Desalination for the Environment:

Clean Water and Energy

27–30 April 2025, Alfândega Congress Centre, Porto, Portugal

BOOK OF ABSTRACTS

CONTENTS

PT 1

Desalination as a strategic enabler for green hydrogen production in Algeria: Opportunities and challenges

Najib Drouiche

CRTSE, Algiers 16038, Algeria
Tel. +213 660621509; nadjibdrouiche@yahoo.fr

As the global demand for green hydrogen surges, regions with abundant renewable energy resources are increasingly being targeted for hydrogen production. Algeria, with its vast solar potential, is well-positioned to become a major player in this emerging industry. However, the arid nature of the country necessitates the development of a sustainable water source for water electrolysis, making desalination a critical component of green hydrogen production. This paper explores the integration of desalination technologies in Algeria's green hydrogen value chain. We analyze the potential of using solar-powered desalination plants to supply the necessary water for hydrogen production, considering the energy and environmental implications. The study also examines the technical and economic feasibility of various desalination methods, including reverse osmosis, and its adaptability to the Algerian context. Key challenges such as water-energy nexus, cost efficiency, environmental impact, and infrastructure requirements are addressed. Furthermore, the policy and regulatory framework needed to support the development of desalination infrastructure for green hydrogen production is discussed. Our findings suggest that with the right combination of technology, policy support, and investment, desalination could play a pivotal role in unlocking Algeria's potential as a green hydrogen hub. This study aims to provide a roadmap for policymakers and industry stakeholders to harness this opportunity, contributing to both national energy security and global decarbonization efforts.

Keywords: Algeria; Desalination; Green hydrogen; Decarbonization

PT 3

PRE-1900 solar distillation in present-day Namibia

Jim Birkett

West Neck Strategies, 556 West Neck Road, Nobleboro, ME 04555, USA
Tel. +1-207-563-8773; westneck@aol.com

The broad purpose of this work was to expand our knowledge of desalination innovation prior to 1900. If successful, the intent was to publish the information in the retrieval literature so it would be available for future researchers.

The method was to start with an obscure figure from a 19th Century German marine technical journal and build links with knowledgeable experts on the technical and social history of the region in precolonial and early colonial times. Nothing was available in the searchable literature. Thus on-the -ground contacts were invaluable. Directly relevant publications were hard to come by. As a result the author had to resort informal newsletters circulated among the German colonies in Africa, biographies, histories and even letters from the inventor to his wife at home in Germany,

It is well-known and documented that solar distillation (desalination) was employed in the latter part of the 19th century in Peru and Chile to provide drinking and boiler feed water for the guano and mineral mining activities. This paper will show that similar activities were also carried out in precolonial Southwest Africa under analogous circumstances and during the same period. By remarkable and fascinating coincidence, the essential player in this was Adolph Luderitz, a key figure in the colonial and pre-colonial history of the area and and an entrepreneur and early explorer.

Luderitz reported a performance of 15.4 L/d/m^2 (but this was only reported for a short period.) Nonetheless, this well exceeds that of the 5 L/d/m^2 in the Chilean operations.

The conclusion of this work was that, indeed, solar desalination had been used in the late 19th century in present day Namibia to provide drinking water to the nascent colony.

The recommendations are that future researchers attempt to ascertain how Luderitz came up with the concept. Did he have direct or indirect communication with his contemporaries in South America or was it all his invention?

Keywords: Solar distillation; Solar desalination; History of desalination

PT 6

Valorization of research: Perspectives and cases studies on membrane application

Najib Drouiche

CRTSE, Algiers 16038, Algeria
Tel. +213 660621509; nadjibdrouiche@yahoo.fr

Algeria is making significant strides in scientific valorization, focusing on fostering innovation through research and development. A key priority is the promotion of technology transfer, aiming to bridge the gap between scientific research and practical applications across various industries. The environmental research team at the Centre de Recherche en Technologies des Semi-conducteurs pour l'Énergétique (CRTSE) plays a vital role in this effort. Their participation in international research programs such as PRIMA which focus on sustainable water management, highlights the practical applications of scientific research in addressing environmental challenges.The team also contributes to strengthening both national and international research collaborations, working with partners to advance green technologies and improve resource management. These initiatives are designed to enhance the impact of scientific advancements, promote sustainable development, and bolster the country's technological and industrial capabilities.

Keywords: Research valorization; Technology transfer; Innovation; Research collaborations; Industrial applications

PT 7

Techno-economic analysis of solar and wind powered desalination to meet the water needs of hundred homes in Karachi, Pakistan

Qamar Abbas*, Hafiz Muhammad Ali

**King Fahd University of Petroleum and Minerals, Dhahran, 31261, Saudi Arabia*
Tel. +966 500162498; g202315910@kfupm.edu.sa

Desalination removes salts and other impurities from seawater or brackish water so that humans, agriculture or industries can use it. Desalination plants have thermal or electrical load requirements depending upon the type of desalination. This work involves the techno-economic analysis of solar and wind energy systems to run a desalination plant that can supply water for 100 homes in Karachi, Pakistan. The results showed that the solar system is more feasible for the selected location than the wind system considering the levelized cost of energy and water. It is found that the annual AC energy obtained from the solar and wind systems for the weather conditions of Karachi is ~64 MWh and ~73 MWh, respectively. The cost of desalinated water for solar and wind systems is 1.07 $/m^3$ and 1.8 $/m^3$, respectively. The designed solar and wind systems can cover the energy requirement of the desalination plant for the whole year except for January, November, and December for the solar system and February for the wind system.

Keywords: Techno-economic; Desalination; Solar powered; Wind powered; Pakistan

PT 9

String-driven rectifier for power take-off systems for harvesting energy from oscillatory forces

Mahmood Khaja Muhieitheen*, Mohammed Khair Al-Solihat

**King Fahd University of Petroleum and Minerals, Dammam 31421, Saudi Arabia*
Tel. +966 503213041; mahmoodkm3000@gmail.com

Wave energy has been one of the promising sources of renewable energy for energy experts for a long time. It overcomes the disadvantages of intermittence and unpredictability, unlike solar and wind energy resources. It also has the highest energy density in comparison to other renewable energy resources, but it is also among the least developed technologies. The reasons for this have been reported in the literature to be fewer technological developments in the past and higher energy generation costs. However, there have been significant improvements in the wave energy sector to reduce the drawbacks, making it possible for large-scale implementations.

Wave energy is harvested through devices called wave energy converters (WECs). A crucial component of WEC is the power take-off system (PTO). PTO systems are responsible for converting the wave motion to rotational motion, which then drives a generator to generate electricity. This study focuses on a string-based mechanical motion rectifier as a PTO to harvest wave energy. The strings help in reducing the weight of the overall

mechanism and thus increase energy conversion efficiency. This versatile design is applicable to not just wave energy harvesting, but to any oscillatory motion. Since it is applicable for offshore technologies, it can be an excellent choice for desalination purposes as the energy obtained can be used to pump water through membranes and then transported later for consumption. Sufficient support from literature has proved that wave energy is an excellent choice for desalination.

An initial model was conceptualized and later designed for visualization. The model involves a floating bar that oscillates with the wave, a fixed support that stays perpendicular to the surface, and two wheels attached to the arm that rotates the shaft. The wheels are incorporated with a freewheel mechanism to facilitate unidirectional rotation. A spring mechanism is fitted with the wheels to ensure the string remains tautly wound on the wheel. Later, a mathematical model was developed to study the outcome of the design. This model facilitated the theoretical validation of the system. Angular displacement and speed of the rotating shaft were obtained through MATLAB for a specific set of chosen parameters. The resulting graph was compared with existing literature and the behavior of the system was as expected. Based on the developed design, a prototype was 3D printed to validate the motion of the system mechanically.

Based on theoretical and mechanical validation, further work involves fine-tuning the current design for experimentation along with setting up the experimental apparatus to obtain the actual energy harvested for different magnitudes and frequencies of force. This design offers a lightweight, efficient, and versatile solution to harvesting energy from oscillatory sources, representing a significant step forward in renewable energy technology.

Keywords: Wave energy converter; Power take-off systems; Renewable desalination; Renewable energy; Energy conversion; Ocean energy

PT 10

Techno-economic analysis and optimization of hybrid renewable energy systems for electricity generation and desalination

Mahmood Khaja Muhieitheen*, Qamar Abbas

**King Fahd University of Petroleum and Minerals, Dammam 31421, Saudi Arabia*
Tel. +966 503213041; mahmoodkm3000@gmail.com

Electricity and fresh water are the major requirements of today's world considering the growing population and their demands. Although most of Earth is covered with water only a limited amount is fresh hence it is necessary to desalinate it which also requires electricity. The world's electricity requirements can be met by renewable and non-renewable energy sources. This study focuses on the techno-economic analysis of hybrid renewable energy systems (HRES) to meet the electricity and desalination demands of a population of 100,000 in various coastal cities of Saudi Arabia. Solar, wind, and geothermal sources are considered, with pumped hydro storage and batteries as storage components. The analysis is performed using commercial software, HOMER, with Levelized Cost of Electricity (LCOE) and Net Present Cost (NPC) as termination criteria for sizing.

The results show that pumped hydro storage is a cost-effective energy storage, making it a feasible option for optimal systems of all locations. The optimal systems integrated with pumped hydro storage exhibit the lowest LCOE ranging from 0.101 $/kWh to 0.181 $/kWh from NEOM to Lith respectively throughout the coastal cities. The energy potential of each source is a key factor in sizing the optimal systems for all locations. The lowest LCOE from all locations is for NEOM making it the most cost-effective city for electricity generation by incorporating solar, wind, and geothermal resources. Additionally, the cities with good geothermal potential showed optimal results when combined with solar energy because of good solar potential throughout the kingdom. This research contributes valuable insights into the optimal configuration of HRES for coastal cities in Saudi Arabia considering economic metrics. The results showed the versatility of hybrid systems in addressing the unique energy landscape of the region, promoting sustainable development for a growing population, and meeting the country's targets for Vision 2030.

Keywords: Renewable energy; Desalination; Co-generation; Hybrid renewable energy system; Saudi Arabia; Neom

PT 12

Membrane-based recovery and utilization of HF/HNO rinse water in photovoltaic cell manufacturing for circular economy and green hydrogen

Najib Drouiche

CRTSE, Algiers 16038, Algeria
Tel. +213 660621509; nadjibdrouiche@yahoo.fr

The photovoltaic (PV) industry, particularly the wafer cleaning process, generates significant volumes of wastewater containing hydrofluoric acid (HF) and nitric acid (HNO). This hazardous wastewater poses environmental risks and can be costly to dispose of. This research explores the potential of membrane-based technologies to recover and utilize HF/HNO rinse water within the PV manufacturing process, promoting a more circular economy and reducing environmental impact. By implementing advanced membrane processes, such as reverse osmosis and nanofiltration, HF and HNO can be selectively recovered from the wastewater. The recovered acids can be reused within the PV manufacturing process, reducing the need for fresh acid inputs and minimizing chemical waste. Furthermore, the treated wastewater can be further processed to produce green hydrogen through processes like electrolysis or microbial electrolysis cells. This study investigates the feasibility of integrating membrane-based wastewater treatment and green hydrogen production into the PV manufacturing supply chain, focusing on the recovery and reuse of HF/HNO rinse water. It evaluates the technical and economic performance of various membrane configurations and hydrogen production methods, considering factors such as acid recovery efficiency, water quality, and hydrogen yield. The research aims to demonstrate the potential of membrane technology to enable a more sustainable and circular PV industry, contributing to both environmental protection and energy security.

Keywords: HF/HNO rinse water recovery; Membrane technology; Photovoltaic cell manufacturing; Circular economy; Green hydrogen production; Water reuse

PT 16

The selection of nanofiltration membrane characteristics to purify landfill leachate and reduce concentrate

Alexei Pervov*, Viacheslav Dzyubenko[2]

**Moscow State University of Civil Engineering, 26, Yaroslavskoye Shosse, Moscow, Russia, ale-pervov@yandex.ru*
[2]JSC RM Nanotech, 224d, Dobroselskaya str., Vladimir, Russia, v.Dzyubenko@membranium.com

State of the art of landfill leachate treatment using reverse osmosis is presented. When preparing the review, the widespread use of seawater membranes is striking. This can be explained by high osmotic pressure values of leachate.

A serious disadvantage of this approach is the use of reverse osmosis high pressure membranes which leads to losses of membrane permeability and necessity of the additional treatment of the concentrate.

This approach is used in seawater desalination technologies to reduce concentrate and is known as "membrane brine concentration" (MEC) technology.

The presented research results propose the use of nanofiltration membranes instead of high pressure reverse osmosis in landfill leachate treatment application.

Not only operational costs (such as energy and membrane replacement) are compared. The value of operational costs is influenced by calcium carbonate precipitation rate, as well as fouling rates of other organic and inotganic deposits that create the hydraulic resistance increase of membrane channel. Results of investigation are presented that demonstrate that the formation of calcium carbonate is excluded when using nanofiltration membranes.

The increase and growth of hydraulic resistance of membrane channel is easily avoided by the use of modified spacer that provides an increase of area of the live section of the stream and improves it's hydrodynamic characteristics flow when suspended solids and organic fouling occur in the channel. This measure also improves the efficiency of hydraulic flushing procedures applied to destroy and remove fouling layers.

Results of determination of scaling and organic fouling rates are presented and illustrated by the SEM photos of fouling layers and their spectral analysis performed after membrane element autopsies.

Contrary the fears of experts, the main obstacle in membrane safe operation is attributed not to organic fouling and not to high COD values of feed water but to calcium carbonate "hidden" in the organic fouling layer and formed due to supersaturation conditions provided by high pressures and high membrane rejection of "seawater" membranes.

Results of economical calculations are presented that demonstrate advantages of the new proposed technology based on the use of low rejection membranes to reduce concentrate flow as compared to conventional high pressure ("seawater") membrane application.

Keywords: Reverse osmosis; Nanofiltration; Membrane rejection; Scaling; Organic fouling of membranes; Increase of hydraulic resistance of membrane channel; Membrane spacer; Improvement of membrane spacer

PT 19

PROTON®: A tool for modeling and simulation of membrane technology performance

Gabriele Brummer

American Water Chemicals, 1802 Corporate Center Ln,
Plant City, FL 33563, USA
Tel. +1 3058791623, gbrummer@membranechemicals.com

As the global demand for freshwater rises, efficient and reliable desalination methods become increasingly crucial. Reverse osmosis is a well-established technology for desalination in various industries across the globe, and a proper understanding of its hydraulic and chemical limitations is essential for stable operation. Modeling software, such as American Water Chemical's PROTON®, allows for the accurate simulation of membrane technologies, such as reverse osmosis and nanofiltration, before costly on-site testing. By providing a feedwater chemistry and a system design, PROTON® can determine the chemical speciation of the ions and complexes to accurately predict the permeate and concentrate water for a given system design. Integral to this prediction is the simulation of the hydraulic limitations in the system, including excessive fluxes, low concentrate flow rates, and elevated pressure requirements. The software also allows the user to simulate basic software-generated membrane systems or more advanced custom designs, including semi-batch reverse osmosis processes.

All this is essential in determining the fouling and scaling potential of the system for a wide range of pH and temperature conditions. Users can also see the implications of altering operational parameters such as recovery, membrane model, or pH on the scaling potential and product quality near instantaneously. Extensive post-membrane process treatment tools are also included to aid designers in understanding the downstream impacts of changes to the membrane process. Be it blending, pH adjustment, degasification, or calcite contactor, the software can simulate their impact on final product water quality, stability, and corrosivity. PROTON®'s proprietary database is continuously updated with extensive internal laboratory testing and thermodynamic data from peer-reviewed research papers to ensure the accuracy of such detailed modeling.

