energy-efficient desalination system design.

Keywords: Fouling; Scaling; Seawater reverse osmosis; Electrochemical processes

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Submerged UF on the rise again: DuPont Inge ultrafiltration technology in submerged mode

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Historically, hollow fiber In-to-Out PES membranes were exclusively used in pressurized configurations, whereas Out-to-In hollow fiber PVDF membranes have been utilized in pressurised mode and in open submerged systems. Employing hollow fiber PES membranes in a submerged environment presents a novel approach which can provide significant benefits. These benefits are based on the intrinsic higher permeability and lower Trans Membrane pressure (TMP) with PES, which is vital for submerged systems in which the maximum physical and technical limitation of TMP is ~0.7 bar. With a lower TMP, the system can run at higher fluxes similar to pressurized configurations, with lower energy costs even under variable, cold, and challenging feed water quality conditions. In the case the UF is used as a pretreament to seawater RO, , lower TMP's leads to improved handling of algal cells due to lower shear stress conditions (Kim et al, 2015) which can help lower the biofouling rate on the RO. A significant advantage of the DuPont™ Inge™ ultrafiltration module in submerged configuration is the simplicity of the rack, in which the module has a single connection with the rack. This same connection is used for vacuum filtration and for backwashing when the flow direction is reversed. The rack design is also flexible, allowing the submerged system to be adapted to many basins. An analysis of total water costs demonstrates substantial savings potential in terms of energy, capex, complexity and maintenance. Due to the suction pump being on the filtrate side of the membranes, the simplicity of the rack design, as well as the high flexibility of rack and system sizing, submerged systems with DuPont™ Inge™ ultrafiltration modules are also ideally suitable to be used as a 'direct coupling' pre-treatment solution prior to a reverse osmosis system in a desalination plant. This study demonstrates the performance of DuPont™ inge™ ultrafiltration modules in submerged mode for three different sources of water. All three pilot studies confirm a stable performance under varied conditions at fluxes up to 80 l/(m2hbar), employing the DuPont™ Inge™ MB and the DuPont™ Inge™ MB PRO ultrafiltration fibers. These fluxes are not temperature corrected and could be maintained even at low feed water temperatures down to 2°C, and with highly variable water qualities. The advancements presented herein demonstrate the potential for DuPont™ Inge™ ultrafiltration modules to establish new standards in water treatment efficiency, effectively reducing energy demand and total water costs, while addressing both current challenges and future demands.

Keywords: Ultrafiltration; Submerged mode; Water cost; Energy demand

EuroMed 2026
Desalination, Water Reuse and the Environment
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Material selection and design challenges of GRP filtration housings for seawater RO pretreatment

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Pretreatment filtration is a critical protective barrier in seawater reverse osmosis (SWRO) desalination systems, directly affecting membrane integrity, energy consumption, operational cost, and plant availability. Given seawater's highly corrosive nature and the continuous operating profile of desalination facilities, the design and material selection of pre-RO filtration housings represent a key engineering consideration.

This presentation examines the technical challenges and design considerations associated with the application of glass-reinforced plastic (GRP) filter housings in seawater pretreatment systems. The material characteristics of GRP are evaluated in the context of SWRO operating conditions, with particular focus on corrosion resistance in high-chloride environments, mechanical performance under sustained hydraulic loading, pressure and temperature limitations, and chemical compatibility with typical pretreatment chemicals used in seawater applications.

Critical design aspects including pressure rating, structural integrity under static and cyclic loading, internal element support, sealing arrangements, and compliance with applicable international standards for pressure vessels and desalination infrastructure are reviewed. Operational considerations such as installation practices in coastal environments, inspection and nondestructive testing requirements, maintenance accessibility, and longterm durability under continuous seawater exposure are also discussed.

A comparative assessment of GRP filter housings versus metallic alternatives highlights both the advantages and limitations of GRP in SWRO pretreatment service. The work aim to provide practical guidance to engineers, designers, and operators to support informed material selection and design decisions that balance performance, safety, reliability, and lifecycle cost, thereby enhancing the protection and longterm performance of SWRO membrane systems.

Keywords: Desalination; SWRO; Water treatment; Pretreatment filtration; Seawater desalination; Innovation; Filtration engineering; GRP housings; Membrane protection; Process engineering; Industrial filtration

Challenges and opportunities of blending desalinated water with conventionally treated water for a stable potable water supply – A UK focused case study

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Seawater desalination is becoming an increasingly vital part of the UK's water supply mix as pressures from population growth, climate change, and regional water scarcity continue to rise. The potential blending of desalinated water with mains water (conventionally treated potable water) presents challenges related to chemical compatibility, stability within distribution networks, and compliance with drinking water quality standards. This study examines the blending of desalinated water, produced from North Sea water, with mains waters from two regions of the UK, and evaluates its effects on key water quality parameters such as pH, alkalinity, mineral content, and total dissolved solids. It also explores the implications of blending desalinated and mains water on water stability within distribution networks.

The importance of this work lies in its systematic, UK-specific evaluation of desalinated water blending, which simultaneously examines source water chemistry, blending ratio, distribution system stability, and regulatory compliance within a single analytical framework. The study assesses how variations in blending ratios affect final water quality and its suitability for distribution. Corrosion and scaling indices are used to characterise chemical stability and identify blending ranges that minimise infrastructure deterioration while remaining within UK regulatory limits. The quality of the blended water is analysed using Water Research Centre's WaQCoM tool.

The study further examines the implications of various blending ratios, including risks related to corrosion, discolouration, and turbidity mobilisation at the point of use, which are especially relevant to ageing UK distribution networks. The impact of the blending ratio on constituents of regulatory interest, such as boron, is assessed, and the necessary blending thresholds to ensure compliance with UK drinking water standards are identified. The effects of temperature differences between desalinated and mains water on chemical stability are also evaluated. The findings provide new, UK-specific evidence to support the stable integration of desalinated water into existing mains water supply systems. The outcomes offer practical guidance for UK water utilities on choosing blending ratios that protect distribution assets, maintain stable and compliant water quality, and support resilient service delivery.

Keywords: Desalination; Reverse osmosis; Water blending; Distribution quality; Corrosion and scaling indices; Water stability; pH adjustment; Mineral balance

EuroMed 2026
Desalination, Water Reuse and the Environment
22–25 June 2026, Marrakech, Morocco

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Diving into the transfer of small organics in seawater reverse osmosis desalination: Insights and cascade strategies

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The rapid expansion of seawater reverse osmosis (SWRO) desalination has become essential to address global freshwater scarcity. While SWRO is highly efficient for salt removal, its ability to ensure the complete elimination of organic micropollutants remains a critical and insufficiently understood challenge. Increasing evidence shows that trace organic contaminants, including pharmaceuticals, dyes, and emerging pollutants, can partially permeate RO membranes, raising concerns about the long-term quality and safety of desalinated water.

This lecture addresses the fundamental question: *why do certain organic micropollutants transmit through RO membranes despite their molecular size, and how can process design mitigate this limitation?* Drawing on systematic experimental investigations conducted in both brackish and seawater matrices, we demonstrate that molecular weight alone is not a reliable predictor of rejection. Instead, solute transfer is governed by a complex interplay of solute–membrane–solvent interactions.

A broad range of organic compounds (molecular weights from 254 to 916 g·mol^{-1}, with diverse charge and hydrophobicity profiles) were investigated using commercial SWRO membrane. The analysis reveals consistent partial transmission of all studied micropollutants. By coupling experimental results with Hansen solubility parameter analysis, we show that affinity-driven interactions play a dominant role in governing solute transport, challenging conventional size-exclusion assumptions in RO desalination.

Beyond diagnosis, this lecture explores process-level solutions. Advanced membrane cascade configurations with internal recycling are evaluated as a strategy to simultaneously enhance water recovery and micropollutant rejection. Simulation results indicate that multi-stage cascade arrangements can reduce micropollutant concentrations in the permeate by up to two orders of magnitude while maintaining high salt rejection.

This work provides an understanding and controlling of micropollutant transmission in desalination. The findings highlight the necessity of rethinking both membrane selection and process architecture to ensure that future desalination technologies deliver not only sufficient quantities of water, but also water of uncompromised chemical quality.

Keywords: Organic pollutant; Desalination; Membrane cascade; Reverse osmosis; Transfer mechanisms

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Innovative pretreatment processes for next-generation SWRO desalination plants

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As seawater reverse osmosis (SWRO) continues to expand in response to escalating water scarcity in the Mediterranean region and worldwide, the sustainability and resilience of desalination plants are becoming as critical as their production capacity. In this context, pretreatment represents a decisive step, governing not only RO membrane performance and plant reliability, but also energy demand, chemical consumption, and the overall environmental footprint of desalination systems.

This contribution presents innovative pretreatment strategies for sustainable SWRO desalination, with a particular focus on the largest industrial-scale Ceramic Membrane Filtration (CMF) pretreatment system in the world, deployed by OCP Green Water at the Safi desalination plant. This project constitutes a pioneering global experience, demonstrating the technical and operational feasibility of ceramic membranes as a robust and sustainable alternative to conventional pretreatment schemes. The central scientific question addressed is how CMF-based pretreatment can contribute to reducing the overall operational expenditure (OPEX) of SWRO plants while ensuring long-term technical, economic, and environmental sustainability.

This keynote will highlight the Safi desalination platform, which integrates advanced ceramic filtration with optimized in-line coagulation and tailored hydraulic operating modes to cope with highly variable Atlantic seawater conditions. Operational feedback indicates enhanced removal of suspended solids, turbidity, and organic matter, resulting in stable SDI values, improved RO membrane protection, and a substantial reduction in chemical consumption for membrane cleaning and preservation.

Beyond process performance, the Safi experience illustrates how local engineering, process simplification, and the long-term durability of ceramic membranes can contribute to lowering life-cycle costs and reducing the carbon footprint of desalination infrastructure. By sharing the system design, operational lessons learned, and scale-up challenges, this presentation aims to provide practical insights into how innovative pretreatment technologies can support the next generation of sustainable, resilient, and regionally adapted SWRO plants.

Keywords: SWRO; Ceramic membrane filtration; Seawater pretreatment; Sustainable desalination; Industrial-scale innovation.

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Water and ion transport properties of high-pressure nanofiltration membranes for brine treatment

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As global water scarcity intensifies, the effective management and treatment of high-salinity brine streams have surged to the forefront of environmental and economic agendas. Traditional desalination processes often reach a limit - both thermodynamically and operationally - when tasked with processing hypersaline concentrates. In this context, high-pressure nanofiltration (HPNF) has emerged as a particularly promising alternative. Unlike traditional reverse osmosis (RO), HPNF offers moderate salt rejection, which allows it to process high-salinity feed solutions without breaching the system's osmotic pressure limits. This unique characteristic facilitates effective solute-solute fractionation and significant volume reduction.

However, the application of HPNF is often hindered because transport properties under high-pressure conditions tend to deviate significantly from standard operating ranges. This divergence frequently leads to the failure of existing performance prediction models, which typically rely on the assumption of constant transport coefficients. Consequently, this study aims to clarify the complex impact of operating conditions on both the water permeability coefficient (*A*) and the solute permeability coefficients (*B*) specifically within the HPNF framework.

To investigate this, experiments were conducted using a lab-scale crossflow HPNF system engineered to withstand elevated pressures. Three commercial NF membranes from Toray Chemical Korea, including NE40, NE90, and ARM, were evaluated using complex, high-salinity mixed electrolyte solutions (comprising NaCl, $CaCl_2$, and Na_2SO_4) across a broad salinity range of 1 to 10 wt%. Response Surface Methodology (RSM) was employed as our primary statistical tool to systematically map the dependency of transport parameters on various operating variables.

Results reveal that A and B values are not intrinsic constants; rather, they are dynamically altered by the operating environment. Highly non-linear relationships were found between these parameters and variables such as feed pressure, concentration, and ionic composition. Specifically, the observed reduction in water permeability and shifts in ion selectivity can be attributed to a complex interplay of physical membrane compaction and electrochemical phenomena, including charge shielding and alterations in effective pore size under high pressure. By applying RSM, it was possible to quantitatively elucidate these effects, paving the way for the development of modified transport model equations that account for parameter variability. These refined models offer a far more robust framework for predicting membrane performance in hypersaline environments. As a next step, future work will focus on scaling these modified equations from flat-sheet laboratory data to full-scale NF spiral-wound elements, thereby bridging the gap between fundamental transport phenomena and industrial-scale brine reclamation.

Keywords: Nanofiltration (NF); High-salinity brine; Response surface methodology (RSM); Transport model; Performance prediction

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Optimizing coagulation dose, pH and rapid mixing with MFI-UF to reduce particulate/colloidal fouling in RO/NF

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Traditionally, coagulation and flocculation have targeted the removal of DOC and turbidity in surface water treatment. However, these parameters cannot be used to improve coagulation efficiency in RO/NF as they show poor correlation with particulate/colloidal fouling. The aim of this study is to use the MFI-UF method to assess the role of coagulant dose, pH and rapid mixing in reducing particulate/colloidal fouling in coagulation pretreatment in RO/NF.

Reservoir water, collected after a 30 µm microstrainer, was used in laboratory jar test experiments where coagulation pH was varied from 5-8, coagulant dose (Fe^{3+}) from 0-20 mg/L and rapid mixing intensity (G) from 300-700 s^{-1}. Rapid mixing (10 s) was followed by flocculation (20 min), sedimentation (30 min) and 0.45 um filtration. Particulate fouling was assessed using the MFI-UF (10 kDa at 100 LMH). Other water quality parameters such as DOC, LC-OCD, residual iron and turbidity were also measured.

Increasing coagulant dose from 2.5 to 10 mg/L increased MFI-UF removal from 34 to 65% but increasing coagulant dose beyond 10 mg/L showed no further improvement in MFI-UF removal. Lowering feedwater pH from 8 to 5 further increased the removal of particulate/colloidal fouling (MFI-UF) and a coagulant dose of 10 mg/L at pH 5, resulted in more than 88% of MFI-UF compared with 63% at pH 8. The effect of rapid mixing intensity (G) was pronounced in the low coagulant dose range (2.5–10 mg/L) and increasing G from 300 to 700 s^{-1} increased MFI-UF removal by 20%. However, above a coagulant dose of 10 mg/L, no effect of G was observed on MFI-UF removal as sweep coagulation (and not charge neutralization) is expected to play a dominant role.

MFI-UF removal at pH 5 with a coagulant dose of 10 mg/L and G > 700 s^{-1} corresponded to a biopolymer removal of 93% and humic acid removal of 90% compared with 70% and 55% at pH 8, respectively. In general, a strong correlation (R^2 > 0.96) was observed between the removal of particulate/colloidal fouling (MFI-UF), biopolymers (>20 kDa) and humic acids during coagulation. However, the biopolymer fraction was identified as the most likely cause of particulate/colloidal fouling in surface water as the rejection of biopolymers (in raw water) by the 10 kDa MFI-UF membrane was > 99% whereas the rejection of all other organic fractions was < 10%.

In this study, the MFI-UF method was used to optimize coagulation and minimize particulate/colloidal fouling in NF/RO. Coagulant dose, pH and G had a significant impact on MFI-UF removal and an optimal coagulation regime could be identified with a coagulant dose of 10 mg/L,

pH 5 and G (rapid mixing >700 s^{-1}) which resulted in 88% reduction in MFI-UF. The biopolymer fraction of organic matter (> 20 kDa) was the most probable source of particulate/colloidal fouling in this surface (reservoir) water application.

However, further research is required to understand the mechanisms of pticulate and colloidal fouling removal during coagulation.

Keywords: Particulate/colloidal fouling; Coagulation; Nanofiltration; Reverse osmosis; Pre-treatment

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Key performance and energy challenges in small scale brackish water desalination systems

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Small-scale brackish water desalination systems producing ≤1 m^3/h of freshwater are increasingly explored as decentralized solutions for augmenting water supplies in off-grid, rural, and resource-constrained settings. These units commonly employ desalination technologies, such as nanofiltration (NF), reverse osmosis (RO), and electrodialysis (ED), each presenting distinct performance attributes and energy demands. While these technologies are deployed approach for brackish water desalination but operate at higher specific energy consumption (SEC) compared to large-scale plants, despite their simplicity and compatibility with renewable energy inputs.