PROTON® can also be leveraged to determine operational expense (OPEX) impacts of changes to the treatment process, including chemical and electrical consumption and cost. Overall, the evolution of modeling and simulation software is vital for accurately forecasting and monitoring membrane system performance and ensuring optimal productivity.

PT 20

Performance evaluation of a 14-effect distillation system driven by solar heat

Behzad Shahzamanian Sichani*, Szabolcs Varga, Diego Alarcón-Padilla

INEGI, Campus of the Faculty of Engineer, Porto 4200-465, Portugal
bsichani@inegi.up.pt

Multi-effect desalination (MED) technology integrated with solar concentrators is a suitable combination for sustainable heat-driven desalination. To boost the system's performance, it can be coupled with absorption heat pumps. Experimental studies were carried out to evaluate the performance of the MED plant driven by solar energy located in the Plataforma Solar de Almería (PSA). It includes 14 effects with a forward feed configuration coupled with a double-effect absorption heat pump.

The impact of the heating water temperature (Th), top brine temperature (TBT), and temperature difference between effects (?T) on performance ratio (PR) of the MED plant was studied for the range of 60–70°C, 54-63°C and 1.1–1.6°C, respectively. PR, kg of distillate produced for every 2326 kJ of thermal energy supplied to the system, was almost constant with a variation of less than 5% and a maximum recorded value of 12.4. The results demonstrated the robustness of the system operation for the whole range of operating conditions considered.

Author gratitude is expressed to the PSA for providing access to its installations, the support of its scientific and technical staff, and the financial support of the SFERA-III project (Grant Agreement No 823802). Special thanks to the access provider staff members who ensured the access support.

Keywords: Multi-effect distillation; Performance ratio; Robustness; Solar energy

PT 21

Dual benefits of immobilized carbonic anhydrase: enhancing water quality and reducing carbon footprint in desalination processes

Veerle Vandeginste, **Philippe Tob***, Jacob Rubel, Dharmjeet Madhav

**Aqvita SRL, Avenue Louise 523, Brussels 1050, Belgium*
Tel. +32 493521434, philippe@aqvita.com

Carbonic anhydrase (CA), an enzyme that catalyzes the reversible conversion of carbon dioxide and water into bicarbonate and protons, presents a promising approach to accelerate the dissolution of carbonate salts. This dissolution is essential for remineralizing desalinated or purified water, which often lacks vital elements like calcium and magnesium. This study aims to immobilize CA on solid supports to enhance its stability, reusability, and dissolution efficiency. Moreover, this approach may reduce the carbon footprint of

seawater desalination through efficient capture and use of CO_2 in the post-treatment phase. The study used both free-flowing and immobilized enzymes. Supports tested for enzyme immobilization included epoxy resin, amino resin, and chitosan. The stability and activity of both free-flowing and immobilized enzymes were evaluated in batch and continuous flow experiments. The dissolution efficiency of dolomite, which primarily contains magnesium and calcium, was assessed under different conditions, including carbonated water and immobilized CA. Batch tests were conducted by preparing calcium carbonate ($CaCO_3$) suspensions and adding CO_2 with and without CA. The evolution of pH and calcium concentration were monitored, and the results indicated that CA significantly accelerated dolomite dissolution compared to CO_2 alone. Microbial CA showed similar performance to bovine CA. Dissolution rates varied depending on the mineral type, highlighting the importance of mineral selection in the process. Continuous flow tests simulated more practical conditions. These tests revealed that immobilization of CA on various supports reduced catalytic activity, but still enhanced dissolution rates in the presence of CO_2. Passing carbonated water through the immobilized CA and dolomite system resulted in increased calcium concentrations. Amino resin demonstrated slightly better immobilization efficiency compared to epoxy resin, but still faced challenges in maintaining high enzyme activity. Hence, immobilizing CA presents challenges, notably the loss of enzyme activity, and variable stability of enzyme-support complexes. The presence of CO_2 is crucial as CA catalyzes carbonic acid formation, aiding dolomite dissolution. To conclude, immobilized CA has potential for improving carbonate salt dissolution in water remineralization, though immobilization reduces enzyme activity. CA still enhances dissolution rates in the presence of CO_2, offering a pathway to reduce the carbon footprint of seawater desalination through efficient capture and use of CO_2 in the post-treatment phase. Future research should focus on optimizing immobilization techniques, exploring alternative supports, and improving enzyme stability and activity. This technology could lead to more cost-effective and eco-friendly solutions for producing high-quality mineral water from desalinated water, addressing global water sustainability challenges.

Keywords: Desalination; Post-treatment; Magnesium; Carbon footprint; CO_2 capture; Remineralization

PT 22

Low-energy SWRO and ultra-high recovery inland desalination with true batch processes: Singapore and Texas pilot demonstrations

Quantum Wei, **Christine Kleffner***, Jenny Smythe

Harmony Desalination, Boston, MA 02135, USA
Tel. +49 1638771857; christine@harmonydesalting.com

Our work addresses the issues of high energy consumption in seawater desalination and brine disposal costs for inland desalination. Our approach is to operate desalination membranes in a batch process, which advances the energy-efficiency of the process and prevents formation of scale. We implement this process with the use of standard desalination components in a way that is readily scalable.

We will present data from two pilot demonstrations: Energy-efficient seawater desalination (4 m^3/: Singapore) and solar-powered, ultra-high recovery of brackish well water for irrigation (50 m^3/d: Texas, USA).

The seawater reverse osmosis (SWRO) pilot is a small-scale pilot (4 m^3/d) which will precede a full-scale demonstration (1,000 m^3/d) designed to achieve <2 kWh/m^3 for the energy consumption of the whole plant. A fully batch process achieves lower energy consumption compared to other dynamic processes by avoiding the entropy of mixing. Compared to conventional RO, batch processes reduce the risk of fouling with lower peak fluxes fluxes and the ability to directly control crossflow velocity. Our aim is to reduce the levelized cost of water (LCOW) by minimizing the energy costs of seawater desalination over the lifetime of a plant.

For the other pilot demonstration, we are partnering with a small farm in Texas to desalt their well water, enabling them to grow wine grapes on a plot of arid land. For end-users like them, conventional desalination is not a viable solution due to the lack of grid power and high costs associated with brine disposal via evaporation ponds or hauling. Our solar-powered pilot will reach an ultra-high water recovery by combining a batch RO process for treatment to irrigation quality and a batch nanofiltration (NF) process for brine concentration. The use of NF membranes allows us to halve the size of the required brine evaporation pond with the use of equipment rated to standard desalination pressures (<60 bar). The inherent scaling resistance of our batch process minimizes the need to dose antiscalants.

In our batch processes the variable-pressure operation, a more balanced flux distribution, and flexible crossflow contribute to the lowest possible specific energy. Rapid salinity cycling and regular permeate backwashing allow us to surpass the water recovery rates of conventional, steady-state RO processes. Data from these pilots demonstrate that batch processes can improve the affordability of desalination across a range of scales and applications.

Keywords: Batch process; Low energy; High recovery; Seawater desalination; Inland desalination; Brine concentration

PT 24

Determining the origin of faradaic yield values greater than unity during treatment industrial wastewater by electrocoagulation

Belkacem Merzouk*, Mohammed Hamidou, Mohammed Tiaiba

**University of M'sila, Department of Hydraulics, Faculty of Technology, M'sila 28000, Algeria*
Tel. +213 772782963; belkacem.merzouk@univ-msila.dz

The faradaic aluminum yield corresponds to the ratio between the quantity of aluminum produced experimentally by oxidation of the anode, and the theoretical quantity of aluminum that should be produced according to Faraday's law.

Predicting and controlling the dissolution rate of aluminum electrodes would not only have financial benefits but would also significantly reduce the duration of preliminary kinetic studies.

The objective of this work is to understand the mechanism of aluminum oxidation in order to predict the dissolution rate of electrodes during electrocoagulation treatments. The study was carried out on the elimination of the nylosan red dye present in textile wastewater using a continuous electrocoagulation.

The results found showed that:

- The average faradaic yield values are all less than unity (1), except for the monopolar series connection (S-MP), where a value of 1.16 has been recorded.
- For alternating current (AC), the turbidity removal efficiencies were less than 15.78% at low current densities (100 and 200 A/m²) for the three connection modes (monopolar MP, bipolar BP, monopolar series MP-S). For the monopolar parallel configuration (MP-P) and with 300 A/m², the turbidity removal rate reached 56.25% after one hour of treatment. Increasing the current density to 400 and 450 A/m², allowed us to achieve a turbidity removal rate of 88.8% and 95.62%, respectively.
- or direct current (DC), the process performed well for all connection modes studied, with turbidity removal rates ranging from 94.13 to 99.42% for a current density of 100 and 300 A/m², respectively.
- he monopolar parallel configuration with 2 and 4 electrodes is the most efficient in all aspects including that of energy consumption.

Keywords: Electrocoagulation; Aluminum electrodes; Turbidity; Dye; Electrode configurations; Direct current; Alternating current; Faradaic yield

PT 26

Optimization of seawater reverse osmosis: innovations in pretreatment systems

Ratul Das*, Thomas Altmann, Yasmeen Nadreen, Graciela Gonzalez Gil, Johannes Vrouwenvelder

**ACWA Power, Innovation Cluster, 3-185, 4700 KAUST, Thuwal 23955, Saudi Arabia, Tel. +966 500699425, rdas@acwapower.com*

The Gulf Cooperation Council (GCC) is one of the most arid regions globally and faces an imminent threat of freshwater scarcity in the coming decades. Given its extensive access to seawater, desalination technologies have become indispensable for meeting the freshwater needs of the GCC's population and economy. Among these technologies, membrane-based reverse osmosis (RO) is the most prevalent within the GCC due to its efficiency and low environmental footprint. As industrialization and population growth continue to accelerate in GCC countries, reliance on seawater reverse osmosis (SWRO) is increasing. Consequently, efforts are underway to optimize existing SWRO plants and develop new ones, requiring effective plant design and process optimization to ensure long-term operational efficiency and consistent production of high-quality water.

For an SWRO plant to operate at optimal potential and consistently produce high-quality water, having an effective pretreatment system is essential. Effective pretreatment enhances the quality of seawater feed to the RO membrane by reducing fouling potential, thereby minimizing damage to the downstream RO membrane and maximizing its lifespan. This can be achieved through various pretreatment methods, including chlorination, pH adjustment, coagulation, and the dosage of antiscalants, among others.

The latest SWRO plants in operation or under construction in the GCC region use a combination of Dissolved Air Flotation (DAF) and Dual Media Filtration (DMF) as pretreatment stages in SWRO. The current filtration media used in DMFs are designed to operate at lower loading rates, which results in a large footprint, high capital expenditure, and significant civil work requirements. They also require coagulants for effective operation, but have demonstrated variable removal efficiencies of fouling components, leading to inconsistencies in RO feed quality. We present a new filtration media technology that operates at 2–3 times the loading rates of traditional media, requires no addition of chemicals, while producing high-quality filtered water. The study assesses the physical, chemical, and microbiological parameters, including the microbial growth potential (MGP) of the pretreated seawater.

Keywords: Desalination; Seawater reverse osmosis; Filtration; Coagulation

PT 27

Valorizing EC-sludge for MF kaolinite membrane fabrication: a sustainable approach for seawater pretreatment for RO desalination

Abdessamad Belgada*, Raowia Lamhar, Fatima Zohra Charik, Ibrahim Ounouss, Adil Dani, Saad Alami Younssi

University Mohammed VI Polytechnic, Lot Essabah Rue 17, Nr 14, Sidi Moumen, Casablanca 20630, Morocco
Tel. +212 660030474, abdessamad.belgada@um6p.ma

The pretreatment of raw seawater has proven to be an important factor that contributes to the optimization of seawater reverse osmosis (SWRO) desalination processes. In addition, seawater pretreatment contributes to extending lifetimes of RO membranes and improving their performance and cost-effectiveness. Many conventional processes are used for the pretreatment of raw seawater prior to RO desalination such as coagulation-flocculation and media-filtration. However, membrane-based technology, notably microfiltration (MF), exhibits many advantages over coagulation-flocculation such as high permeate flux and low cost. In particular, MF ceramic membranes have proven to be effective for seawater pretreatment for desalination. Nevertheless, the high cost of commercial membranes made of metal oxides such as alumina, zirconia, and titania, limits their use in a large scale. Therefore, the use of alternative materials (e.g., geomaterials and wastes) for the development of low-cost MF ceramic membrane is highly encouraged.

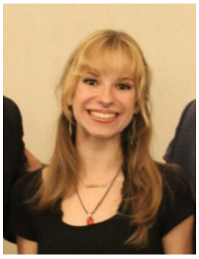
On the other hand, electrocoagulation (EC) is a water treatment process, widely used in various industries due to its outstanding ability to remediate wastewaters regardless their complex compositions. However, EC generates a highly contaminated byproduct (EC-Sludge) composed of heavy metals, ashes, dyes, and others. Subsequently, Addressing the sludge valorization through a green approach becomes crucial to transforming the EC into a resilient process.

Accordingly, this work lies in the fabrication of a low-cost MF ceramic membrane through the combination of abundant geomaterial (i.e., kaolinite) and waste (EC-Sludge). Firstly, EC-Sludge was thoroughly characterized using multiple physicochemical analyzes such as XRF, XRD, FTIR and DTA/TGA. Afterwards, specimens of the mixture of kaolinite/sludge varying waste content, up to 30 wt.% EC-Sludge, were subjected to dry pressing, and sintered at 1100°C to prepare MF flat ceramic membranes. Kaolinite/sludge membranes were characterized for mechanical resistance, porosity, pore size and permeability. The optimal kaolinite-sludge composite membrane was identified as the one containing 15 wt.% EC-Sludge. The optimal membrane exhibits outstanding features notably high mechanical strength and permeability. It was tested for the enhancement of feedwater for SWRO desalination and shows that it is able to reject up to 95% of turbidity, along with high total organic carbon (TOC) and chemical oxygen demand (COD) rejection and considerable reduction in silt density index (SDI). Fouling mechanism investigation and antifouling study were performed and demonstrated that cake filtration best describes the dominant fouling mechanism, especially in the later stages of filtration where a fouling layer or "cake" forms on the membrane surface, significantly diminishing seawater flux, yet the membrane was able to recover up to 80% of its original flux after simple water washing.

Keywords: Seawater pretreatment; Ceramic membrane; Low-cost; Waste management; Microfiltration; Desalination; Sustainability

PT 28

Predicting specific flux of ultrafiltration membranes using machine learning methods



Izzy Medeiros*, James Malley, Irina Zaikina

University of New Hampshire, 291 Long Highway,
Little Compton, RI 02837, USA
Tel. +1 4015297250; medeiros.isabel13@gmail.com

This research presents results of developing machine learning methods to inform operations staff on membrane fouling and the scheduling of cleaning practices to improve the sustainability and costs of long-term operation. PWNT operates an Ultrafiltration (UF) membrane pilot facility in Andijk, North Holland with the objective of optimizing PWN's full-scale UF facility in Heemskerk, NL. This study builds upon previous research at PWNT that investigated machine learning approaches to predict transmembrane pressure (TMP) and found that a random forest model (RF1) might have potential since it provided predictions with the lowest error of the models explored in that preliminary research. Our work first expanded RF1 (RF2) to provide operators with an estimate of TMP far enough in the future to allow ample time for scheduling the cleaning in place (CIP) procedure. Current research (RF3) employs a full-scale dataset recorded from Heemskerk's 8 UF membrane skids

to predict specific flux (SF); a value calculated by dividing membrane flux by temperature normalized TMP. SF, a more sensitive parameter than TMP, can provide a description of the state of membrane permeability with higher accuracy and is therefore more valuable to CIP scheduling, so it was chosen as the target variable.