Conservative energy estimates for small desalination membrane processes underscore that electrical energy input remains a dominant operational cost and a key constraint on viability, particularly in regions lacking reliable energy infrastructure. Small-scale units further face intrinsic limitations including membrane fouling and scaling, feed-water variability, and the inefficiencies that derive from limited energy-recovery integration compared to larger installations. These challenges are compounded when renewable energy sources are paired with desalination units, as intermittency and storage requirements influence performance and economics. The interplay between freshwater productivity, energy efficiency, and system reliability highlights important trade-offs that must be considered in design, deployment, and optimization. Addressing energy consumption, enhancing membrane performance, and integrating robust, low-carbon energy sources are essential steps toward improving the sustainability and practical utility of small-scale desalination technologies.

Keywords: Brackish water; Desalination; Membrane separation; Energy efficiency; Renewable energy

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Design of a small scale filter media system for seawater pretreatment prior desalination

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Effective pretreatment is a critical requirement for ensuring the stable operation and longevity of seawater reverse osmosis (SWRO) desalination systems, particularly at small scale where process robustness and operational flexibility are limited. This study investigates the design of a small-scale filter media system for seawater pretreatment prior to desalination, with the objective of evaluating the performance of different granular filter media configurations.

The design is based on existing large scale filter media process, while the assessment is based on key pretreatment performance indicators, including total suspended solids (TSS) removal, turbidity reduction, and the resulting silt density index (SDI), in relation to standard SWRO feed water requirements. Experimental investigations are conducted under representative seawater conditions to compare the filtration efficiency of selected media types and configurations. The results highlight the influence of filter media characteristics on particulate removal efficiency and SDI control, demonstrating the importance of appropriate media selection for achieving reliable seawater pretreatment. The findings provide practical insights into the design and optimization of compact filtration systems capable of improving feed water quality and supporting the sustainable operation of seawater desalination units.

Keywords: Seawater pretreatment; Seawater desalination; Filter media; Silt density index; Conventional pretreatment

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Photothermal graphene-based membranes meets sunlight: Efficient brine valorization

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Membrane distillation–crystallization (MD–MCr) is a promising technology for solar-driven desalination and brine valorization; however, its efficiency is strongly limited by temperature polarization (TP), which reduces the vapor pressure gradient at the membrane–feed interface. Early strategies to mitigate this limitation relied on noble-metal-based photothermal membranes, which successfully demonstrated the feasibility of localized solar heating but were constrained by high cost, limited scalability, and long-term stability issues.

To overcome these drawbacks, attention was shifted toward carbon-based photothermal materials, particularly graphene and graphene oxide (GO), owing to their high light absorption, thermal stability, and processability. A stepwise development strategy was adopted. Initially, vertically aligned GO architectures were designed to maximize solar absorption and interfacial heat localization. Subsequently, mixed-matrix membranes were developed by dispersing GO within polymeric matrices, improving mechanical integrity and compatibility with conventional membrane fabrication processes. Finally, composite photothermal membranes were engineered by integrating GO layers onto hydrophobic PVDF supports, ensuring scalability while preserving high photothermal performance.

Under one-sun irradiation, the photothermal membranes exhibited rapid surface heating, achieving temperatures above 80°C and solar-to-thermal conversion efficiencies of approximately 75%, leading to a significant enhancement of vapor flux compared to pristine membranes. The localized heating effect effectively reversed temperature polarization, enabling stable operation under hypersaline conditions and promoting direct salt crystallization, thus supporting brine valorization. Additionally, GO-induced antifouling properties indicating improved operational stability.

Overall, the transition from noble-metal systems to scalable graphene-based photothermal membranes provides a viable route toward energy-efficient MD, addressing its critical thermodynamic limitation while enabling sustainable desalination and resource recovery from concentrated brines.

Keywords: Photothermal membrane; Graphene oxide; Temperature polarization; Brine valorization; Solar desalination; Brine mining

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Hybrid photothermal membrane distillation-selective electrodialysis for enhanced lithium recovery from hypersaline brines

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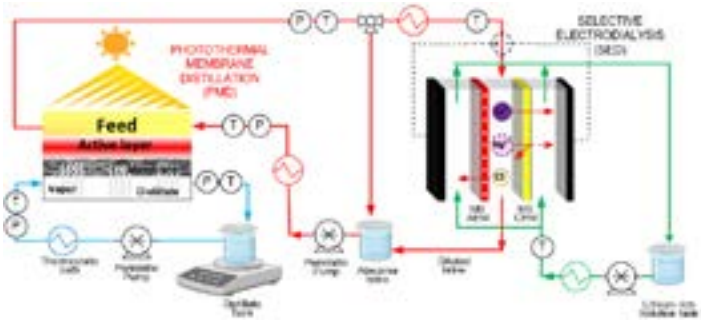
The escalating global demand for lithium, propelled by the rapid expansion of lithium-ion batteries for electric vehicles and stationary energy storage systems, necessitates innovative recovery strategies from salt-lake brines. Conventional solar evaporation ponds remain dominant yet suffer from protracted processing times, excessive freshwater consumption, and suboptimal selectivity amid elevated Mg^{2+}/Li^{+} ratios characteristic of hypersaline Atacama brines (>1 g L^{-1} Li, 4.6 mol kgH_2O). These limitations exacerbate aquifer depletion and ecological disruption in arid basins, compelling the development of integrated membrane processes. This investigation presents a solar-driven photothermal membrane distillation-selective electrodialysis (PMD-S-ED) hybrid tailored for co-recovery of freshwater and lithium from synthetic Atacama brine (4.6–6.4 mol kgH_2O). The PMD stage utilizes graphene oxide-coated polyvinylidene fluoride membranes within a cross-flow module (A = 4.91 cm^2) under 1-sun irradiation (1000 W m^{-2}), where localized interfacial photothermal conversion mitigates bulk temperature polarization, thereby amplifying the transmembrane vapour pressure differential. Initial permeate fluxes ranged from 2.11 to 3.93 kg m^{-2} h^{-1} (40–60°C) with concentration factors of 1.42–1.45 (~30% water recovery). PMD thermal requirements were normalized as kWh per gram of Li contained in the processed brine (initial concentration 1.19 g L^{-1}), providing a direct mass-normalized basis for energy comparison while accounting for water recovery achieved during PMD. On a system basis, photothermal activation lowers the total Linormalized specific energy demand from 600–1020 kWh kg^{-1} Li (dark operation) to 250 – 430 kWh kg^{-1} Li, corresponding to a 52–59% decrease. Subsequently, S-ED stackequipped with monovalent-selective cation exchange membranes (PC-MVK, PC-Cell) was systematically examined to determine the coupled effects of feed molality (4.6–6.4 mol kgH_2O), temperature (25–60°C), and cell potential (1–4 V) on limiting current density, current efficiency, and Mg^{2+}/Li^{+} separation factor. Optimal conditions (4.6 mol kgH_2O, 2 V, 40°C) yielded SLi/Mg ≈19.7 and current efficiency ~82%, with electrical specific energy consumption of 1.8-2.0 kWh kg^{-1} Li. Operation beyond limiting current induced selectivity decline through enhanced boundary-layer depletion and weakened Donnan exclusion. Reagent-free operation, integration of solar thermal harvesting, and dual-output recovery of freshwater and Li-concentrate render PMD-S-ED as a promising paradigm for process intensification in brine valorization beyond the limitations of reverse osmosis and evaporation-based schemes.



Keywords: Brine valorization; Integrated membrane systems; Resource recovery; Photothermal membrane distillation; Selective electrodialysis

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Influence of objective selection on VMD module design and global performance: A comparative study between permeate flowrate vs. flux-based optimization

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Autonomous desalination for off-grid areas is the core aspect in valorizating critical metals and freshwater production from brines (ExBrineR). With this interest, our research group developed an integrated hollow fiber solar-collector vacuum membrane distillation (HF-SC-VMD) module, designed for heat loss reduction and process intensification, at semi-industrial scale. The key scientific question pertinent to this study is understanding what is the influence on module design and global performance when optimizing either permeate flowrate or flux as an indicator of water productivity in VMD.

A comparative study was done by maximizing either F_p or J_p, while minimizing specific electrical energy (SEEC). A set of decision variables was explored within predefined ranges to quantify its influence. The variables are feed flowrate (F_{in}), permeate pressure (P_p), module length (L), packing density (θ), shell radius (r), and solar concentration factor (CF). This bi-objective optimization was efficiently solved using an archive-based multi-objective evolutionary algorithm with memory-based adaptive partitioning strategy over a search space (AMOEA-MAP). For the analysis, commercial polypropylene HFs, a 100 g kg^{-1} NaCl feed solution, and 2710 W m^{-2} solar irradiation, were fixed.

A comparison of the results for F_p and J_p optimization is presented in Table 1. Notably, to

achieve the highest F_p (7.74 kg h^{-1}), the module tends toward an extensive design with large module dimensions, bundle compacity, high F_{in} and P_p, and high CF. However, when maximizing J_p (6.41 kg m^{-2} h^{-1}), the system necessitates a smaller module with reduced dimensions, bundle compacity, and operating conditions (F_{in} and P_p). For instance, a higher P_p (10.0 kPa) favors high permeate productivity as it has a greater reliance on solar collector area, and needs a high F_{in} to transfer sensible heat in the module (shown by low S_{SC}/S_m). While a maximum J_p relies more on a higher VMD driving force (lower P_p) so the system is less dependent on solar energy collection and transfer. A higher S_{SC}/S_m (4.75) indicates that more thermal energy is absorbed and transferred to the module for a maximum J_p. Thus, productivity is less constrained by module design.

In conclusion, maximizing J_p or F_p can result in a HF-SC-VMD system with similar SEEC's, but lead to different module designs, with varying strategies to manage solar heating. Furthermore, technical feasibility and manufacturing cost of large modules remain a concern when maximizing Fp, while a higher vacuum pump demand should be considered for maximum Jp. Nevertheless, these findings highlight how strategic module design can be exploited to meet different production criteria for VMD.

Table 1
Comparison between F_p and J_p maximization on module design and system conditions

	F_p maximization	J_p maximization
Fp (kg h^{-1})	**7.74**	0.29
Jp (kg m^{-2} h^{-1})	0.02	**6.41**
SEEC (kWh m^{-3})	5.85	7.55
F_{in} (L h^{-1})	3000	91
Pp (kPa)	10.0	4.15
L (m)	4.0	1.5
(%)	50.0	1.0
r (m)	0.15	0.020
CF	6.0	6.0
S_{SC}/S_m	0.011	4.75

*S_{SC}; solar collector surface area,S_m: membrane surface area

Keywords: Vacuum membrane distillation; Solar collectors; Hollow fibers; Multi-criteria optimization; Module design; Coupled heat and mass transfer

The project EXBRINER – HORIZON-MSCA-DN-2021 has received funding from the European Union's Horizon Europe research and innovation programme under the Marie Sklodowska-Curie grant agreement No. 101072449.

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Magnesium sulphate recovery from multistage seawater nanofiltration brine using photothermal membrane crystallization

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The GO-PVDF membrane shows surface temperature increment from 24.3 to 66.3°C under 1 sun condition in <5 min which highlights the effective photothermal effect. The membrane provides stable flux in the range of 3.2–5.6 kg·m-²·h-1 in absence of the exciting radiation with pure water and 5.7–8.1 kg·m-²·h-1 under photothermal mode induced by the simulated solar radiation at the pre-heating bulk feed temperature (T_f) of 50°C and 60°C respectively. On utilizing highly concentrated NF brine the obtained transmembrane flux values were 2.8 and 3.2 kg·m-²·h-1 at T_f = 50.4 °C and 60.1 °C vs 20 °C permeate temperature. $MgSO_4 \cdot 7H_2O$ crystals with nucleation rate (B) at T_f = 60.1°C and 50.4°C were observed in the order of 10^{10} and 10^9 crystals·m-³·s-¹ respectively. The effective growth rate (G_{eff}) of recovered $MgSO_4 \cdot 7H2O$ decreased from 3.0 ×10-8 to 1.7 ×10-8 m·s^{-1} on increasing Tf from 50.4 to 60.1°C. Broder crystal size distribution (CSD%) and high coefficient of variation (CV%) was observed at T_f = 50.4°C. The mean crystal size was observed in the range of 196-300 µm. On comparing the XRD peaks with commercial $MgSO_4 \cdot 7H_2O$ and NaCl salts, almost all peaks were coincided with $MgSO_4 \cdot 7H_2O$ but none with NaCl that proves high purity of the recovered crystals.

Keywords: Brine mining; Magnesium; Photothermal membrane crystallization; Nanofiltration; Desalination

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Hypersaline brine valorization using cation exchange membrane: Experimental and modelling approach

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Hypersaline brine can cause environmental harm if improperly discharged. However, it may also constitute a valuable source for energy production and raw material recovery. This work

aims to develop a low-resistance, highly permselective cation exchange membrane for lithium extraction from brine. Lithium is recovered through Donnan Dialysis (DD), a separation process driven by ion activity gradients across a membrane [1]. The proposed membranes consist of sulfonated thin films incorporating metal–organic frameworks (MOFs) selective toward monovalent alkali metal ions (e.g., ZIF-8, H-KUST-1, UiO-66), including lithium. These mixed-matrix membranes are fabricated via phase inversion, with MOFs forming nanochannels that enhance lithium-ion transport and separation [2]. MOFs are synthesized using state-of-the-art solvothermal methods [3]. The resulting membranes combine the advantages of sulfonated films and MOFs, exhibiting high selectivity, stability, and ionic conductivity for DD applications [4,5]. The polymer binder chosen for membrane fabrication is fully hydrocarbon-based polystyrene-block-poly(ethylene-ran-butylene)-block-polystyrene (PSEBS). This material is known for its good film-forming ability and mechanical properties, which in principle allow the incorporation of high MOF loadings. Additionally, PSEBS can be readily sulfonated. As a non-fluorinated polymer, it avoids the environmental concerns associated with fluorinated materials. PSEBS is also commercially available, which is advantageous from a capital cost perspective. Modeling is carried out using the Poisson–Nernst–Planck model, in which the Nernst–Planck and Poisson equations are coupled and local deviations from electroneutrality are permitted [6]. Preliminary modeling results indicate that conventional membranes fail to achieve the required performance, particularly with respect to lithium selectivity, highlighting the necessity of a novel approach such as that proposed in this study.

Keywords: Metal organic frameworks; Lithium; Mixed matrix membrane; Brine; Donnan dialysis

Acknowledgements

The authors thank the EU commission for financial support of this project EXBRINER (project no. 101072449) within framework of REA.A program (Marie Skłodowska-Curie Actions & Support to Experts A.1 – MSCA Doctoral Networks).

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3D printing of profiled ion-exchange membranes

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Electromembrane technologies, such as electrodialysis, flow-electrode capacitive deionisation, and reverse electrodialysis, are becoming increasingly significant for applications like desalination of water, recovery of valuable resources, and generation of sustainable energy. These systems are typically based on plate-and-frame membrane stacks, where flat ion-exchange membranes (IEMs) are separated by spacers to form flow channels. However, spacers introduce additional pressure losses and shadow effects. Recent research suggests that profiled membranes can alleviate these limitations.

This work presents a new method for fabricating membranes using fused deposition modelling (FDM) 3D printing. This solvent-free, cost-effective, and highly customisable technique enables precise control over the membrane geometry, allowing for the direct production of both flat and profiled IEMs. After printing, the membranes were chemically modified by sulfonation to prepare cation-exchange membranes [1] and by chloromethylation followed by amination to prepare anion-exchange membranes.

The 3D-printed membranes exhibited electrical resistance and permselectivity that were similar to those of commercially available membranes. The ability to make custom, profiled ion-exchange membranes with little material waste (E-factor 1.5) and less complicated processing is a big step forward in membrane design and production. It opens new possibilities for better performance across various electromembrane desalination and separation processes.