Membrane filtration operation is strongly influenced by fouling, resulting in the decline in membrane permeability (indicated by SF) and increase TMP for a facility operating at constant flux. Persistent fouling that remains on the membrane after hydraulic backwashing must be removed with an enhanced CIP. At the pilot facility, the CIP should occur once the TMP reaches 100 kPa or when the SF is 40% less than its initial value during a filtration period. There currently is no early warning system to alert operators when this threshold has been reached, therefore, UF operators must conduct frequent checks of TMP to determine an appropriate time to conduct a CIP.

RF3 was developed in this work to improve the RF2 and RF1 model accuracies by employing a more extensive dataset (full-scale data of an entire membrane life), and by minimizing the presence of data leakage found in RF1 during research. RF1 was trained using two months of pilot-scale TMP and temperature data as operational inputs. RF2 was trained using two years of pilot-scale data, operational inputs (temperature, TMP normalized to 10 ?, feed flow) and water quality inputs (turbidity and UVT254). Despite the expansion of training data, RF2 was unable to predict future TMP beyond predicting the average TMP found during training. The pilot-scale training data was subject to setting changes and system shutoffs unexplained to the model through additional features. Thus, this work will report on the efforts of employing feature engineering and continuous full-scale data for model training of RF3 and may investigate other ML algorithms such as RNN-LSTM.

Keywords: Machine leaning; Random forest; Ultrafiltration membranes; Specific flux; Full-scale drinking water treatment data

PT 29

Microwave-synthesized 3D manganese oxide monoliths for efficient lithium extraction from geothermal brine

Omar Jair Licea Martínez, Lenka Svecova,
Jair Fernando Rangel Sequeda, Luis Mario González Rodríguez,
Gloria Lourdes Dimas Rivera, Ladislao Sandoval Rangel,
Gerardo Antonio Flores Escamilla, Ricardo Briones Martínez,
Carlos Enrique Escárcega González, **David De Haro Del Rio***

**Tecnológico de Monterrey, Garza Sada, Monterrey 64849, Mexico
Tel. +52 4949499033, deharo@tec.mx*

This study presents the formation of a stable 3D monolith based on manganese oxide for the adsorption of lithium from real brine sourced from a Mexican geothermal site. The precursor phase was prepared using microwave-assisted hydrothermal synthesis followed by calcination to achieve the desired crystalline phase, $LiMn_2O_4$. The monolith was formed

using additive manufacturing, allowing precise control over its size and shape. It was then washed with HCl to generate adsorption sites for lithium. The materials were characterized by XRD, FTIR, TGA, N_2 physisorption, and SEM-EDS, confirming the retention of the crystalline structure throughout the process. The kinetic characteristics of the adsorption process were evaluated using pseudo-first and pseudo-second order equations, as well as Freundlich and Langmuir equations to describe thermodynamic equilibrium. The monoliths demonstrated a lithium adsorption capacity of up to 13.84 mg/g, with the Freundlich equation (R^2=0.9751) describing the equilibrium and the pseudo-second order equation (R^2=0.9130) best describing the kinetic behavior. The results showed that the monoliths are selective towards lithium even in the presence of competing cations. The stability of the materials was evaluated through adsorption-desorption cycles, demonstrating competitive reuse after five cycles. This research introduces a promising new approach for developing efficient and sustainable lithium extraction methods from geothermal brine, highlighting the potential for practical applications in the field of desalination and resource recovery.

Keywords: Lithium adsorption; 3D printing. Microwave-assisted synthesis; Geothermal brine; Environmental sustainability

PT 30

Modeling of mass transfer dynamics in spacer-filled channels in membrane processes using direct numerical simulations

Santiago Cespedes*, Bastiaan Blankert, Cristian Picioreanu

**KAUST, Thuwal 23955, Saudi Arabia*
santiago.cespedeszuluaga@kaust.edu.sa

Fundamental understanding of mass transfer in feed spacer-filled channels is crucial for improving desalination processes such as Reverse Osmosis (RO) and Nanofiltration (NF). Furthermore, dynamics conditions are common to these membrane processes due to the presence of spacers and changes in the hydrodynamics. The mass transfer coefficients are mostly evaluated through traditional correlations involving dimensionless numbers, such as Reynolds (Re) and Schmidt (Sc). However, most of these correlations give global values, overlooking the local distribution of water flux, solute flux, concentration on the membrane and the effect of possible dynamics behavior such as vortices. Direct Numerical Simulations (DNS) allow to study these local variables and evaluate their effect on the solute mass transfer coefficients. We computed local and global mass transfer coefficients with a 3D Direct Numerical Simulation model for spacer-filled feed RO and NF channels, by coupling hydrodynamics with the solute transport (convection/diffusion) and permeation through the membrane. Accurate spacer geometries were obtained by CT-scans of commercial spacers. The geometry construction was done through MATLAB code processing the 3D CT scan of one representative spacer unit and then creating arrays of various lengths. The DNS model was implemented and solved in ANSYS Fluent 2023R2. We evaluated different hydrodynamic conditions considering changes in channel height, spacer position and flow velocity. The numerical results were compared with mass transfer coefficients determined experimentally in standardized flow cells ("membrane

fouling simulator", MFS type), filled with commercially available feed and permeate spacers. In the experiments, the transmembrane pressure and cross-flow velocity were varied systematically. Several improvements have been made in the design of the experiments, providing more reliable values of the mass transfer coefficients, with details reported elsewhere. In general, models show non-uniform distributions of concentration and mass transfer coefficients on the membrane surface. It was found numerically that while a fully developed flow establishes within 1 cm from the inlet, the mass transfer coefficients reach quasi-steady values only over lengths <20 cm, in typical operation conditions. The 3D models allow obtaining useful correlations even at dynamic conditions, and the results can be comparable with those found by experimental evaluation. However, much care should be taken when comparing model with experiments, because of many influential factors: the way mass transfer coefficients are defined, types of boundary conditions (permeation or not), numerical accuracy and mesh convergence.

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

PT 31

Optimization of complex RO system design using AquaGRID

Harish Warsono*, Yoshiyuki Kawashima

Toray Membrane Middle East LLC, Al Khobar 31952, Saudi Arabia
Tel. +966 536689012, harish.warsono.p6@mail.toray

Most of RO system has always been designed using RO projection software using a limited template of common design: 1 Pass and 2 Pass RO system, including their slight variation.

AquaGRID, the latest RO projection software from TORAY membrane, has been contributing to the industry to be the only software that, with its high level of flexibility, is able to accommodate a more complex RO design that enable user to pursue a more energy efficient design.

With the higher complexity in the design, sometime more effort need to be done in the thorough process of optimization. Users need to execute enormous number of cases with multiple parameters to ensure the design is matching the requirement.

Therefore, a new function has been developed to enable operation to seek the optimum parameter for a specific case, as well as to allow the execution of multiple operation cases while seeking for the best parameter under certain specified condition.

In this paper, we will elaborate how far this new function will help the optimization of the design process that save a significant amount of time of the designer to reach the most efficient design. And it is confirmed that with this new function, AquaGRID can help user to conduct the optimization process efficiently, regardless the complexity of the design, including the common 2 Pass RO system.

Keywords: RO projection software; Complex system; Simulation

PT 33

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

Lutz zur Linde, Gerhard Lang

Herrenknecht AG, Schlehenweg 2, Schwanau-Allmannsweier 77963, Germany
Tel. +49 151 16346377, lang.gerhard@herrenknecht.de

Due to water scarcity, seawater desalination plants are being built all over the globe. The installation of shore approaches for the seawater intake and brine outlet lines are a major part in desalination plant construction. Construction works in coastal areas can have significant environmental impact and are therefore getting more and more public attention. Trenchless solutions are indispensable to minimize environmental impact and achieve public acceptance of large and medium-sized seawater desalination projects. Microtunnelling technologies, including conventional pipe jacking and Direct Pipe, are the most widespread techniques to construct tunnels or install pipelines from onshore to offshore with subsequent subsea recovery of the tunnel boring machine. These microtunnelling methods have been considerably further developed in recent years to enable longer drives and safe installation, reducing the share of required offshore operations to a minimum.

An important milestone has been achieved in Kuwait in 2022, where a 1,960 m pipe jacking sea outfall (ID 2200 mm) has been completed. This tunnel forms part of the Umm Al Hayman Wastewater Treatment Project and is one of the longest pipe jacked tunnels in the world. It has been constructed using an upskinned AVN2000AB for pipe jacking. With Direct Pipe, pipelines can be installed from onshore to offshore in one single step, in diameters from 24” to 60”. The record installation length of Direct Pipe has been achieved in New Zealand on a 2,021 m long shore approach for a sewer pipe installation.

This paper will share the latest innovations and case studies of slurry microtunnelling in desalination projects, as successful references create trust with clients and planners, with positive impact on planning opportunities and subsequent project execution.

Keywords: Trenchless shore approach; Microtunnelling; Desalination plant construction

PT 35

On-site demonstration of a robust rotary energy recovery device

Francesco Giuseppe Ladisa*, Victor Ruiz, Juan De Salas

**Flowserve, Coslada 28823, Spain*
Tel. +34 661104442, email: fladisa@flowserve.com

In designing modern desalination plants, reliability, energy consumption, and system availability are major drivers. This manuscript will describe the demonstration of the robustness of 7 Flowserve FLEX™ rotary energy recovery devices after 15,000 h of operation

in a seawater reverse osmosis desalination plant in Canary Island, Spain. A robust design with fewer parts, minimal maintenance and reduced footprint was considered a critical element to ensure the reliable operation of the energy recovery device.

In the world of desalination and water reuse, choosing the right materials for durable systems is crucial for efficiency and long-term performance. This presentation dives into the world of material science, spotlighting the Flowserve FLEX™ split configuration and casted Titanium made casing - an innovative material choice for robust desalination systems as well as a patented axle positioning rotor configuration for its internal high purity ceramic core.

This presentation offers a unique opportunity to share and discuss the results obtained from plant's operational experience. The focus remains on providing valuable insights into the practical implications and performance benchmarks achieved through sustained operation. Through a detailed examination of operational data and material performance, this presentation aims to contribute to the broader discourse on advancing desalination technologies, fostering sustainable solutions for global water challenges.

Keywords: FLEX; ERD; Energy recovery device; Maintenance; Footprint

PT 37

The influence of water permeability, solute resistance and mass transfer coefficient on water flux behavior in forward osmosis

Abdulrahman Alalawi*, Ibrahim Al-Mutaz, Nawaf Bin Darwish

**King Abdulaziz City for Science and Technology, Riyadh 12354, Saudi Arabia*
Tel. +966 566985835, aalalawi@kacst.gov.sa

Forward osmosis (FO) is an innovative membrane process with growing potential. Mathematical models for predicting water flux in forward osmosis (FO) are valuable for understanding the system behavior and helpful in optimizing the performance. This work explores the relationship between water flux and some key factors, namely water permeability, solute resistance and mass transfer coefficient which affecting the water flux behavior. The influence of these parameters on water flux behavior is analyzed, highlighting how water permeability governs the water transport capacity, solute resistance dictates the rejection of solutes, and the mass transfer coefficient reflects the impact of external boundary layers.

Keywords: Forward osmosis; Permeation flux; Water flux; Water flux behavior; FO desalination

PT 38

Unidirectional porous membrane prepared by combined crystallization and diffusion method for desalination

M Asipi Qostolani*, Mohammed Abdul Azeem, Turki Nabieh Baroud

King Fahd University of Petroleum and Minerals, Student housing street, KFUPM, Dhahran 34463, Saudi Arabia
Tel. +966 501884998, g202203560@kfupm.edu.sa

Membrane distillation is a promising solution for sustainable water management, specifically in high salinity desalination application. This study aims to apply, optimize and modify PVDF membranes using the Combined crystallization and diffusion (CCD) inspired by freeze casting or ice templating. This technique is capable to produce unidirectional porous membranes that suitable for water filtration applications. By systemically varying key parameters, including solution and additive concentration, temperature of freezing, we aimed to enhance the performance of PVDF membrane for membrane distillation.

The optimized membranes demonstrated significant performance improvement, achieving the highest flux of 21.7 kg $m^{-2}h^{-1}$, while maintaining a salt rejection of 99.5% for 24 h in water gap membrane distillation. In contrast, NIPS PVDF membrane exhibited a flux of 9.17 kg $m^{-2}h^{-1}$ with salt rejection of 96.7%. This represents improvement in flux compared to NIPS method. Additionally, the membranes exhibited a larger pore size distribution and a slightly enhanced water contact angle. Scanning electron microscopy (SEM), atomic electron microscopy (AFM), and Fourier transform infrared spectroscopy were utilized to characterize the membrane. These results indicate the modified membranes are promising candidates for efficient membrane distillation in high saline water desalination, offering higher flux and stable salt rejection.

Keywords: Membranes; CCD; Flux; PVDF; Unidirectional porous

PT 39

Desalination for decarbonized fertilizer production: a comparative analysis of seawaters in the MENA region using MLD strategies

Nikhil Dilip Pawar*, Thomas Pregger, Patrick Jochem

**DLR, Stuttgart 70565, Germany*
Tel. +49 178 8905566, nikhilpawar132@gmail.com

The Middle East and North Africa (MENA) region is the world's most water-stressed area, with 83% of its population facing extremely high-water stress [1], exacerbating tensions between domestic, agricultural, and industrial sectors [1] in a region also struggling with low food self-sufficiency rates [2].

While fertilizer application can enhance crop yields [3], its production is currently energy- and water-intensive [4], [5]. Decarbonizing this sector requires renewable hydrogen, produced using ultrapure water (UPW). Co-locating a fertilizer plant with a seawater desalination facility creates synergies by providing potable water, UPW, mineral recovery opportunities in an eco-friendly approach [6], and demand-side flexibility to renewable energy production.

This study models and extends the nanofiltration-reverse osmosis-membrane brine concentration (NF-RO-MBC) plant configuration [6] to meet the water demand of a fertilizer plant at minimum liquid discharge (MLD) while recovering valuable minerals like magnesium hydroxide ($Mg(OH)_2$) and sodium chloride (NaCl). A novel hybrid method for levelized cost calculation of individual products is introduced, allowing us to assign costs without assuming revenue from remaining products.

We compared the results for two seawaters in the MENA region: the Arabian Gulf and the Eastern Mediterranean. Our analysis for a 2500 m^3 feed/h plant shows that the extended NF-RO-MBC plant at the Mediterranean sea requires 14.5% less electricity than its counterpart in the Arabian Gulf. While the levelized costs of potable water & UPW are marginally lower for the Mediterranean sea, NaCl production is approximately 4% more costly. The recovery of $Mg(OH)_2$ at about 600 USD/ton was associated with large NaOH requirement and a significantly higher brine generation as compared to that of NaCl. A sensitivity analysis revealed that the weighted average cost of capital and cost of sodium hydroxide (a raw material for $Mg(OH)_2$ recovery) are critical parameters.

Future studies should investigate demand flexibility and cost dynamics of such configurations in operation with renewables.

Keywords: Seawater desalination; NF-RO-MBC system; Minimum liquid discharge (MLD); Decarbonization of fertilizer production; MENA region

References

[1] Samantha Kuzma, et al., 25 Countries, Housing One-Quarter of the Population, Face Extremely High Water Stress, 2023.
[2] S.-H. Lee, et al., Assessment of food trade impacts on water, food, and land security in the MENA region, Hydrol. Earth Syst. Sci., 23(1) (2019).
[3] W. M. Stewart, et al., Food security and the role of fertilizer in supporting it, Procedia Engineering, 46 (2012) 76–82, .
[4] C. Bhushan, et al., Green urea: economic and environmental benefits of a low carbon future, International Forum for Environment, Sustainability and Technology (iFOREST).
[5] S. Narain et al., GRAIN BY GRAIN: Green Rating of the fertilizer sector, 2019.
[6] A.S. Al-Amoudi, et al., Dual brine concentration for the beneficial use of two concentrate streams from desalination plant - Concept proposal and pilot plant demonstration, Desalination, 564 (2023) 116789.

PT 40

MOFs based membranes for industrial wastewater (IWW) treatment by electrodialysis (ED) technologies

Eugenia Pilar Quirós-Díez*, Alberto Maimone, Xuefei Yang, David Carvajal, Cristina Martínez

Fundación CETIM, Parque empresarial de Alvedro, Rúa H, 20, Culleredo 15180 Spain
Tel. +34 881 105 624 (Ext. 2) equiros@cetim.es

The increasing demand for water across urban, rural, and industrial areas presents significant ecological and economic challenges for water management. Additionally, many industrial processes consume vast amounts of water, generating large volumes of wastewater (WW) or spent streams that contain both contaminants and valuable resources. Addressing these issues, the RESURGENCE EU project focuses on advancing industrial circular water systems through a comprehensive approach. This includes implementing efficient technologies (membranes, electrochemical technologies, adsorbents, advanced oxidation processes and hybrid biological systems) for water reuse, energy, and feedstock recovery, all aimed at supporting the EU's goal of achieving climate neutrality.

Among all technologies explored, this study specifically focuses on the synthesis and evaluation of MOF-based membranes for the recovery of phosphate, a Critical Raw Material, from the WW generated by the steel industry, using electrodialysis (ED). Metal-organic frameworks (MOFs), a class of porous materials, are characterised by their customizable pore sizes, high porosity, and large specific surface areas, which makes them interesting for water treatment technologies. In particular, ED measurements are one of the newest processes for WW treatment. It can be characterised for low energy consumption and high recovery rates (~95%). In the last years, the use of MOF-based membranes in ED applications have been in the spotlight. This could be due for their intrinsic properties (different size holes, structural variety, etc) which makes them ideal for the selectively recovery of different compounds from the WW.

According to this, ZIF-8, MIL-53, MIL-125, UiO-66, UiO-66-NH2, MIL-101, ZIF-67 based membranes were obtained by different methods including direct grow, Mixed Matrix Membranes (MMMs) and filtration. Their surface, thickness and composition were analysed by SEM/EDX and XRD measurements. The permselectivity (P), resistance (R), and water uptake (Wup) of the membranes under zero electrical current conditions were analysed to assess their performance in phosphate separation. Finally, the performance of the membranes as anion exchange materials (AEM) in ED technologies for selective phosphate recovery was systematically evaluated using synthetic industrial wastewater (IWW) of varying compositions. In preliminary results, a 98% of phosphate recuperation have been reached.

In conclusion, various synthetic approaches have been explored to investigate the potential of MOF-based membranes for application in ED technologies. This study provides a foundational framework for advancing membrane engineering technologies obtaining a highly selective performance for phosphate anions.

Keywords: MOFs; Electrodialysis; IWW; Phosphate

PT 41

Biomass-derived carbon and carbon nanofibers integrated electrospun Janus membranes: a new frontier in membrane distillation

Md. Emdad Hossain*, Turki N. Baroud, Md. Abdul Aziz

**King Fahd University of Petroleum and Minerals, P.O. Box 5040, Dhahran 31261, Saudi Arabia*
Tel. +966 532730241, emdadulhaque.tex@gmail.com

Membrane distillation (MD) is an innovative desalination technique that utilizes low-grade energy to extract water vapor from saline solutions. In thermally driven MD systems, optimizing heat transfer while maximizing mass transport is crucial. In this study, we developed dual-layered electrospun Janus nanofibrous membranes with asymmetric wettability. The membrane consists of a hydrophilic bottom layer made of PVDF-co-HFP combined with biomass-derived jute carbon particles (PH/JC), and a hydrophobic top layer formed with PH/carbon nanofibers (PH/CNF). We investigated the impact of various carbon nanoparticles on the membranes by examining their chemical structure, morphology, water contact angle (WCA), pore size, porosity, thickness, liquid entry pressure, and mechanical and thermal stability. The optimal hydrophobic layer achieved a WCA of 138° while the hydrophilic layer measured 72°. The best-performing Janus membrane, composed of PH-0.5CNF/PH-0.5JC, exhibited a remarkable water flux of 71.72 kg m^2h^{-1} (a 162% increase compared to the pristine PH membrane) and a salt rejection rate of 99.98% during water gap membrane distillation. Additionally, it demonstrated stability over 50 h with real seawater, showcasing resistance to scaling and fouling. The proposed strategies provide a novel approach to fabricating Janus membranes, and their performance highlights a strong potential candidate for commercial water desalination plants.

Keywords: Biomass-derived carbon; Carbon nanofibers; Electrospinning; Janus membranes; WGMD

PT 42

Maven brine mining plant – 1st commercial OARO project in the world

İlker Akbas, Francisco Jimenez-Castellanos*, **Georg Herborg**

**Danfoss, Cordoba 14006, Spain*
Francisco.jimenez-castellanos@danfoss.com

I. Introduction

Desalination is crucial to securing freshwater supplies for a growing global population. However, the increase in desalinated water production also results in brine, a by-product typically discarded into the sea. With stricter environmental regulations, brine mining has emerged as a sustainable way to extract valuable minerals from brine, reducing its environmental impact. Membrane brine concentrator technologies are seen as better alternatives to thermal processes, offering energy efficiency and lower carbon footprints compared to conventional zero liquid discharge (ZLD) methods.

This study explores the innovative Osmotically Assisted Reverse Osmosis (OARO) technology, used in the world's first commercial brine mining project. The paper examines the technology's design and its impact on operational efficiency and energy consumption.

II. Research

Osmotically Assisted Reverse Osmosis (OARO) is designed to concentrate brine at typical SWRO pressures allowing for decades of proven equipment. Standard membranes can only concentrate brine up to 85,000 ppm at 80 bar, while OARO can achieve up to 250,000 ppm at 70 bar. This efficiency makes OARO a suitable solution for both desalination and brine mining applications.

OARO's integration into reverse osmosis systems allows for enhanced energy efficiency and water recovery. Hyrec has been developing this technology since 2018, with a near-commercial demonstration plant operating in Umlujj, Saudi Arabia. The plant has produced 6 tons of salt and 220 m^3 of desalinated water daily, demonstrating the technology's feasibility.

III. Results and Conclusion

In Indonesia, the OARO project aims to produce 220,000 tons of salt and 25,000 m^3 of desalinated water daily. The plant's development involved comparing three membrane designs for Seawater Reverse Osmosis (SWRO) and brine concentration processes to determine the most efficient configuration. By using OARO technology in combination with axial piston pumps and isobaric energy recovery devices, the project achieved the best specific energy consumption making it the most energy-efficient solution for brine concentration.

The OARO system integrates with standard seawater reverse osmosis technologies, allowing for significant energy savings and improved operational efficiency. The system's overall recovery rate is 78%, with a power consumption of 9.5 kWh/m^3 for brine concentration.

Conclusion

OARO technology offers significant improvements in energy efficiency and sustainability in brine management. By utilizing proven desalination components and reducing operational costs, the technology ensures the long-term viability of brine mining projects. This success marks a key step toward more sustainable and economically viable desalination and brine mining processes.

Keywords: Brine mining; OARO; Efficiency; High-pressure pumps; Energy recovery devices; Salt production

PT 43

Optimizing SWRO: single vs. new innovative multiple stages designs

Francisco Jimenez-Castellanos*, **Georg Herborg**

**Danfoss, Cordoba 14006, Spain*
Francisco.jimenez-castellanos@danfoss.com

The ongoing pursuit of optimization in seawater reverse osmosis (SWRO) systems has brought the debate between single-stage and multi-stage configurations to the forefront of the desalination community. Increasing recovery rates has become a key focus, as it could reduce CAPEX/OPEX associated with intake systems and pre-treatment. This potential for cost savings is driving attention to system design choices, particularly as high-pressure RO (up to 124 bar) technology gains traction.

The decision between single-stage and multi-stage systems, as well as standard RO versus high-pressure RO designs, depends on multiple parameters, such as:

- Membrane replacement costs and frequency.
- Capital investment for plant design and construction.
- Energy costs and operational efficiency.
- Variability in operational conditions.

This study presents a comprehensive theoretical benchmark comparing various single-stage and two-stage SWRO system configurations. The analysis explores the advantages, challenges, and trade-offs of adopting high-pressure RO designs under varying operational scenarios.

GenSave-Isobaric Hybrid Design: a novel approach

Central to this work is the introduction of an innovative two-stage hybrid system design combining:

1. Axial Piston Pump (APP) for Interstage Boosting: Positive displacement technology that ensures high efficiency and flexibility under variable pressure and flow conditions. Its modular design supports consistent performance and simplifies plant scalability.
2. APP Energy Recovery: Acting as control valve with a built-in ERD which recovers energy from the concentrate stream, optimizing energy consumption and saving costs especially for multi-stage designs.
3. Active Isobaric Energy Recovery Devices (ERDs): Isobaric are renowned for their efficiency in desalination, ERDs equipped with precise motor control enable unprecedentedly low and consistent salinity increase values, reducing high-pressure pump demands and overall plant energy consumption.

This hybrid system effectively combines the benefits of multi-stage configurations with the operational advantages of high-pressure RO. Field measurements and simulations demonstrate its potential to optimize recovery rates, reduce energy costs, and simplify plant operations, ultimately lowering the cost of water.

This study underscores how the integration of APP and ERD technologies offers a scalable, efficient solution for modern SWRO plants, setting a new standard for performance and cost-effectiveness in desalination.

Keywords: Seawater reverse osmosis (SWRO); Energy efficiency; Multi-stage RO design; Axial piston pump (APP); Energy recovery devices (ERD); Cost reduction in desalination

PT 44

Polysulfone support modifications for high-flux nanofiltration: applications in desalination and micropollutant control

Elham Saud Alkhulaify, **Shehzada M. Sajid Jillani***, Khalid Alhooshani

**King Fahd University of Petroleum and Minerals, Dhahran 31261, Saudi Arabia Tel. +966 542897795, shehzada.m.jillani@kfupm.edu.sa*

The demand for potable water is increasing globally. Drinkable pollutant free water is the need of this recent era. Various technologies have been adopted for this purpose. Membrane based approaches have been found the most energy efficient. Whereby, nanofiltration is known for rejecting most of the divalent salts and emerging micropollutants. Membrane based approaches are known for water-flux tradeoff. This work has been designed to achieve higher flux without compromising the rejection of the salts and micropollutants. Polysulfone is known for its hydrophobic character, therefore, a hydrophobic diamine is utilized to modify the polysulfone support layer. The polysulfone and hydrophobic diamine were dissolved into dimethylacetamide solvent. This dope solution was then cast as thin layer over PET non-woven support. Later, typical interfacial polymerization of nanofiltration membranes was completed using piperazine and trimesoyl chloride. The diamine present inside the polysulfone support may also contribute to the formation of the active layer. Therefore, the resulting membrane performed differently than the primitive membrane. Various characterization tests were conducted to see morphology, chemistry, roughness, and the hydrophilicity of the membrane. It includes SEM, EDX, FTIR, AFM, WCA. The membranes have been tested using crossflow filtration machines at various feed pressures and results were found highly encouraging. The best optimized membrane has shown 30% higher permeated flux than the primitive membrane. The rejection of the salts was similar to the primitive membrane while the new membranes rejected the pharmaceutical drugs better than the primitive nanofiltration membrane.

Keywords: Desalination; Modified polysulfone; Higher flux; Low cost; Micropollutant rejection

PT 45

Exploring the effects of feed and permeate temperatures on fouling and wetting of PTFE membranes within membrane distillation

Atefeh Tizchang*, Itzel Alcaraz Bernades, Wolfgang Gernjak, Morgan Abily

The Catalan Institute for Water Research (ICRA), Carrer Emili Grahit, 101, 17003 Girona, Spain, Tel. +34 627424988, atizchang@icra.cat

Technological advancements have introduced innovative solutions to enhance water circularity and promote water reuse. Industrial wastewater reuse is of great significance due to its impact on fostering a sustainable environment. Surfactants are common components that are present in industrial wastewater since they are used in the production of many products such as paints, pesticides, plastics etc. One of the novel green technologies for the treatment of industrial wastewater containing such pollutants is membrane distillation (MD). MD processes are thermally driven separation processes that can utilize low-grade heat sources such as waste heat or renewable energy. However, they usually suffer from two main drawbacks that constrain their full-scale deployment. One is their high energy requirements compared to pressure-driven processes, and the second is unstable operation due to fouling and wetting in comparison to other membrane processes.

In this work that is funded by the EC-funded iWAYS project (grant agreement: 958274), an initiative that promotes the reuse of waste heat, we performed a set of experiments on a commercial PTFE membrane for a saline feed solution containing three different concentrations of non-ionic surfactant agent called Octylphenol polyethoxyethanol (Tritin X-100) to systematically investigate the fouling and wetting behavior of the membrane as a function of feed and permeate temperatures. All the experiments have been performed in the presence and absence of NaCl. The results showed that for all the surfactant concentrations in presence and absence of NaCl, increasing the feed temperature can lead to higher permeate flux but shorter overall operation time, which was due to the potential wetting in the membrane. However, in the absence of NaCl in the feed solution, the wetting and fouling phenomena happened later which showed that inorganic salinity and organic contaminants do interact, which directly impacts process performance.

Keywords: Membrane distillation; Surfactant; Membrane wetting; Membrane fouling

PT 46

Maximize energy efficiency: parallel axial piston pumps and active energy recovery devices

Francisco Jimenez-Castellanos

Danfoss, Cordoba 14006, Spain
Francisco.jimenez-castellanos@danfoss.com

Reverse osmosis (RO) is the leading technology for seawater desalination, yet energy demands remain a primary challenge, constituting the majority of operational costs. This study showcases field measurements demonstrating how the combination of Axial Piston (AP) pumps and the Danfoss MPE 70 Active Isobaric Energy Recovery Device (ERD) achieves the most efficient plant. Together, these technologies optimize energy consumption, enhance operational flexibility, and set a benchmark for performance in the desalination industry.

Axial piston pumps

AP pumps, based on positive displacement technology, excel in delivering consistent energy efficiency under varying operational conditions. Field data reveals:

- Efficiency: AP pumps maintain efficiencies of up to 91.6%, even with 36% pressure and 25% flow variations.
- Modularity: Installing modular AP pumps in parallel ensures consistent performance, simplifies plant design, and reduces operational costs.
- Flexibility: Seamless adaptation to salinity, temperature, and production changes without compromising efficiency.

Active ERD (MPE 70) performance

Isobaric energy recovery devices have proven to be the most efficient technology for desalination plants, making them the best choice for achieving the lowest Specific Energy Consumption. The Danfoss MPE 70, with its integrated motor, offers precise performance control, enabling plants to achieve incredibly low salinity levels and maintain them consistently throughout their operational lifetime.

Conclusion

The combination of AP pumps and the MPE 70 ERD enables unmatched efficiency in SWRO plants. Together, these technologies optimize energy consumption, reduce operational complexity, and enhance reliability, setting a new standard for sustainable desalination. This study presents field data that underscores how these solutions work in tandem to deliver transformative results, making desalination plants more efficient and cost-effective than ever before.