Keywords: Ion-exchange membranes; 3D printing; Fused deposition modelling; Profiled membranes; Electromembrane processes; Desalination

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Organic fouling of anion exchange membranes

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Organic fouling of anion exchange membranes is fundamentally governed by physicochemical interactions occurring at the membrane surface, where electrostatic, hydrophobic, and hydration effects govern foulant adsorption, layer formation, and reversibility. Although organic fouling under electrodialysis operation has been widely reported, existing studies predominantly rely on macroscopic electrochemical responses to describe fouling severity, without explicitly resolving how membrane surface chemistry and membrane–foulant interactions at the interface control foulant adhesion strength and fouling mechanisms. As a result, the physicochemical interfacial factors governing fouling initiation, development, and persistence at the membrane surface remain insufficiently understood.

In this work, organic fouling of anion exchange membranes is investigated using a materials and interface perspective, with emphasis on how membrane surface properties influence membrane–foulant interactions under electro-driven conditions. Pristine and surface-modified membranes are subjected to controlled fouling and cleaning protocols using sodium dodecylbenzenesulfonate (SDBS) as a model organic foulant, while maintaining identical operating, exposure, and cleaning conditions. Electrodialysis desalination is employed to reproduce realistic interfacial driving forces and to define fouling states, whereas the analysis focuses on membrane surface and interfacial properties rather than overall process performance.

A comprehensive surface- and interface-sensitive characterization is carried out on pristine, fouled, and post-fouled membranes. FTIR and XPS are used to identify foulant-related chemical functionalities and assess their persistence after cleaning, while adhesion force measurements by atomic force microscopy quantify the interaction strength between SDBS and the membrane surface and reversibility at the molecular scale. Electrochemical impedance analysis probes changes in interfacial transport resistance associated with fouling, and microscopic techniques are used to examine the spatial distribution of foulant deposition. By correlating surface chemistry, interaction energetics, and interfacial resistance development, this study provide insight into how membrane surface chemistry and membrane–foulant interactions govern foulant adhesion and fouling behavior at the interface, contributing to a mechanistic understanding of organic fouling in anion exchange membranes relevant to desalination and water reuse.

Keywords: Anion exchange membranes; Organic fouling; Surface physicochemistry; Interfacial interactions; Fouling reversibility; Electrodialysis

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Development of MOF-embedded cryogels for advanced water treatment

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In this work, we present the development and characterization of a novel composite material through the combination of poly(sodium) acrylate (PSA) cryogel and metal-organic framework (MOF) nanoparticles, for the effective water decontamination of water. The PSA matrix is formed by cryopolymerization of the sodium acrylate monomers, leading to a 3D network with highly interconnected pores, high number of active sites, good mechanical strength, enhanced swelling capability and water interaction, all properties desirable for water treatment applications. On the other hand, MOFs are currently of high interest due to their structure, which offers high porosity and an easily tunable network for the desired surface functionality, important attributes for applications in adsorption. Their practical use, however, is limited by the need of stabilization within a solid matrix. In this study, we develop the Zr-based UiO-66 and its derivative UiO-66-NH_2, which show exceptional stability in water. We demonstrate the successful formation of the PSA/MOFs composites through a facile route and further characterize their structure, physicochemical properties and water stability. Lastly, we proceed with adsorption tests using water loaded with organic contaminants as well as metal ions, demonstrating advanced performance compared to the isolated components. The final aim of the study is to obtain an inexpensive, easy-to-use, stable and highly adsorbent material for the effective removal of contaminants from water.

Keywords: Hydrogels; Metal-organic frameworks; Composites; Adsorption; Water treatment; Gravity-driven filtration

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Towards sustainable desalination in Morocco: brine valorization in the agri-food industry as a circular economy lever

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In Morocco, seawater desalination has emerged as an ambitious and strategic solution to confront water scarcity and secure supply for both drinking water and irrigation. However, the large-scale deployment of this technology faces significant challenges. As the recent report of the court of auditors revealed that the desalination present high operational costs and the environmental footprint of brine discharge is neglected in general.

The brine, a hypersaline byproduct rich in salts, minerals, and chemical elements, poses a major environmental threat to marine ecosystem near discharge sites. The main aim of the study is to explore a shift in perspective by transforming this environmental liability into an economic asset through valorization.

The proposed research focuses on the potential of integrating brine into the agri-food industry, specifically for washing processes, industrial processing, or the conditioning water of certain vegetables. This integrated and sustainable management approach, rooted in circular economy principles, aims to achieve the minimizing of the negative impact on marine ecosystems and reducing the overall cost of water production. By creating a value chain for byproducts, desalination can become a more cost-effective and ecologically responsible solution for Morocco's water future.

Keywords: Desalination; Brine valorization; Circular economy; Agri-food industry; Environmental impact; Sustainable management

EuroMed 2026
Desalination, Water Reuse and the Environment
22–25 June 2026, Marrakech, Morocco

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Potassium recovery from liquid digestates with a combination of membrane technologies and adsorption/ desorption processes

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In the last years, nutrients recovery has become an important issue in the frame of the circular economy. Reserves of nutrients are scarce (as in the case of phosphorous) or are unevenly distributed in the Earth (as in the case of potassium). On the other hand, alternative ways of producing nutrients for fertilizers are searched to reduce their production costs and to avoid wars or other conflicts in the producers' countries affecting their supply.

This study investigates the combination of membrane processes and adsorption/desorption for the recovery of potassium, or the simultaneous recovery of nitrogen and potassium, within a circular economy framework. The proposed approach integrates nanofiltration with an ion exchange resin.

Specifically, two nanofiltration membranes have been tested (NF-90 and NF-245). Test were carried out in in recycled mode at different transmembrane pressures (10 and 15 bar). Adsorption/desorption tests were conducted in batch mode with the ion exchange resin IRN77 in a two-stage configuration. In the first stage (R1), 10 $g \cdot L^{-1}$ of resin was used to preferentially remove divalent cations, while in the second stage (R2) 50 $g \cdot L^{-1}$ of resin was applied for selective potassium recovery. Potassium was desorbed using a 2 N HCl solution.

The results showed that nanofiltration membranes recovered potassium and nitrogen in the permeate stream. Under the studied operating conditions, NF membranes reduced ionic competition and prevented ion exchange resin saturation, allowing affective potassium and ammonium separation (>90%). However, the flux for NF membranes highly decreased due to the organic matter content and solids concentration in the liquid centrate. Adsorption tests showed a proper recovery of the ammonium and potassium (>75%). These findings indicate that liquid digestates can be successfully separated from liquid digestates.

Keywords: Liquid digestates; Potassium; Nanofiltration; Ion exchange resins; Zeolites

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Manufacturing low-cost membranes from HIPS recycled

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The revision of water reuse regulations across the European Union has significantly increased the performance requirements imposed on wastewater treatment plants (WWTPs), particularly with respect to microbiological safety and effluent stability for reuse applications. In Spain, the recently enacted Royal Decree 1085/2024 transposes these regulatory objectives into national law, introducing more stringent effluent quality thresholds and effectively requiring the implementation of advanced treatment technologies beyond conventional secondary treatment.

Within this regulatory context, membrane-based processes—most notably ultrafiltration (UF)—have become increasingly relevant as enabling technologies for regulatory compliance. UF is a mature and robust treatment option that provides high removal efficiencies for turbidity, organic matter, and a broad range of microorganisms, including protozoa, bacteria, and viruses (Yang et al., 2020). Consequently, UF is widely implemented as a tertiary barrier in water reuse schemes and is recognised as a key technology for achieving consistent compliance with reuse standards.

More recently, alternative process configurations have been proposed in which UF is applied to primary effluent rather than solely as a tertiary treatment. This approach allows for enhanced capture of particulate and colloidal organic matter for anaerobic digestion, while simultaneously reducing the organic load and aeration demand of downstream activated sludge processes (Sanchis-Perucho et al., 2023). Such configurations are increasingly discussed in the context of energy efficiency and resource recovery, which are also central objectives of current EU water policy.

Despite these advantages, the wider deployment of UF remains constrained by operational and economic limitations. Membrane fouling, incomplete permeability recovery after cleaning,

and associated increases in maintenance intensity continue to represent major barriers to large-scale implementation (Judd, 2017; Qu et al., 2019; Benites-Zelaya et al., 2020; Liu et al., 2021). These challenges translate into elevated operational costs, which can hinder the adoption of membrane technologies in WWTPs facing stricter regulatory requirements.

In parallel with regulatory tightening, European policy frameworks increasingly promote circular economy principles, including material reuse and waste valorisation. Within this context, the use of recycled polymers for membrane fabrication has emerged as a potential strategy to reduce material costs and partially offset the economic burden associated with membrane fouling and cleaning, while contributing to plastic waste recovery (Goh et al., 2021).

In this study, high-impact polystyrene (HIPS) sourced from a recycling facility (ACTECO S.L., Spain) was employed as the membrane-forming material. Previous studies have demonstrated the suitability of HIPS-based membranes for the removal of model organic compounds, such as humic acids (García-Ivars et al., 2016; Khaled et al., 2022). The present work extends this knowledge by evaluating the performance of recycled HIPS membranes for wastewater treatment under realistic operating conditions, using real WWTP effluents.

Permeability tests indicated permselective behaviour characteristic of ultrafiltration membranes, with permeability values within the same order of magnitude as those reported for conventional UF materials. Filtration experiments conducted with secondary effluent as feed water achieved turbidity rejection above 90%, chemical oxygen demand (COD) removal of 60–75%, protein removal of approximately 30%, carbohydrate removal of 55–60%, and complete removal of pathogenic microorganisms. These results indicate that recycled HIPS membranes can meet key effluent quality requirements relevant to current EU water reuse regulations, while supporting broader policy objectives related to sustainability and circular economy implementation

Keywords: Low-cost membranes; Recycled polymers; Wastewater treatment; High-impact polystyrene (HIPS)

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Analysis of energy consumption and efficiency standardization for hydraulic energy recovery devices

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Although energy recovery devices (ERDs) are currently employed in nearly all seawater reverse osmosis (SWRO) desalination systems, as well as in an increasing number of brackish water reverse osmosis (BWRO) systems, there remains an absence of a standardized definition for the efficiency of these devices. Given that ERD efficiency is frequently considered during the equipment selection and design process, the establishment of a universally accepted definition is imperative to ensure predictable energy consumption and operating costs.

This paper examines the deficiencies present in existing published ERD efficiency criteria and introduces a standardized efficiency definition that aligns with those utilized in other industries, while incorporating additional factors specific to reverse osmosis (RO) applications. The analysis demonstrates that published ERD efficiency data often exhibit limited correlation with the actual energy consumption of the RO system.

Two factors are presented to facilitate a more precise characterization of ERD efficiency under practical field conditions: hydraulic power transfer efficiency and field efficiency. The influence of several ERDs on the energy consumption of a hypothetical 20,000 m^3/day SWRO train is analyzed to illustrate the limitations inherent in currently adopted ERD efficiency definitions, as well as to highlight the value of the new definitions proposed herein. The ERDs evaluated include:

1. Pelton Impulse Turbine
2. Standard Turbocharger
3. Isobaric Chamber
4. Motorized Turbocharger

All calculations are presented with full transparency and are supplier neutral.

Keywords: Desalination; Efficiency; SWRO; SEC; Seawater; ERD; Energy

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An introduction to AMTA's New Guideline for Membrane System Safety and Reliability (G-002) for Membrane Desalination Facilities

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The use of membrane technology has grown significantly since the 1970s. Today, thousands of plants exist across the globe from low pressure wastewater reclamation systems to high pressure seawater desalination systems. As these membrane systems age, and operating pressures and system piping complexity increases, the importance of proactive and reliable practices to ensure safe system operation cannot be overstated. While most facilities have operated for many years without issue, an increasing number have now experienced problems including catastrophic failure. These failures can all be linked to either inferior product design, system design and assembly that fails to address the unique requirements of system components, or a lack of proper maintenance that negatively affects aging pressure vessels.

While existing codes and standards address general pressure vessel design and inspection, they do not address the unique safety and reliability challenges with membrane system designs, including membrane housings in their interfacing mechanical components. The AMTA G-002 Guideline provides an industry informed best practice framework to close that gap, and represents a major leap forward, in helping the industry reduced risk, protect personnel, and extend asset life through informed, practical decision-making. Importantly, the guideline is intentionally published as guidance, rather than a standard, allowing facilities to apply its recommendations based on site specific risk, cost, operating conditions, and regulatory context.

This presentation will introduce the upcoming American Membrane Technology Association guideline written specifically for membrane system safety and reliability. It will be educational for end users, equipment manufacturers, consultants, and all those interested in membrane system, safety, and longevity. In addition to documenting historical membrane system, failures and events, the guideline also identifies common failure modes, and identifies preventative and precautionary processes to mitigate safety and liability risks. The document provides guidance on system, design, procurement, construction, operation and maintenance.

Keywords: Membrane; Safety; Vessel failure; Coupling failure; Maintenance

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Bifunctional ceramic membranes from lay and spent coffee grounds for selective removal of pharmaceuticals and textile dyes

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This study presents a sustainable strategy for fabricating bifunctional ceramic membranes that combine size-exclusion and adsorption mechanisms for advanced water purification. Spent coffee grounds (SCG), was incorporated into a kaolin matrix to simultaneously act as a pore-forming agent and a source of surface functional groups. The application of the low cost novel membranes for the removal of Indigo Blue (anionic dye) and Metformin (cationic pharmaceutical) was evaluated. The optimization of the composition in SCG content and sintering temperature to maximise membrane water permeability and pollutant removal was determined.

The resulting membranes exhibited high porosity (up to 45.5%) and strong negative surface charge (-36.8 mV). Optimal formulations achieved 99% dye rejection at 770°C and 91% pharmaceutical removal at 900°C, with permeabilities of 67.6 and 103 L $m^{-2}{\cdot}h^{-1}$ bar^{-1}, respectively. Mechanistic analysis revealed electrostatic repulsion governing dye removal and electrostatic attraction plus hydrogen bonding for metformin retention. Fouling behavior was pollutant-dependent: reversible for dyes (flux recovery 94.6%) and partially irreversible for pharmaceuticals (79.8%). These findings demonstrate the potential of SCG-derived ceramic membranes as cost-effective solution for treating complex wastewater streams, contributing to the circular economy and sustainable water management.

Keywords: Spent coffee grounds (bio-waste); Kaolin; Bifunctional membrane; Selective removal; Metformin; Indigo blue dye

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Upgrading OCP's SWRO plant in Morocco: A compact i-UF solution

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We would like to focus on a case study of one of our products recently installed in Morocco. In this case, our customer (OCP) had an existing SWRO plant with a pre-treatment consisting of disc filters + pleated cartridge filters. This pretreatment was not producing the required water quality, leading to a rapid fouling of the SWRO membranes.

Based on customers' experience (they have multiple UF plants in the area), they wanted to install a UF system as a reliable pretreatment to feed the SWRO system, but unfortunately, they had no available space to do so. Fluytec was able to deliver a solution based on our integrated UF (i-UF), under which we could provide a direct coupling with the SWRO and install a double filtration stage (screening + UF) in the (very limited) space where the disc filters were previously installed.

This case study will focus on how we were able to do so. We believe that this may result in interest in other applications where a UF system needs to be installed within an existing site (i.e. installation of tertiary treatment on existing WWTPs).

Keywords : OCP; Jesa; Fluytec; Ultrafiltration; i-UF

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Osmotically assisted reverse osmosis for high-salinity brine management: recent advances and future technology development needs

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Osmotically assisted reverse osmosis is a proven membrane process for concentrating high-salinity brines, pushing the limits of conventional reverse osmosis in desalination and ZLD applications. Recent advances confirm OARO's potential to achieve higher recoveries while reducing the energy demands of thermal evaporation. This presentation reviews recent progress in process design, piloting, and industrial deployment, highlighting key operational challenges encountered at high salinities. We will cover requirements for adoption across industries, including improved tolerance to elevated temperatures (≈50°C), enhanced fouling resistance, robustness to frequent flushing and chemical cleaning, and discuss membranes engineered for optimized salt rejection and flux under extreme osmotic conditions.