Keywords: HPP; Axial piston pumps; Efficiency; SWRO; Modularity; Positive displacement

PT 47

Chlorine-resistant membrane phosphate zeolite nanofiltration for sustainable water treatment

Mahmoud Barakat*, Muhammad Sajid Jillani, Elham Alkhulaify, Saheed Ganiyua, Isam Aljundi, Khalid Alhooshani

**King Fahd University of Petroleum and Minerals, Dhahran 31260, Saudi Arabia, mahmmodbrakat@gmail.com*

Membrane-based filtration systems offer a more energy-efficient alternative to traditional desalination. Still, they face challenges such as the flux-rejection trade-off, where higher water flux reduces salt rejection efficiency. Additionally, persistent micropollutants like pharmaceuticals often remain untreated. Chlorination further complicates this by degrading the polyamide layer of nanofiltration membranes, reducing their efficiency and lifespan. To solve these issues, high-flux membranes with robust salt and micropollutant rejection and chlorine resistance are essential. This study explores SAPO-34 for improving flux, salt and micropollutant rejection, and chlorine resistance.

The experimental work included synthesizing and functionalizing SAPO-34 and fabricating thin-film nanocomposite membranes. Characterization and performance tests for flux, rejection of salt and pharmaceutical drugs, and the resistance of chlorine. Three membranes were conducted on a primitive piperazine-TMC membrane and two SAPO-34-modified membranes (0.025%, 0.05% and 0.1% loadings). The modified membranes demonstrated double the flux of the primitive one, with equal or superior rejection, and showed a high chlorine resistance.

Keywords: High flux; Chlorine resistant; Divalent selective; SAPO-34; Desalination; Water pollution

PT 48

Recovery of interest chemicals and industrial water reuse by means of bipolar electrodialysis

Maroš Grošík

*MemBrain s.r.o., Pod Vinicí 87, Stráž pod Ralskem 47127, Czech Republic
Tel. +420-773-674-855, maros.grosik@membrain.cz*

Surface treatment processes are an integral part of many industries that deal with improving the surface properties of materials such as metals. For surface treatment, acid pickling is often used. When the pickling bath is depleted, the acid is usually replaced by the fresh one. This generates a significant amount of liquid waste which is difficult to treat before the discharge because of its low pH, high TDS and dissolved metal content. This project aimed at evaluation of the possibility of using chemical precipitation followed by bipolar electrodialysis (EDBM) for recovery of dissolved metals, acid and base and at significant reduction of TDS in the industrial wastewater.

A sample of an industrial wastewater (spent pickling bath) was processed by chemical precipitation with sodium hydroxide NaOH. The pH was adjusted gradually to the alkali region to isolate the metals separately. In the next step, the pure filtrate was treated by EDBM to recover the acid and base, and to obtain a diluate with significantly lower TDS. EDBM module was assembled using homogeneous monopolar membranes Fumasep® and homogeneous bipolar membranes GCTR.

The tests revealed high NaOH (10% wt.) consumption of 2.52 kg per 1 kg of wastewater. Selective separation of metals (Zn, Fe and Ni) was achieved by gradual increase of pH. During EDBM tests, the conductivity of the NaOH concentrate was maintained at 230–250 mS/cm which corresponds to NaOH concentration about 6.4% wt. (1.7 mol/L). The second product was a mixture of HCl and H_2SO_4 with a conductivity of 450–500 mS/cm, resulting in an acid concentration of up to 5.9% wt. (1.7 mol/L). A TDS reduction of more than 92% was also achieved. The combination of chemical precipitation and bipolar electrodialysis provides several benefits, which are:

1. preparation of acid suitable for recycling back to the pickling bath,
2. separation of metals with the possibility of further use,
3. substatial economic benefit in the form of reduced payments for TDS discharges and external solid or liquid waste disposal.

Keywords: Bipolar electrodialysis; Wastewater; Acid and base recovery; TDS reduction

PT 51

Innovative testbed for desalination brine valorisation: circular economy and NF-OARO synergies from Desal+ Living Lab

Ángel Rivero Falcón*, Yanira López López, Baltasar Peñate Suárez, Noemi Melián Martel

**Canary Islands Institute of Technology (ITC), Santa Lucía de Tirajana 35119, Spain*
Tel. +34 928727584, ariverof@itccanarias.org

Water reuse, including brine valorisation from desalination plants, is a key pillar of Circular Economy policies across Europe. Within this context, the Canary Islands Institute of Technology (ITC) has established a Brine valorisation open testbed, integrated into the DESAL+ Living Lab platform in Pozo Izquierdo, Gran Canaria (Spain). This initiative not only aims to provide a space for ITC's research work, using innovative pilot plants, but also offers external companies with a unique opportunity to test disruptive technologies in a real-world environment with diverse brine inputs.

This work presents new developments in ITC´s research. The Nanofiltration (NF) pilot plant features a new energy recovery device, an in-line hardness analyser, and the usage of a 2-stage RO brine as feed. Long-term evaluation tests have also been conducted. Similarly, the Osmotically Assisted Reverse Osmosis (OARO) pilot plant also incorporates an energy recovery device and a new heat exchanger, which enables extended performance assessments. A comparative study between these pilot systems and a large-scale plant underscore the critical role of pilot-scale validations in optimizing operational reliability, cost-effectiveness and scalability.

In parallel, two new initiatives are underway in collaboration with innovative start-ups to test brine valorisation processes. These companies focus on electrochemical brine treatment coupled with CO_2 capture, contributing to sustainable advancements in the sector. These developments and synergies underscore the critical role of public-private cooperation in driving innovation and highlighting the potential for disruptive technologies to reshape the desalination industry.

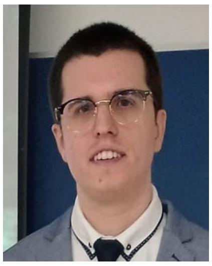
ITC´s findings and collaborations reaffirm the vital role of pilot scale research and cooperative frameworks in overcoming the challenges of brine valorisation. This work positions the open testbed as a pioneering hub for innovation, integrating scientific excellence with industry engagement, aiming to shape a sustainable future for desalination and brine valorisation systems.

This work has been supported by HORIZON EUROPE program through the SOL2H2O project (GA Number: 101079305); and INTERREG MAC 2021–2027 program through the IDIWATER project (1/MAC/1/1.1/0022).

Keywords: Desalination brine; Seawater reverse osmosis; Brine mining; Industrial valorisation; Open testbed; Nanofiltration; OARO; Pilot plants

PT 52

Sustainable cleaning procedures for fouling removal in reverse osmosis plants



Núria Adroer*, **Alex Pascual-Esco**, Jordi Aumatell, Paula Sagué, J. Ignacio Ramos, João Lourenço, Hugo Pereira, Aurélie Biurrarena

ADIQUIMICA S.A., C/ d'Albert Llanas, 32, Barcelona, 08024, Spain
Tel. +34 932846665, nadroer@adiquimica.com

Membrane fouling is a persistent problem throughout reverse osmosis (RO) systems that reduces plant efficiency and increases operating costs. The commonly used cleaners contain EDTA, which is non-biodegradable, and phosphorus, that contributes to eutrophication.

In this context, an innovative and environmentally friendly cleaner was developed. It is an EDTA-free and phosphorus-free alkaline powdered cleaner formulated with highly efficient active agents to remove biofouling and colloidal fouling.

The aim of this work was to evaluate and validate the effectiveness of the EDTA-free and phosphorus-free powdered cleaner in removing biofouling and colloidal fouling from RO membranes for a wide range of applications.

To validate the capability of the powdered cleaner to remove biofouling and colloidal fouling, it was applied in three RO real plants: sea water desalination plant, brackish water desalination plant fed with well water and wastewater reuse plant. The three plants showed symptoms of fouling that included low normalized permeate flow and high differential pressure (ΔP).

A methodology based on membrane autopsies has been applied to identify and characterize the composition and the mechanism of fouling that was reducing the performance of the plants. The results showed that the membrane surfaces were covered by a deposit layer that had a dense and compact structure. These deposit layers contained biofouling and colloidal fouling in the three membranes, and, in the case of the sea water membrane, algae were also present.

After determining the fouling behavior and mechanisms involved in membrane fouling for each element, our study focused on designing and optimizing a cleaning protocol using the environmentally friendly formulated cleaner for each membrane. This procedure was performed in pilot plants that simulate the conditions of the real plants.

Fouling composition analyses were performed before and after the application of the cleaning procedures to evaluate their effectiveness using CLSM, ATR-FTIR, ATP analysis, bacterial counts, SEM-EDX, and optical microscopy.

The analyses results confirm the removal of the bacteria and extracellular polymeric substances (EPS) that compose the biofilm, the colloidal fouling, and the algae present in the sea water membrane.

The designed cleaning protocols were applied to the real RO plants: sea water desalination plant, brackish water desalination plant fed with well water and wastewater reuse plant. The cleaning procedure restored the membrane performance to initial start-up situation in the three RO plants.

The results demonstrate that the formulated EDTA-free and phosphorus-free powdered cleaner is an environmentally friendly, cost-effective, and economically viable membrane cleaner for a wide range of applications. Furthermore, it is effective at low doses so it reduces operating costs and minimizes chemicals discharge to the environment and does not contribute to eutrophication.

Keywords: Reverse osmosis; Membrane cleaning; Environmentally friendly cleaner; EDTA-free and phosphorus-free cleaner; Biofouling; Colloidal fouling

PT 53

CFD application for operational analysis of self cleaning filters at Jorf Lasfar (Morocco) desalination plant

Mohamed Amine Rabitateddine

JESA, Zenith Rabat, Imm D, Rabat 10220, Morocco
Tel. +212 669653150, mohamedamine.rabitateddine@jesagroup.com

Self cleaning filters are used to protect and reduce the clogging of equipment, mainly UF membranes. There is a lot of technologies available in the market. Couple of them are implemented at Jorf Lasfar (Morocco) Desalination plant. The design and operation of such devices is fairly simple. However, there is a lack of understanding of the complex flow happening during filtration and backwash modes. Giving insights to operators on this topic may help them to better manage these devices and improve their efficiency and sustainability. For this work, we implemented a CFD (Computational Fluid Dynamic) approach. It consists of the resolution of Navier Stockes equations for a full 3d self cleaning geometry. We worked on existing models, already installed at Jorf Lasfar desalination plant and used field measurements to calibrate the numerical model, mainly screen's parameters, that have been modeled as porous media. For the first geometry, we considered one central screen. which is the most common configuration. We also analyzed a second model with multiple screens. We were interested to evaluate the 3D velocity field inside each filter and check if the flow pattern is uniform all along the screens or quantify non-uniformities. The localization of areas with high velocities is essential to predict potential failure and can be considered during predictive maintenance. The methodology implemented during this work can be applied by operators with good CFD knowledge to understand and improve self cleaning filters on their own plants.

Keywords: Self cleaning filter; CFD

PT 54

Production of remineralization chemicals from RO brines: Pilot platform development

Antonino Campione*, Giuseppe Lo Burgio, Fabrizio Vicari, Alessandro Tamburini, Lorenzo Ventimiglia, Fabrizio Vassallo, Giuseppe Battaglia, Andrea Cipollina, Giorgio Micale

**SUEZ, Paris 75017, France*
Tel. +33 787151283, antonino.campione@suez.com

The need to increase sustainability in desalination technologies has paved the way to the ideation of circular schemes that allow the reduction of the external raw materials to be supplied to the process. Within this context, a patented treatment line for the valorisation of RO brine has been conceived. The goal of this line is to focus on the chemicals requirements of a desalination plant. Therefore, a specific amount of brine is treated, with the aim of producing just enough products to satisfy the abovementioned needs. In particular, the value generation of the line includes:

- The production of gaseous CO_2 and of a mineral mixture of Ca and Mg that can be used for the remineralization of the RO permeate
- Acid and base solutions to provide full circularity to the scheme and for internal use in the plant (e.g. seawater feed pre-treatment, membrane cleanings, chemicals production, etc.)
- High-purity magnesium hydroxide, generated as a by-product, to be integrated in a wider circular economy scheme (e.g. coupling with a wastewater treatment plant) or to be sold to the external market

The proposed solution has been developed at the pilot scale, with a fully integrated pilot plant that has been tested and validated in a real industrial environment. In particular, the main achievements include:

- High recovery of CO_2 from brine alkalinity and successful reuse within the remineralization purposes
- Full recovery of high-purity magnesium hydroxide
- Production of a high-quality Mg/Ca mineral mixture and optimized dissolution in the RO permeate

The pilot experience implementation, its main achievements and challenges will be presented and discussed, revealing how this advanced pilot testing will lead to the industrialization of the first circular brine-to-value line for municipal desalination.

Keywords: Carbon dioxide; Valorization; Calcium; Magnesium; Circularity; Remineralization; Brine

PT 55

Sustainable solutions to concentrate management: a novel solar-driven membrane crystallizer for zero-liquid discharge

Kerri Hickenbottom*, Jeb Shingler, Minna Allouzi, Varinia Felix, Shelbi Jenkins, Wei Pan, Robert Norwood

University of Arizona, 1133 James E Rogers Way, Tucson, AZ 85721, USA
klh15@arizona.edu

The advancement of water treatment technologies that increase water and energy utilization and efficiency and achieve zero-liquid discharge - especially in inland and arid regions - can strengthen the desalination innovation ecosystem and close the loop on the circular water-energy-resource economy are needed. This study investigates direct coupling of a demonstration-scale membrane distillation crystallization-concentrated solar power/photovoltaic (MDC-CSP/PV) system for inland concentrate management and off-grid applications. Experiments were performed on the demonstration scale hybrid MDC-CSP/PV system to integrate staged thermal storage management and flow regime controls for sustained heat supply given temporal variations. System performance was evaluated under different AGMD circulation flow rates, salinity, and module lengths. Additionally, crystallization rate and production was evaluated. Specific thermal energy consumption (STEC), specific electrical energy consumption (SEEC), distillate production, and water vapor flux were analyzed as performance indicators. Results indicate that increasing the CSP system thermal storage capacity with the staged reservoir system resulted in a 2.7-fold increase in thermal energy available for the the MD system in the winter months. Compared to the winter months, operating the hybrid system in summer months when direct normal irradiance is at its peak results in a sixfold increase in average distillate production. Additionally, with increased MD circulation flow rates a tradeoff exists for higher STEC and greater distillate production rates independent of membrane area. Compared to shorter membrane modules, utilizing longer membranes modules resulted in nearly 50% less thermal energy utilization, 165% decrease in STEC, and a 28% increase in distillate production. Experimental data was used to validate a system model that evaluates specific energy consumption, water recovery, and economic costs. Modelling results were used to perform an environmental life-cycle assessment (LCA) with SimaPRO. A sensitivity analysis was performed to evaluate the influence of select model inputs, including MD operating temperatures, module area, flow rates, and energy source on system costs and LCI. Results indicate that the MDC-CSP/PV system to be a competitive option compared to conventional concentrate management systems, producing high quality water for less than 1.50 $/m^3$. Results highlight important design and operating considerations for integrating thermal desalination with solar energy resources in an operational environment.