Keywords: OARO; Brine concentration; Brine management

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Lessons learned: Delivering high-recovery brine through osmotically assisted reverse osmosis (OARO)

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Osmotically Assisted Reverse Osmosis (OARO) membrane systems have advanced from pilot-scale concepts to commercially viable solutions operating across diverse industrial sectors. As global water scarcity intensifies and industries seek sustainable approaches to brine management, OARO offers a critical intermediate step between traditional reverse osmosis (RO) and energyintensive thermal concentration systems. By leveraging osmotic pressure differentials, OARO enables significantly higher brine concentrations than conventional RO while maintaining relatively favorable energy consumption. This presentation examines the drivers behind OARO deployment, critical design considerations, and fieldvalidated performance metrics that demonstrate its ability to minimize brine volumes, enhance water recovery, and facilitate resource extraction such as sodium chloride and lithium.

Keywords: OARO; Brine; Water recovery

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Upstream pretreatment for reverse osmosis: impact, design optimization, and maintenance to ensure process durability amidst raw water fluctuations

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The reliability of reverse osmosis (RO) desalination is intrinsically dependent on the efficiency of the pretreatment chain. Given the increasing variability in raw water quality (algal blooms, turbidity spikes), conventional configurations often reach their limits, compromising the durability and reliability of the system.

This presentation analyzes the direct impact of pretreatment failures on accelerated membrane fouling and reduced module lifespan. We will explore design optimization strategies, notably the integration of hybrid technologies (ultrafiltration vs. conventional media filtration) and the use of real-time sensors for dynamic chemical adjustment. Emphasis will be placed on robust predictive maintenance as an essential lever to control operating costs (OPEX) and guarantee the longevity of the installation. The objective is to maintain consistent performance despite environmental shocks, thereby ensuring the technical and economic sustainability of the assets.

Keywords: Reverse osmosis; Pretreatment; Fouling; Optimization; Raw water fluctuations; Operating cost; Durability; Longevity

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Synergistic optimization of membrane processes and energy mix: Towards a low-carbon desalination model with reduced OPEX

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In the context of the energy transition, the desalination industry must reconcile economic competitiveness with environmental sustainability. This communication presents a holistic approach aimed at synchronizing membrane flux optimization with the direct integration of renewable energy sources (solar, wind).

The study demonstrates how the dynamic adjustment of reverse osmosis operational parameters—modulated according to intermittent energy availability—allows for a drastic reduction in operating costs (OPEX). We will analyze technological innovations related to next-generation energy recovery devices (ERD) and intelligent demand response strategies. This synergistic model guarantees system reliability while maximizing the longevity of the installation through control systems adapted to power variations. This approach transforms energy variability into a performance lever, ensuring the durability and economic viability of modern desalination projects.

***Keywords*:** Energy mix; Reverse osmosis; OPEX; Synergy; Renewable energy; Reliability; Durability; Operational optimization

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Water Positive: How water stewardship is shaping the next carbon market

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The global water crisis is increasingly defined by a simultaneous triad: too much water, too little water, and water that is too polluted. The binding constraint is no longer absolute planetary water volume, but the destabilization of the hydrological cycle and the resulting loss of functional availability, quality and access at local and basin scales. In 2023, the World Health Organization (WHO) and the United Nations Children's Fund (UNICEF) reported that over two billion people lacked access to safely managed drinking water, a figure projected to double by 2050 if current trajectories persist. Because more than 90 percent of global water use and impact are embedded in productive systems and supply chains, positioning water not merely within Sustainable Development Goal (SDG) 6 Clean Water and Sanitation, but fundamentally within Sustainable Development Goal (SDG) 12 Responsible Consumption and Production, where the economic architecture of this emerging market truly begins and corporate demand, value chains and financial attribution converge.

The United Nations (UN) estimates that 50 to 100 liters per person per day are required to meet basic human needs, yet actual water footprints in developed economies range between 3,000 and 7,500 liters per person per day. This systemic miscalculation reveals that water is consumed largely invisibly and unsustainably, and it is precisely within this distortion that the opportunity for systemic transformation emerges. This paper explains why a new market architecture is forming around place-based water outcomes. Unlike carbon, where atmospheric mixing enables fungibility, water risk is inherently territorial: basin conditions, seasonality, quality and infrastructure determine whether an intervention produces a meaningful outcome. Consequently, the "next carbon market" for water cannot operate as a fungible trading system but must function as a network of verified outcomes anchored in quality, quantity and access within defined geographies.

Impact investment provides the operating bridge between public governance constraints and the seven trillion dollars required by 2030 to reverse decades of structural underinvestment in water systems, aligned with the Global Impact Investing Network (GIIN) standards. By integrating the GIIN's core principle of intentionality with the market rigours of additionality, permanence and measurable performance, concepts originating in environmental asset markets and refined under the Kyoto Protocol and standards such as Gold Standard and Verified Carbon Standard (Verra), water outcomes become investable assets rather than aspirational goals. This shifts the focus from generic good practice toward verifiable system change, establishing the boundary conditions and core pillars of the market through place-based Monitoring, Reporting and Verification, independent assurance and transparent economic attribution.

We present an implementation-ready model in which corporations finance water outcomes beyond their operational fence line, shifting from internal efficiency toward regenerative economics. **This model positions water regeneration as the solvent of the bioeconomy, where water is treated not as a commodity to be depleted, but as a renewable biological flow that sustains biomass production and ecosystem services**. The model is structured around deployable project archetypes including agricultural efficiency, regeneration, water quality restoration, aquifer recharge and Non-Revenue Water reduction, while utilities and territories gain resilience without relying solely on tariffs. Using Sustainable Development Goal Indicator 6.4.1 expressed in USD per cubic meter as an economic and hydrological bridge, we demonstrate how specialised water marketplaces operate as transparency infrastructure, connecting corporate demand with solution providers and transforming water from a hidden systemic risk into a visible, regenerative and investable asset class.

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Managing the unexpected: Response, challenges, team coordination and recovery following the Paphos Desalination Plant fire

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The fire incident that occurred at the Paphos Desalination Plant on December 6, 2024, represented one of the most significant operational and technical challenges faced by the company. The event caused extensive damage and created an immediate need for rapid assessment, effective coordination, and restoration of critical systems to ensure water supply security and the safe return of the plant to operation.

This presentation outlines the technical, operational, and organizational challenges encountered throughout the emergency response and recovery process. It presents the actions strategies and decision-making processes that supported the successful reconstruction and recommissioning of the facility while maintaining focus on operational continuity and infrastructure resilience.

Particular emphasis is placed on crisis management under severe time pressure, coordination among the various teams involved, technical recovery planning, and the strong culture of teamwork that proved essential in successfully managing the incident. The presentation will also highlight key lessons learned regarding emergency preparedness, risk management, communication, and recovery planning for critical desalination infrastructure.

The experience demonstrated the importance of preparedness, collaboration, resilience and effective communication during emergency situations, while providing valuable insights for the management and recovery of desalination facilities and other critical infrastructure following major incidents.

Keywords: Desalination; Fire incident; Emergency response; Crisis management; Infrastructure recovery; Operational resilience; Teamwork

EuroMed 2026
Desalination, Water Reuse and the Environment
22–25 June 2026, Marrakech, Morocco

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Plant-based coagulants for sustainable water treatment: A review and emerging research perspectives

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Conventional chemical coagulants remain the backbone of water and wastewater treatment worldwide, yet raise documented concerns: residual aluminum toxicity, high sludge volumes requiring regulated disposal, and supply-chain fragility in resource-limited settings. These pressures have sustained research interest in plant-derived coagulants as biodegradable, low-toxicity alternatives. The published literature has grown substantially over the past decade, but its breadth has outpaced its rigor: most studies are single-laboratory jar tests conducted on synthetic turbid matrices, with turbidity as the sole outcome measure.