Keywords: Concentrate management; Hybrid water-energy system; Techno-economic and life cycle assessment

PT 56

A pilot plant scale circular approach for the CO_2 extraction from RO brines

Giuseppe Lo Burgio*, Antonino Campione, Fabrizio Vicari, Alessandro Tamburini, Lorenzo Ventimiglia, Fabrizio Vassallo, Giuseppe Battaglia, Andrea Cipollina, Giorgio Micale

**Suez, Paris 92040, France*
Tel. +39 3278340768, giuseppe.loburgio@suez.com

In the current scenario of growing concern for the rise in atmospheric CO_2 levels, the interest in circular solutions for its capture and possible uses has been rapidly increasing in the latest years. Within the field of desalination, a circular approach is proposed in order to take advantage of the high concentration of CO_2 contained in the form of bicarbonates in the RO waste brines. This product could be potentially used to treat the RO permeate during the remineralisation process, to obtain a desired alkalinity value of the potable water. This approach would eliminate the need for external supply of one of the key raw materials used in the desalination industry. This principle was successfully tested in an integrated pilot plant platform, through the following units:

- The CO_2 extraction from RO brines was performed in a stripping packed column, operating under vacuum and with ambient air as the stripping gas, in which the required amount of RO brine is processed. The brine undergoes in-line acidification prior entering the column, with the purpose of shifting the equilibrium of the bicarbonates towards free CO_2. The column can produce either pure CO_2 or a gaseous mixture of air and CO_2, which can then be injected in the RO permeate.
- The injection of CO_2 was performed in an injection unit, in which RO permeate is processed, with a hydro ejector (Venturi tube) capturing the gaseous CO_2/air mixture, after which NaOH is injected to reach an alkaline pH and fix the carbon dioxide in the form of bicarbonates.
- These integrated pilot scale units were tested and operated in the real industrial environment of a desalination plant. The units were validated, achieving the following main results:

- High removal values (up to 90%), of gaseous CO_2 from RO brines.
- Complete absorption of the extracted CO_2 in RO permeate.

In this document the implementation of the two units will be discussed, focusing on its integration in a fully circular scheme for the production of chemicals for desalination plants.

Keywords: Carbon dioxide; Valorisation; Recovery; Remineralisation

PT 57

Air-cooled dehumidifier for efficient water desalination using membrane distillation

Atia Khalifa*, Mohamed Kotb, Suhaib Alawad

**King Fahd University of Petroleum & Minerals, Mechanical Engineering Department, Room 63-306, Dhahran 31261, Saudi Arabia*
Tel. +966 508974225, akhalifa@kfupm.edu.sa

Access to clean water is a growing global challenge, driven by increasing water demand and diminishing freshwater resources. Membrane distillation (MD) has emerged as a promising desalination technology, leveraging low-grade heat sources and low-pressure operation. This study presents a novel integration of a vacuum-assisted sweeping gas membrane distillation (SGMD) module with a multistage air-cooled bubble column dehumidifier (BCD) bank to enhance energy efficiency and cost-effectiveness of water production.

The system's performance was assessed under natural and forced air cooling modes, with cooling airspeeds ranging from 0 to 8 m/s. The results demonstrated significant improvements in system productivity and energy efficiency when forced air cooling was applied. Specifically, forced air cooling enhanced water flux by 40–100% compared to natural convection cooling. At cooling air speeds of 6–8 m/s, the system achieved a specific energy consumption (SEC) as low as 500 kWh/m^3 and a gained output ratio (GOR) of 2. These operational conditions reduced energy consumption by 37%. Furthermore, the integration of the forced air-cooled mechanism achieved a 43% reduction in water unit product cost at an air speed of 8 m/s, enhancing economic feasibility. Compared to previous studies on industrial wastewater treatment or solar-driven SGMD systems, this approach offers a simpler, cost-effective, and scalable solution.

Exergy analysis revealed that the SGMD module accounted for the majority of exergy loss, approximately three times higher than the BCD bank, particularly at feed water temperatures as high as 90°C. This highlights the importance of optimizing the SGMD design to further enhance system performance. The study also found that increasing air speeds beyond 6 m/s provided diminishing returns, indicating an optimal range for system operation.

Parametric studies showed that system productivity improved with higher feed temperatures and optimized cooling airflow rates. However, excessive feed flow rates reduced GOR due to higher energy requirements. The integration of forced air cooling demonstrated its efficacy in mitigating these effects, achieving a maximum flux of 75 kg/m^2·h and a peak GOR of 2.4 under optimal conditions. This performance highlights the effectiveness of the forced air cooling strategy employed in this study. Additionally, the use of a multistage air-cooled BCD bank distinguishes this work from conventional approaches that rely on fin-tube or water-cooled dehumidifiers

This study establishes critical benchmarks and provides detailed guidelines for optimizing SGMD-BCD systems. The findings underline the potential of integrating advanced cooling mechanisms to enhance energy efficiency and economic feasibility, offering scalable solutions for desalination in water-scarce regions. Additionally, the system's modular design supports decentralized applications, making it a viable candidate for sustainable water production.

Keywords: Water desalination; Membrane distillation; Air-cooled dehumidifiers; Performance analysis; Energy efficiency; Exergy analysis; Cost evaluation

Wave to energy and water

Michael Henriksen*, **Emiel Schut**

**Wavepiston, Kronborg 3b, Helsingoer 3000, Denmark*
Tel. +45 40994040, mh@wavepiston.dk

The Wavepiston technology is centered on a novel modular approach. Multiple energy collectors, consisting of a sail and 2 pumps, are coupled on a shared structure and string. To capture the energy from the waves, the effector surfaces (the sails) are moved back and forth by the waves. This movement is transferred to hydraulic pumps generating pressurized seawater, which is piped to the shore. The pressurized seawater is then used to generate electricity through a standard Pelton turbine or to desalinated water through a standard reverse osmosis system. Several strings may be merged in the same system to create a wave energy farm, scalable both to wave resources and to energy/water demands of the customer. We are now at the final stage of testing and demonstrating the full-scale prototype that has been installed in the Atlantic Ocean off the coast of Gran Canaria, and would like to share the results and learnings. In parallel we are preparing the first pilot farms at islands / remote communities.

Keywords: Wave energy; Renewables; Renewable energy; Desalination; Energy

PT 59

Water management on NFE LNG project: closing the loops

Laure Defrance-Ableson*, Fabien Giraud

**TECHNIP ENERGIES, 216 Blvd de La Défense - CS10266, Nanterre 92741, France, Tel. +33(0)1 47 78 53 28, laure.defrance@ten.com*

North Field East (NFE) project benefits from a significant process heritage from former Qatar LNG mega trains, and replication often occurs.

Nevertheless, NFE introduces a significant novelty for utility water production and management, with a core objective: reduce the seawater pumping requirements and limit the perturbance in reject to sea (hydraulics, composition, temperature).

A single LNG train typically requires cooling water in the range of 100,000 m^3/h. Sea water is often used as cooling media source (through a double arrangement of open and closed loop), like most of the heavy industries. For areas with a significant concentration of heavy industries, impact on environment is notorious, mostly due to the temperature increase nearshore around the discharge point.

Presentation will show how NFE project brings a ~40x reduction for the seawater demand and avoids the risk of sea warming by implementation of a large desalination unit, as well as further efforts intended to re-use as much as possible the water on site.

Keywords: LNG; Desalination; Reuse

PT 60

Enhanced energy efficiency strategies in desalination technologies

Guillem Gilabert Oriol*, Harith Alomar, **Maria Perez Macia**, Santhosh Ramalingan, Mahesh Kulkarni

**DuPont Water Solutions, Tarragona, Asturias 33469, Spain*
guillem.gilabertoriol@dupont.com

Reverse osmosis (RO) has emerged as the leading technology for producing high-quality drinking water from seawater, offering substantial energy savings when compared to thermal desalination methods. A critical challenge facing desalination technologies is the need to further reduce energy consumption, as this not only enables significant cost savings but also aligns with the United Nations' decarbonization goals for 2030. This paper explores various innovative strategies aimed at reducing energy requirements for seawater desalination, focusing on the integration of advanced low-energy RO membranes, particularly the DuPont™ FilmTec™ Seamaxx™ membrane element. We present the intelligent application of FilmTec™ BW30XHR PRO-440 membrane element with high-rejection in a second-pass process, demonstrating how their use can lead to enhanced energy efficiency in desalination operations. Real-world case studies are provided to quantify the energy savings achieved through these strategies. Additionally, we assess several key sustainability indicators, including carbon emissions, chemical usage, wastewater generation, solid waste production, and land footprint, demonstrating the environmental benefits that can

be derived from these innovations. The Water Solutions Sustainability Navigator tool is employed to evaluate these metrics, showcasing the potential of these digital tools .to contribute to sustainable desalination practices.

Keywords: Reverse osmosis; Desalination; Energy savings

PT 61

Deep learning models for predicting normalized operational parameters for reverse osmosis membranes

Jover Erreyes Pilozo, Laura Haya, **Cosmin Koch Ciobotaru***

ACCIONA, Barcelona 08820, Spain
Tel. +34 673 10 43 28, ckoch@acciona.com

The paper details the development of a predictive fouling indicator based on artificial intelligence models. Several models were created using historical operational data taken from the SCADA with the objective of predicting process values related to membrane fouling in a reverse osmosis pilot plant for seawater desalination. The developed predictive fouling indicator calculates the gradient of the predictions for three key parameters: differential pressure, salt passage and permeate flow rate, taking as reference the current operating point to quantify the expected fouling over a time horizon. The development consisted of three stages: (1) gradient calculation, (2) comparison with historical data and (3) variation of prediction parameters to improve the model. In the first stage, an AI technology, namely long short-term memory (LSTM) models were used to predict the future values of the process variables and calculate the predicted gradients or expected evolution, indicating potential fouling. The second stage confirmed the accuracy of the model. In the third stage, variations in the prediction time and time window were explored, observing that longer prediction times generally improved the predictive models. The artificial intelligence model chosen to monitor fouling is based on a 24-h prediction window and a 12-h historical moving window as input, as it demonstrated the lowest prediction errors among the tested combinations.

Based on the models obtained and following the same procedure, the prediction time and the historical moving window of each model have been varied in order to increase the representativeness of the model, its sensitivity to changes and, above all, to facilitate its application in the normal operation of desalination plants. There must be at least a 12-h prediction in order to be able to make changes in the operation of the reverse osmosis plants, for example, in order to schedule cleaning or preventive maintenance. For these reasons, the models have been modified by varying the prediction time to 12, 24 and 48 h and the time window to 3, 6 and 12 h. To evaluate the accuracy and suitability of the developed models for predicting fouling in reverse osmosis systems, the following four metrics have been taken into account: mean absolute error, mean square error, root mean square error and R square.

Taking into account all the results obtained for the different combinations of variation in prediction time and time window, we can see that for the first two components, the 24-h prediction model with the 12-h time window is the one that best fits, closely followed by the 12-h prediction model for the same time window.

Keywords: Deep learning; Long short-term memory; Desalination; Predictive maintenance

PT 62

Analysis of offshore hydrogen production using seawater desalination at different locations in Europe

Tom Ruiter*, Heike Glade

University of Bremen, Bremen 28359, Germany
Tel. +49 421 218-64760, tom.ruiter@uni-bremen.de

Various strategies have been developed to counteract the progressive climate change and to secure energy supply. At the centre of these strategies is the replacement of fossil fuels by the use of renewable energies. Hydrogen is a carbon-neutral energy carrier if it is produced by water electrolysis using renewable energies. For green hydrogen production using wind energy, offshore wind exhibits higher average speeds and less fluctuation compared to onshore wind. Usually, the electricity from offshore wind farms is brought ashore using submarine cables, resulting in transmission losses. To avoid this, some approaches are focussing on offshore hydrogen production with electrolysis taking place locally in the offshore wind farm. Compared to alkaline electrolysis, polymer electrolyte membrane (PEM) electrolysis is advantageous for fluctuating renewable energies, as it is characterised by fast response time and high load gradients. Germany and other European countries explore offshore hydrogen production as a way to reduce carbon emissions and decrease dependence on energy imports.

For offshore desalination of seawater, previous studies indicate that thermal desalination processes can offer advantages in comparison to membrane-based processes. Reasons for this are, among others, high product water quality, high robustness, lower pre-treatment requirements, lower chemical demand, and lower maintenance requirements of thermal processes. In this scenario, the waste heat from the electrolyser serves as energy input for the thermal desalination plant.

In this work, the integration of wind power, PEM electrolysis and multi-effect distillation (MED) for seawater desalination has been investigated in more detail. To this end, process models for a wind turbine, PEM electrolysis and MED were coupled. A two-pass reverse osmosis (RO) plant with an energy recovery device was also analysed for comparison. The electricity generated was calculated using the wind turbine model on the basis of measured wind speeds. For electrolysis, various parameters were considered, such as current density, efficiency, hydrogen produced and the waste heat flow rate. The modelling of MED focused on parameters that are crucial for the design and coupling, such as the number of evaporator stages, the process temperatures, the distillate mass flow rate and the hot water demand for heating.

Previous work has shown that the waste heat from the electrolyser can be beneficially utilised to drive an MED plant. However, wind fluctuations often cause power outages, leading to frequent shutdowns of the entire system. In the current study, offshore hydrogen production has been analysed at different locations in Europe. Using wind data over one year from different locations, the hydrogen

production rates and the production interruptions of the MED and the RO plant were calculated. The influence of an integrated battery and its capacity on the production interruptions was analysed.

Keywords: Green hydrogen; Water electrolysis; Offshore desalination; Modelling and simulation; Process integration

PT 63

Evaluation of the operational efficiency and performance of a combined desalination and salt (NaCl) production plant in Indonesia

Ersan Ozdemir, Pablo Canada Garcia*, **Nélio Moreira**

**Veolia WTS, Firenze 50143, Italy*
Tel. +39 3407417567, pablo.canada-garcia@veolia.com

This case study offers an analysis of the operational efficiency and performance metrics of the Indonesia Desalination and Salt (sodium chloride, NaCl) Production Plant, located in Serang City, Indonesia. The plant stands as a pioneering model in seawater desalination, integrating advanced membrane-based technologies to meet the high demands for desalinated water and food-grade salt production in a region characterized by fluctuating climatic conditions.

The study examines each component of the plant's infrastructure, including the pretreatment system, seawater nanofiltration (SWNF) system, seawater reverse osmosis (SWRO) system, and thermal system. Of particular note is the world's largest commercially available membrane-based food grade brine concentration system, which significantly enhances the plant's overall recovery rate and efficiency. The research delves into the design considerations, process variables, and energy consumption patterns, offering insights from the plant's commissioning phase through its current operations.

The plant's design is tailored to Indonesia's unique geographical and environmental conditions, capable of adapting to the varying characteristics of seawater between monsoon and dry seasons. This adaptability is critical in maintaining consistent production levels while optimizing energy use, with specific power consumption rates monitored and analyzed.

The integration of osmotically assisted reverse osmosis (OARO) systems and advanced brine management technologies further underscores the plant's commitment to innovation and sustainability. These systems not only improve water and salt production efficiencies but also minimize the environmental impact by effectively managing brine discharge.

This case study serves as a vital resource for understanding the complexities and technological advancements in modern desalination and brine concentration systems, offering a blueprint for future projects aiming to balance resource utilization with environmental stewardship.

Keywords: Ocean brine mining; Nanofiltration; SWRO; OARO; Osmotically assisted reverse osmosis; NaCl; Salt

PT 65

Pilot scale solar-assisted adsorption desalination and cooling system: Thermodynamic analysis and performance evaluation

Alberto Tiraferri*, Ali Naeimi Tabasian, Alberto Saija, Matteo Morciano, Matteo Fasano, Eliodoro Chiavazzo

**Politecnico di Torino, Corso Duca degli Abruzzi 24, Torino 10129, Italy*
Tel. +39 3451317730; alberto.tiraferri@polito.it

Adsorption desalination emerges as a game-changing solution to the limitations of conventional desalination methods, such as excessive energy demands and costly maintenance. Its compatibility with low-grade heat makes it ideal for integration with solar energy systems or utilizing waste heat sources. Operating under vacuum conditions, this innovative system harnesses an adsorption/desorption cycle where water evaporates at low temperatures, adheres to the surface of a high-affinity solid adsorbent, and then desorbs upon heat application to yield purified water. Thanks to its dual distillate effect, the process produces water with remarkably low total dissolved solids (TDS).