A critical synthesis peer-reviewed studies (2012–2026), covering 54 plant species across 26 distinct wastewater matrices, reveals three structurally important findings. First, the citation landscape is heavily skewed: *Moringa oleifera* accounts for 22% of all records, while 39 species appear in a single study each. Second, estimated material treatment costs span five orders of magnitude — from $0.01/m³ (*Castanea sativa*, 15 mg/L; Lentil Red, 15 mg/L) to $440/m³ (*Salvia hispanica*, 40,000 mg/L) — with only *Castanea sativa*, Lentil Red, and *Vicia faba* combining high removal (85–99%) with costs competitive with alum. Third, overall grade evidence quality is low to very low for most species and reaches only moderate for *M. oleifera*, as 32% of studies rely on synthetic matrices and no pilot-scale trial with multi-parameter monitoring exists in the corpus.

Alongside this retrospective assessment, we present preliminary investigations into *Teucrium polium* (Lamiaceae) as a novel candidate. Rich in polyphenols, flavonoids, and iridoid glycosides with documented surface-active and metal-complexing properties, *T. polium* shows measurable turbidity reduction in initial jar-test trials on synthetic kaolin. Active-fraction characterization and real-effluent testing are underway. Its endemic distribution across North Africa and the Mediterranean makes it a particularly relevant candidate.

Taken together, these findings indicate that the bottleneck is not the discovery of new species but the absence of independent replication, pilot-scale validation, standardized dosage reporting, and life-cycle cost accounting for candidates already identified. Plant-based coagulants hold genuine promise as context-specific tools in sustainable water management; realizing that promise requires the field to move decisively beyond the jar test.

Keywords: Plant-based coagulants; Wastewater treatment; Biocoagulants; Eco-friendly solutions; Sustainable water treatment

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Fabrication and characterization of novel tubular microfiltration ceramic membranes derived from Moroccan geo-materials

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Membrane filtration has become a widely adopted separation technology in industrial and environmental sectors, particularly in water treatment applications such as purification, effluent management, reclamation, softening, and desalination. Tangential flow membrane filtration represents a key industrial unit operation, especially in food processing and dairy manufacturing industries [1]. Its ability to achieve selective separations without phase transitions under moderate operating conditions enhances its economic competitiveness compared with conventional separation methods [2].

Pressure-driven membrane processes are commonly classified into microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO), each tailored to specific separation requirements. These technologies offer operational simplicity, ease of control, and environmental compatibility, notably reducing the need for chemical additives during separation [3].

Ceramic membranes are particularly attractive due to their excellent chemical resistance and mechanical stability under harsh conditions. However, their wider implementation remains constrained by high fabrication costs and inherent brittleness.

This study focuses on the development of composite ceramic membranes using Moroccan red clay as a low-cost raw material. The research highlights the valorization of locally sourced geomaterials to reduce manufacturing costs and enhance sustainability. The raw clay was characterized by X-ray fluorescence, X-ray diffraction, thermogravimetric analysis, and Fourier-transform infrared spectroscopy to determine its chemical, mineralogical, thermal, and structural properties.

Keywords: Red clay; Ceramic membrane; Microfiltration; Geo-materials

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Bringing selectivity to liquid mining: A DFT study of sodalite zeolite (SOD) for lithium recovery from seawater brine

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Seawater desalination processes generate vast volumes of concentrated brines, whose disposal poses significant environmental challenges. At the same time, these effluents represent an untapped reservoir of critical mineral resources, notably lithium (Li), which is essential for energy storage technologies. The selective recovery of Li from these complex media remains difficult due to intense ionic competition with sodium and magnesium, present in overwhelming excess.

While various materials have been explored for lithium extraction, including Metal-Organic Frameworks (MOFs) such as UiO-66, ion-imprinted polymers, and manganese-based oxides, zeolites offer distinct advantages in terms of framework tunability, thermal and chemical robustness, and intrinsic ion-exchange capacity. In this work, we investigate the potential of Sodalite zeolite (SOD) as a selective adsorbent for Li recovery from saline environments using Density Functional Theory (DFT). Our results reveal that Na^+ to Li^+ exchange induces a marked contraction of the cell volume, reflecting the structural adaptation of the β-cage to the smaller lithium cation. Electronic structure analysis confirms the insulating character of the framework, favorable for stable cationic exchange. The SOD structure further exhibits a preferential affinity for Li^+, supported by lower migration energy barriers compared to Na^+, which facilitates insertion kinetics. Additionally, the natural exclusion of Mg^{2+} is governed by the synergistic combination of the narrow six-ring window and the substantially higher dehydration energy barrier of magnesium relative to lithium.

These results validate the potential of Sodalite zeolite as an effective adsorbent for lithium extraction from desalination brines, contributing to liquid mining.

Keywords: Desalination; Brine valorization; Lithium extraction; Sodalite zeolite (SOD); Density functional theory

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Sustainable valorization of *Ulva lactuca* into high-capacity biochar for efficient removal of mordant orange dye from wastewater

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The present study evaluates the adsorption performance of biochar derived from the green algae *Ulva lactuca* for the removal of the industrial azo dye Mordant Orange (MO) from aqueous solutions. The prepared biochar exhibited a remarkable adsorption capacity, with a maximum monolayer capacity (q_m) of 526.31 mg/g at 25°C, indicating its high efficiency compared to conventional adsorbents. Adsorption kinetics were best described by the pseudo-second-order model, while equilibrium data were well fitted by the Langmuir isotherm, confirming monolayer adsorption on homogeneous active sites. Thermodynamic analysis revealed that the adsorption process is spontaneous and exothermic. The practical applicability of the material was further assessed using real wastewater collected from the M'Zar wastewater treatment plant (STEP) in Agadir, where significant pollutant removal efficiencies were achieved, including 67.85% for chemical oxygen demand (COD), 55.88% for biochemical oxygen demand (BOD_5), and 63.01% for suspended solids (SS). Furthermore, process optimization using Response Surface Methodology (RSM) based on a Central Composite Design (CCD) identified adsorbent dose and initial dye concentration as the most influential parameters affecting removal efficiency, while pH was found to be non-significant within the investigated range. Overall, the findings demonstrate that biochar derived from locally available green algae represents a low-cost, environmentally sustainable, and highly efficient alternative to commercial adsorbents for industrial wastewater treatment.

Keywords: Biochar; *Ulva lactuca*; Azo dye; Adsorption; Wastewater treatment; Sustainable adsorbent

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Desalination at scale: Where energy transition meets water security

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What is the future of water security depends as much on electrons as it does on molecules?

In the race to build the economies of the future, the true competitive advantage may not be energy or water alone, but the ability to secure both sustainably and at scale. Drawing on ENGIE's global experience in renewable energy, infrastructure and decarbonization, this keynote explores how clean power, flexible energy systems and desalination can converge to secure water resources while accelerating net-zero ambitions. From Morocco to global growth markets, it is a story of turning two defining challenges of our century -energy transition & water security- into one integrated opportunity for sustainable development.

Keywords: Water-energy nexus; Water security; Sustainability

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3D-printed ion-exchange membranes: achieving commercial performance with a zero-waste approach

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Electromembrane processes, such as electrodialysis, flow electrode capacitive deionisation, and reverse electrodialysis, play a vital role in applications ranging from water desalination and recovery of critical raw materials to sustainable power generation. The most common arrangement of electromembrane stacks is a plate-and-frame configuration, in which spacers separate flat ion exchange membranes (IEMs) to create internal channels. Several recent studies have shown that replacing flat IEMs with profiled IEMs can offer advantages, such as higher mass transfer and lower pressure drop, thereby overcoming the limitations caused by concentration polarisation, fouling, and the spacers' shadow effect.

We developed a pioneering approach to the preparation of ion-exchange membranes by fused deposition modelling (FDM) 3D printing, a solvent-free, cost-effective, and customisable technique. Unlike traditional methods, FDM allows for the precise design and fabrication of both flat and profiled membranes. The 3D-printed membranes were functionalised into cation-exchange membranes by sulfonation and into anion-exchange membranes by chloromethylation followed by amination. The electrical resistance and permselectivity of the obtained membranes are comparable to commercial alternatives [1]. The ability to fabricate tailor-made membranes by FDM 3D printing without using solvents or extensive manual effort marks a significant step forward for manufacturing profiled ion-exchange membranes for diverse electromembrane processes.

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