In this study, a pilot-scale adsorption desalination and cooling system integrated with a solar water heater was rigorously evaluated under various operating conditions. A novel mechanism facilitating water vapor transport through optimized feed and distillate water circulation was implemented, enhancing system efficiency. Key performance metrics include specific daily water production, specific cooling production, and overall conversion efficiency. The adsorbent material was characterized, and an appropriate isotherm model was developed to predict its water adsorption behavior. System performance was assessed under varying desorption temperatures provided by a solar water heater and different cycle durations. At a desorption temperature of 70°C and a cycle duration of 30 min, the system achieved a water production capacity of approximately 4 m^3 water daily per ton of adsorbent. Extending the cycle duration revealed an optimal point for maximizing performance metrics. These findings underscore the feasibility of scaling up adsorption desalination systems powered by solar energy, paving the way for sustainable, energy-efficient freshwater production with added cooling benefits.

Keywords: Adsorption; Solar energy; Pilot scale; Optimization; Energy efficiency

PT 66

Development of a membrane-based zero liquid discharge treatment train for a bio-chemical industry

Sara Salvador Cob

VITO, Mol 2400, Belgium
Tel. +32 14335775, sara.salvadorcob@vito.be

Water plays an essential role in industry, since most sectors require huge volumes of water for its industrial activities. The use of water in industrials settings has a severe impact for the environment, the economy and the society. Due to the urgent need of preserving this valuable resource, we need technological solutions for the reduction and reuse of water in industry.

Some of the most intensive water process industries are the chemical, pulp&paper, steel and mining sectors. Within the R3volution (R3v) project (funded by the European Union) we aim at developing membrane-based Zero Liquid Discharge (ZLD) approaches in these 4 sectors that will allow the recovery of > 90% water, >45% solutes and >50% energy.

One of the case studies in R3v is a biochemical industry, which has developed the first technology to selectively convert the most abundant biopolymers on Earth – cellulose & lignin – into added-value chemical products. To meet the strong increase in demand they will increase their production by 2030, which also means an increase in wastewater production and discharge, and the consequent loss of valuable solutes.

In order to implement circularity in their process a complex treatment train consisting of nanofiltration, reverse osmosis and membrane distillation is being developed. The main challenges of the selected process streams are the presence of organic solvents and the acidic pH, which limit membrane and equipment selection.

The use of ceramic membranes, both native or chemically grafted, might play an important role in this case, due to its robustness, resistance to fouling and extreme operational conditions (temperature and pH).

With the proposed combination of technologies, it is expected to achieve a reduction in chemicals and raw materials cost through the recovery of valuable reactants and products that can be either reincorporated into the process or sold, as well as reuse as much water as possible, as it represents >95% of effluent composition.

Keywords: Water reuse; Zero liquid discharge; Biochemical industry; Membrane technology; Organic solvent stable membranes

PT 67

Desalination in Algeria: a lifeline against water scarcity

Nadjib Drouiche*, Ahmed Kettab

CRTSE, Algiers 16038, Algeria
Tel. +213 660621509, nadjibdrouiche@yahoo.fr

Algeria, grappling with escalating water stress exacerbated by climate change and rapid population growth, has embarked on a significant expansion of seawater desalination. This article examines the multifaceted dimensions of this endeavor, delving into the national policies, substantial investments, and technological advancements driving the country's desalination sector. We critically evaluate the effectiveness of these strategies in mitigating water scarcity, ensuring a reliable water supply for the burgeoning population, and supporting sustainable development across various sectors.The analysis explores the historical trajectory of desalination in Algeria, tracing its evolution from early pilot projects to the current ambitious program of large-scale plants. We investigate the key constraints that necessitated this shift, including dwindling freshwater resources, the impacts of climate change, and the increasing demands of urbanization and industrialization. Furthermore, we delve into the specific strategies employed by the Algerian government to enhance water security through desalination, focusing on its potential to address the specific needs of coastal populations and free up surface water for agricultural use.The article also scrutinizes the challenges inherent in large-scale desalination projects, such as high energy consumption, environmental impacts, and the need for skilled workforce and robust maintenance. We explore potential solutions, including the integration of renewable energy sources, advanced water treatment technologies, and the development of local expertise. Finally, we discuss the future prospects of desalination in Algeria, emphasizing the need for a comprehensive and integrated approach that considers not only technological advancements but also sustainable water management practices, including water conservation, efficient irrigation, and wastewater reuse.This research provides valuable insights into the challenges and opportunities of implementing large-scale desalination projects in water-stressed regions. The findings have significant implications for policymakers, water resource managers, and researchers seeking to address the growing global demand for freshwater in a sustainable and equitable manner.

Keywords: Desalination; Water scarcity; Water security; Algeria; Climate change; Water resources; Water policy

PT 68

Five ways to prevent biofilm on membranes

Fernando Del Vigo, Nuria Peña, Javier Rodriguez, Daniela Vidal,
Mike Sinfield*

H2O Innovation, 3 Aston Way, Middlewich CW10 0HS, UK
Tel. +44 1606837605; mike.sinfield@h2oinnovation.com

Biofilm formation is a leading cause of membrane failure, being the primary foulant in approximately 31% of membrane failures globally, rising to over 50% when considering only membranes used in seawater desalination. Effective biofilm prevention strategies are critical for maintaining system performance and extending membrane life. This study explores five chemical approaches to biofilm control:

1. Chlorine: A widely used oxidising biocide, effective at controlling biofilm but known to cause membrane degradation if not effectively removed ahead of the RO stage.
2. Other Oxidising Biocides: Including ClO_2, bromine-based options, ozone, etc: these chemicals share chlorine's efficacy but carry similar risks of membrane damage.
3. DBNPA: A non-oxidising biocide previously favoured for its rapid action and minimal long-term impact on membranes. However, its recent ban in Europe limits its applicability.
4. Genesol 80: A membrane-compatible biofilm inhibitor specifically formulated for potable water applications. Its targeted mode of action provides effective biofilm control while preserving membrane integrity.
5. Genefloc ABF: Designed for non-potable water systems, this product prevents biofilm formation through advanced anti-fouling chemistry without compromising environmental compliance or membrane lifespan.

While chlorine and oxidising biocides have historically been the go-to solutions, their potential to damage membranes necessitates alternatives. Additionally, use of chlorine risks generating THMs, which pose serious environmental concerns. The fouling risks associated with using sodium metabisulfite to reduce oxidising biocides are discussed. Similarly, regulatory restrictions on DBNPA underscore the importance of innovative solutions. The focus of this discussion is on alternative products, which offer safer, application-specific approaches for biofilm management.

Keywords: Reverse osmosis; Biofouling; Biofilm; Biofilm inhibitor

PT 69

Sustainable approach towards SWRO pre-treatment

Carmen Carbonell*, Caroline Barbé

**SUEZ, Courbevoie, FL 92040, France*
carmen.carbonell@suez.com

A reliable and secure water source is a fundamental necessity for the establishment of a sustainable human community. Currently, freshwater resources in rivers, groundwater and surface water are limited and are being depleted in many places. As 97.5% of the Earth's water is comprised of seawater and saline aquifers, oceans and seas have the potential to serve as sources of water supply.

Nevertheless, seawater is not suitable for human consumption or agricultural uses due to its high salinity. Desalination from seawater has become an important source of drinking water.

However, the sustainability of desalination processes faces a significant challenge rooted in the carbon footprint.

The carbon footprint of industrial plants refers to the total amount of greenhouse gases, mainly carbon dioxide (CO_2), emitted into the atmosphere because of their operation. This footprint is a key indicator of the environmental impact of industrial activities and gathers emissions from energy consumption, manufacturing processes, short-term renewable consumables, and transportation, among others.

By lowering their carbon footprint, desalination plants can actively contribute to global efforts towards the environment.

As a SUEZ commitment, strategies to improve environmental sustainability are key. A focus has been made on the pre-treatment of the SWRO plant, which contributes to CO2 emission. Nowadays, one of the classic pre-treatment processes in desalination plants is the filtration process; this type of water pretreatment is generally carried out by dual media filters, i.e. with at least two media of different particle sizes. The filter can be fed by gravity or pressurized, the reference filtration velocities are:

- Between 8 and 13 m/h for gravity dual media filtration.
- Between 10 and 15 m/h for pressurized dual media filtration.

The choice of the velocities depends on the quality of the seawater and the type and size of the media used.

In this type of pre-treatment, the coagulant, iron based, is dosed within the feed water. Chemical use should be managed properly to avoid heavy waste management and potential environmental pollution. Furthermore, the consumption of chemical reagents has a direct economic impact on the SWRO plants operation. Some chemical reagents can be expensive, challenging to handle and sometimes difficult to supply in specific areas. By minimizing their use, industries can reduce operating costs and improve their competitiveness in an increasingly cost-conscious field.

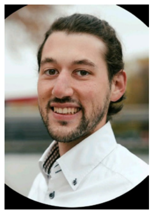
After the media filtration, cartridge filters are installed, which are safety filters that have the function of protecting reverse osmosis membranes. These cartridge filters are consumable and must be replaced annually.

The present innovation proposes the possibility to eliminate the consumption of chemical reagents, avoid generating cartridge filters disposal and reduce the footprint by reducing the number of pre-treatment equipment in desalination plants. For that purpose

Keywords: SWRO; Innovative pre-treatment; Biofiltration; High velocity; Self-cleaning filters

PT 70

Decoupling dual-media filter into combined flotation step and high velocity sand monolayer: Results from demo plant



Rémy Caball*, Caroline Barbé, Delia Pastorelli

SUEZ E&C, Paris La Défense 92040, France
Tel. +33 674654338, remy.caball@suez.com

When seawater degradation is foreseen (algae blooms, high total suspended solids events, high organic content), conventional pre-treatment lines for SWRO plants include a dissolved air flotation step to manage such threat towards the plant operation costs. Most of the time, this step is combined with a filtration process to reach a suitable filtered water quality for the feeding of the reverse osmosis system.

The SeaDAF Plus, one recent technological development from SUEZ, has been developed to increase the flotation velocity while securing the flotation performance whatever the feedwater quality. Consequently, outlet water quality of such product is 100% reliable and enables to boost the downstream pre-treatment. SeaDAF Plus consists in an upgraded DAF where a coarse filtration step is added in the same structure, at the bottom of the flotation. This monolayer filtration step consists of Anthracite/Pumice of a size = 1.2mm.

The Seaclean Monoloayer is a monolayer filter operated at a velocity of 20m/h.

The two processes have been tested together on a demonstration platform in the Arabian Seaand in Perth. They consisted in long-term validation of the technology and determination of the operational philosophy for such pre-treatment.

With suitable media combination, results show a turbidity removal of SeaDAF Plus to always below 0.5 NTU, whatever the applied velocity (30–50 m/h) or seawater quality (SDI3 up to 25%/min). The filtered water quality at the outlet of the monolayer was similar to a conventional reverse osmosis pre-treatment.

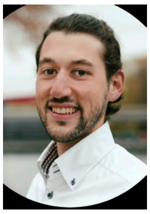
The trials have led to a new approach for the operation of the SeaDAF Plus, driven by outlet turbidity rather than differential pressure, and on providing stable feed water to the downstream monolayer.

Trials for this technology in Perth are still ongoing and will end in February 2025. This presentation will showcase the latest technical developments derived from the trials. It will conclude on the technological boundaries related to the use of this technology (maximum velocity, chemical adjustments, quality requirements).

Keywords: Pre-treatment; Flotation; Filtration; High velocity; Carbon footprint

PT 71

Using satellite data to improve seawater characterization and optimize plant designs



Rémy Caball*, Olivier Raillard, Sébastien Smet, Delia Pastorelli

**SUEZ E&C, Paris La Défense 92040, France*
Tel. +33 674654338, remy.caball@suez.com

With climate change and increasing use of desalination technology around the world, optimisation of the energy consumption of desalination plants is a topic of high interest. One key lever for energy optimisation is to match more efficiently plant designs and seawater qualities. Precise designs will allow for operation around best-efficiency points and increase of plants operation through anticipation of long-term trends.

Traditional methods for characterisation of seawater qualities are in-situ sampling, water studies and usage of data from neighbouring areas. One disadvantage of the two first methods are their punctual aspect, data only reflects specific periods of the year and for a specific year. Disadvantage of the last method is that is does not account for variations of quality locally around the coast.

SUEZ and Actimar are working hand in hand to improve the access to precise information for design of RO plants, by developing a tool allowing to report precisely on:

- Historic data over several years
- Climate data (variations within the year)
- Anticipation of long-term trends

The tool is using satellite data, processing it and making it available in a relevant format. It is currently focused on temperature, salinity, turbidity and chlorophyl a, but could be expanded to other parameters. It currently

With this access to more precise data, plants will still be designed to operate based on the regional minima and maxima, but the best efficiency point will be focused on the most probable seawater quality combination, allowing for reduced energy consumption. In addition, anticipating long-terms variations early on can allow to plan for plant evolutions early on, by adjustments of design or allowance of space for installation of new equipment early-on.

The project development is ongoing. The advancement of the project and current challenges will be presented, along with examples of implementation in recent projects.

Keywords: Seawater characterization; Satellite; Energy efficiency; Climate change

PT 72

Enhancing water production capacity: the role of filtration velocity in multi-media filters for desalination

Ofir Yamin

IDE, Hamatechet 6, Kadima 6092000, Israel
Tel. +972 524434794, ofiry@ide-tech.com

Given growing global water scarcity challenges, desalination plants are seeking innovative ways to expand production capacity and optimize performance. Based on extensive operational and design experience in seawater desalination, this study investigates the impact of increased filtration velocity on gravity multi-media filter (MMF) performance in pre-treatment processes. The research was motivated by the potential to enhance production capacity for existing plants or to reduce capital expenditure (CAPEX) through MMF system optimization while maintaining water quality for new plants.

A comprehensive two-year pilot study was conducted at the Hadera desalination plant in Israel, comparing filtration velocities of 8.5 m/h, 10 m/h, and 12 m/h using dual-media filters containing sand and anthracite. The pilot measured environments parameters, filter performance, filtrate quality throughout different seasons and during extreme events such as major storms. Results demonstrated that operating at 12 m/h versus 10 m/h or 8.5 m/h resulted in no more than a 0.2 increase in Silt Density Index (SDI15). Despite shorter filter cycles and more frequent backwashing at 12 m/h, total production increased by 40% compared to 10 m/h operation, with a 0.32% higher filter recovery rate. No trends were observed in differential pressure rise or 'cake' layer formation rates at higher velocities.

The study concludes that higher filtration velocities can be implemented while maintaining acceptable SDI levels and achieving improved production rates, though proper valve sizing is crucial for optimal performance. These findings effectively address water scarcity challenges by offering a proven approach to increase capacity in existing facilities or reduce CAPEX in future desalination plants through increased MMF filtration velocities, all while maintaining high water quality standards.

Keywords: SWRO; Pre-treatment; Gravity multimedia filters; Filtration velocity; Increasing capacity; CAPEX reduction

PT 73

Evaluating the impact of closed-loop RO systems on ZLD in textile industry: case study from Tirupur, India

Vinay Narayan Hegde*, Joachim Went, Joachim Koschikowski, Harald Schönberger, Werner Platzer

Fraunhofer Institute for Solar Energy System (ISE), Heidenhofstr. 2, Freiburg 79110, Germany
Tel. +49 76145885884, vinay.narayan.hegde@ise.fraunhofer.de

The textile industry is known for high-water consumption and substantial wastewater generation, with dyeing contributing the largest share. Dyeing wastewater is a complex mix of salts, dyes, cleaning agents, and fixing agents, posing severe environmental risks if discharged untreated. In Tirupur, Tamil Nadu, a hub for textile dyeing, untreated wastewater caused significant groundwater and surface water contamination in the early 2000s. In response, the Madras High Court mandated zero liquid discharge (ZLD) systems for dyeing units. While this regulation curbed pollution, it led to increased operational costs, forcing many facilities to shut down or relocate, while others adopted ZLD at significant expense.

Currently, central effluent treatment plants (CEPTs) in Tirupur treat 100 000 m^3/day, ensuring ZLD compliance. These systems recover up to 98 % of water and 75 % of salts, depending on the salts used and treatment technologies. Field visits to dyeing units revealed wastewater with total dissolved solids (TDS) ranging from 5 to 10 g/L, primarily sodium sulphate, sodium chloride, and sodium hydroxide. After biological treatment, effluent undergoes RO treatment, which is key to water recovery. Most units employ 3–4 RO stages: brackish water membranes in the first stages, followed by seawater membranes. RO recovery rates typically range from 85–90 %, with specific energy consumption (SEC) of 4–7 kWh/m^3. However, many units suffer from suboptimal designs, which cause energy loss, higher operational costs, increased maintenance, and elevated capital costs.

This study evaluates the benefits of a semi-batch closed-loop RO (CLRO) system through theoretical analysis of three dyeing units, using a modeling tool developed at Fraunhofer ISE. Results show that CLRO achieves recovery rates of up to 95%, reducing brine volume by 50% compared to the 90% recovery of existing systems. Despite the higher recovery rate, there is a reduction in SEC up to 75 % by CLRO system. Additionally, CLRO decreases system size, requiring 30–35% fewer membrane elements. The system also adapts to variable feed volumes by adjusting RO membrane recovery rates and recirculation flow in CL mode. This optimization significantly lowers ZLD costs, reduces dyeing expenses, and enhances the competitiveness of dyeing units equipped with ZLD systems.

Keywords: CLRO; Textile dyeing; Zero liquid discharge

PT 76

Creating an alternative sustainable water source — reusing MWWTP effluent to produce demineralized water for a power station

Amir Ziv, Aviv Toledano*, Harel Rauch, Miriam Faigon Frisi

BlueGen Water (Formerly GES Israel), Menachem Begin 35,
Tirat Hacarmel 3952065, Israel
Tel. +972 546737484, AvivT@Bluegenwater.com

The MRC Power Station houses Israel's first WTP that repurposes municipal effluents as the primary raw water source, providing an innovative solution for generation of industrial demineralized water (DEMIN) to the energy sector. This initiative responds to the growing demand for sustainable water solutions, allowing the WTP to overcome challenges in municipal effluent quality and to deliver a reliable, high-capacity output of 105 m^3/hr. By strategically reusing treated municipal wastewater, the plant not only achieves environmental objectives for water reuse and reduction of freshwater footprint but also offers substantial operational cost savings and fast ROI, showcasing the feasibility and benefits of sustainable industrial operations.

Keywords: Water treatment plant; Industrial demineralized water; Municipal effluent reuse; Sustainable water

PT 77

Recovery of lithium from brines by flow electrode capacitive deionisation

Hafiz Saif, João Crespo, **Sylwin Pawlowski***

Universidade NOVA de Lisboa, Caparica 2829-516, Portugal
s.pawlowski@fct.unl.pt

The World Economic Forum predicts a 2.5-fold rise in lithium carbonate demand, from 838 kt in 2024 to 2114 kt by 2030, due to electric vehicles and storage industries' boom. In this study, Lithium Membrane Flow Capacitive Deionization (Li-MFCDI), a recently proposed electromembrane process [1], was evaluated to extract lithium from a synthetic geothermal brine. The main challenge was the high amount of sodium in brines (the mass ratio of sodium to lithium was 650). A ceramic lithium-selective membrane (OHARA, Japan) was integrated into a custom-designed and 3D-printed flow capacitive deionisation (FCDI) cell. It rejected 99.98% sodium and achieved a very high lithium selectivity (141 ± 5.85 for Li^+/Na^+ and 46 ± 1.46 for Li^+/K^+). During a seven-day test, the Li-MFCDI process demonstrated consistent performance, consuming just 16.70 ± 1.63 kWh/(kg of Li^+ recovered) [1].

To overcome the limitations of commercial lithium-selective ceramic membranes, which are brittle and expensive and limit lithium flux to under 0.8 mmol/(m^2.h) (at 1.2 V), polymeric lithium-selective membranes, allowing for lithium flux of up to 110 mmol/(m^2.h) (at 0.2 V), were developed [2]. The developed membranes outperformed the commercial monovalent-selective cation exchange membrane (Neosepta® CIMS) to recover lithium from spent lithium-ion battery leachate. These advancements highlight the Li-MFCDI´s potential for sustainable lithium recovery from saline streams and its recycling from spent Li-ion batteries.

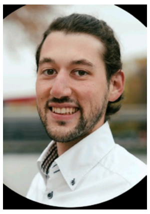
Keywords: Lithium; Brines; Flow electrode capacitive deionization (FCDI); Lithium-selective membranes; Li-ion batteries

References

[1] Saif et al., Lithium recovery from brines by lithium membrane flow capacitive deionization (Li-MFCDI) – A proof of concept, J. Membr. Sci. Lett. 3 (2023) 100059.
[2] Saif et al., Development of highly selective composite polymeric membranes for Li^+/Mg^{2+} separation, J. Membr. Sci. 620 (2021) 118891.

PT 78

Desalination plant fed with 100% renewable energy and process optimization for compactness: case study of Amaala



Ruth Mota, **Rémy Caball***

**SUEZ E&C, Paris La Défense 92040, France*
Tel. +33 674654338, remy.caball@suez.com

Plant designs have been evolving in recent years with the objective of more energy efficient and more compact plants. SUEZ will present the case study and detailed challenges of a plant under execution in Saudi Arabia, which has been designed to be compact, efficient, and reliable. This plant is a 37 MLD plant located on the red sea on the West Coast of Saudi Arabia. The project is part of an off-grid 100% renewable energy system, which will generate electricity from a 250 MW solar photovoltaic park, 700MWh battery energy storage, transmission and distribution lines. The result of a compared carbon footprint of this plant compared to non-renewable electrical supply will be presented. Several process design points will be detailed and emphasized on in the presentation:

- Challenges related to the availability of early water. A specific system composed of beach wells and modular RO skids was installed ahead the execution of the main plant to cope with absence of freshwater in the area
- Consideration of mechanical intake cleaning instead of chlorination which is the most widely used solution in the region. Mechanical intake cleaning reduces the risk of RO membrane operation. The pigging system is an eco-friendly and sustainable solution.
- Design of metallic limestone filters instead of concrete version, due to lower footprint. Contact time and velocity in the limestone filter was defined to allow for high remineralization bypass, allowing to reduce the footprint further.
- Sludge thickening through optimised Densadeg process. The Densadeg was adjusted to comply with specific requirements on site, such as high temperature leading to risk of algae growth and high variations of sludge flows. The presentation will conclude

on the improvements of plants such as Amaala as reference for future plants moving forward, in particular in terms of 100% renewable supply, reduction of chemical dosing and of the footprint.

Keywords: Renewable energy; Solar panels; Footprint reduction; Case study; Saudi Arabia

PT 79

Optimization and design of energy recovery systems

Hussain Basamh*, Muhammad Ridwan, Thomas Altmann, Ratul Das

ACWA Power, Jeddah 23545, Saudi Arabia
hbasamh@acwapower.com

The rising cost of power necessitates innovative approaches to energy conservation. Minimizing the specific energy consumption (SEC) is a critical design factor when planning Reverse Osmosis (RO) plants. In the water treatment sector, the use of Energy Recovery Devices (ERDs) is essential to reduce energy wastage. These devices utilize the brine pressure, which is slightly lower than the feed pressure, to transfer energy to the RO feed. Given that most new desalination plants rely on reverse osmosis (RO) to address water scarcity, conserving the energy used in this process is crucial. The ERD Program evaluates the performance of existing or new energy recovery systems, calculates energy consumption for each pump in an RO system, and determines overall energy usage. Consequently, the tool recommends a new pressure exchanger system by calculating the required number of pressure exchanger units, overall efficiency, and potential power savings compared to the current system. Additionally, the tool's ERD Analytics function generates historical charts for pressure exchanger overall efficiency as well as pretreatment and RO specific energy consumption. This software aims to enhance energy conservation, reduce operational costs by avoiding the use of excess pressure exchanger units, and improve the overall efficiency of the pressure exchanger system. By providing data and insights, it facilitates informed design decisions.

Keywords: Pressure exchanger efficiency; Specific energy consumption; Energy recovery device; Brine pressure; Reverse osmosis; Data-driven analytics; Diagnostic

PT 81

Eutectic solvent (ES)-based flow electrodes for water desalination

Elena Gabirondo, Hafiz Saif, Vitor Alves, João Crespo, Liliana Tomé, **Sylwin Pawlowski***

**Universidade NOVA de Lisboa, Caparica 2829-516, Portugal*
s.pawlowski@fct.unl.pt

Flow-electrode capacitive deionisation (FCDI) is an emerging electro-membrane desalination method where electrodes) are used to extract ions from salty water. In FCDI, a flowable carbon particle slurry (usually made of activated carbon dispersed in water) is used instead of the fixed electrodes employed in other desalination technologies, allowing for continuous desalination without needing a separate electrode regeneration step.

This study pioneers using eutectic solvents (ES) as flow electrodes in FCDI, offering a novel and better alternative to water-based flow electrodes. The eutectic solvent, choline chloride-urea (ChCl-U), was selected for its broad electrochemical stability window to apply voltages higher than 1.23 V without inducing water splitting. The effect of water incorporation on the viscosity and performance of the ES-based flow electrodes was investigated. The cyclic voltammetry measurements confirmed the electrochemical stability, while rheological and electrochemical impedance spectroscopy demonstrated that the addition of water reduced viscosity and enhanced the conductivity of ChCl-U, making it suitable to be used as flow electrodes in FCDI systems. Desalination experiments were performed within a potential range of up to 2.2 V.

The ChCl-U flow electrode with 20 wt.% water and 10 wt.% activated carbon achieved the best balance among desalination efficiency (83%), desalination rate (0.17 mg/cm²·min), and effluent quality. Furthermore, 1H NMR analysis demonstrated the absence of eutectic solvent traces in the dilute stream. The results obtained highlight the potential of ES-based flow electrodes to improve desalination processes by enabling higher operational voltages and improved performance, thus paving the way for more efficient FCDI desalination systems.

Keywords: Flow electrode capacitive deionisation; Desalination; Eutectic solvents; Flow electrodes

PT 82

Dolomite for magnesium supplementation of desalinated drinking water in Saudi Arabia

Christopher Fellows*, Ali Alhamzha

**University of New England, Villa 208, Jubail 31951, Saudi Arabia*
cfellows@une.edu.au

Magnesium (Mg) in drinking water is important for cardiovascular health and it is anticipated that the World Health Organization will introduce minimum Mg recommendations. The Kingdom of Saudi Arabia is dependent on desalinated water which has a low Mg content and it is necessary to find a cost-effective means of supplementation. Dolomite ($CaMg(CO_3)_2$) is available at a similar cost to the limestone currently used in post-treatment. Replacement of limestone with dolomite in existing contactors in two commercial desalination plants was effective in raising magnesium concentrations in the produced water by 2.4±0.5 ppm (Shoiabah, multi-stage flash desalination) and 2.9±0.2 ppm (Al Khobar, Reverse Osmosis desalination), sufficient to lift total Mg above the Saudi Arabian guideline value of 5 ppm.

Keywords: Post-treatment; Magnesium; Health; Limestone contactor; Dolomite

PT 84

Optimization of forward osmosis (FO) modules arrangement for high-efficiency feed concentration in single-pass operation

Rajashree Yalamanchili*, Pere Olives Cegarra, Albert Galizia,
Gaëtan Blandin

**LEQUIA - University of Girona (UdG), Girona 17003, Spain*
Tel. +34 666694729, rajashree.yalamanchili@udg.edu

Introduction

Forward osmosis (FO) has emerged as a promising low-energy membrane-based concentration technology, leveraging osmotic pressure differences to separate water and solutes. This capability positions FO as an alternative to conventional thermal and pressure-driven processes, which, while effective, face limitations such as high energy requirements, fouling and scaling. FO systems can achieve high recovery rates while maintaining low energy consumption, making them applicable in diverse sectors, including desalination, nutrient recovery and valuable compound extraction. Previous studies have not assessed high feed solution (FS) concentration conditions and were conducted using small scale setups and recirculating FS and draw solution (DS). Despite its advantages, realizing FO's full potential requires a deeper understanding of its modular configurations, flow dynamics, and scalability, especially in single-pass continuous operations.

Methodology

Three new Aquaporin HFFO2 modules were employed and initially tested individually to identify operational differences in co-current and counter-current orientations. Tests used two FSs, DI water and 5 g/L saline with a DS salinity of 35 g/L. Flow rates were set at 54 L/h for the FS and 22.2 L/h for the DS. Following the same operating conditions, subsequently, linear configurations were tested by sequentially connecting two and three modules, followed by a tree configuration with modules arranged in a branching pattern across two stages. A MATLAB-based model was developed considering the mass-transfer limitations in FO and validated with experiments to study key performance metrics, including osmotic pressure evolution, flux, recovery, and flow rates across module lengths.

Results and discussion

When testing individual FO modules, most significant performance variations arose from differences in the FS rather than among the modules themselves. For single-module operation, flow direction showed no significant performance impact. Modules achieved recovery of 64.27–71.81% with DI FS and 45.45–51.67% with 5 g/L FS, reflecting osmotic gradient effects. The MATLAB model showed strong agreement with experiments in both flow directions. In linear configuration, counter-current flow outperformed co-current, optimizing osmotic pressure utilization and achieving an FS concentration factor of 4.59 versus 2.61 with three modules in linear. However, simulation results revealed linear arrangement was limited by operational instability due to handling high diluted DS volumes. Tree configuration addressed the limitations of linear setup by enabling parallel flows in the first stage and a single flow in the second, improving volumetric management and flow distribution. In counter-current mode, it slightly outperformed the linear configuration, achieving an FS concentration factor of 5.1 with more balanced flow rates. Its design ensured stable flux across modules, enhancing scalability and operational reliability.

Keywords: Forward osmosis; Single-pass; Modular configurations; Counter-current flow; Concentration process

PT 85

Optimizing solar and wind energy for reverse osmosis desalination in water-stressed regions

Ahmed Geweda*, Ahmed Omera, Awad Alquaity

**King Fahd University of Petroleum and Minerals, Alzahran, Saudi Arabia*
Tel. +966 569516682, g202215240@kfupm.edu.sa

This study addresses freshwater shortages and sustainable energy supply by integrating renewable energy systems specifically photovoltaic (PV) and wind energy into a reverse osmosis (RO) desalination plant to produce total water consumption about 30 MCM/year (3500 m^3/h). Using the System Advisor Model (SAM) software, the feasibility of a 25 MW plant was assessed under local conditions. The PV system, comprising mono-crystalline

modules with 20.95% efficiency, achieved an annual energy output of approximately 64 million kWh at a capacity factor of 22%. The financial analysis showed a nominal LCOE of 7.93 ¢/kWh and an IRR of 5.78%, with a net capital cost of $48.9 million. Meanwhile, the wind system, using 10 turbines of 2.5 MW each, generated about 65 million kWh annually with a 29.7% capacity factor. Its financial metrics included a lower LCOE of 6.20 ¢/kWh and a higher IRR of 31.18%, with a capital cost of $40.9 million. While the wind system demonstrated superior efficiency and financial returns, the PV system proved advantageous in solar-dominant regions due to stable and low-maintenance energy production. Both systems significantly reduced reliance on fossil fuels and aligned with sustainability goals. This research demonstrates the feasibility of renewable-powered desalination, offering a scalable solution to water and energy challenges, reducing emissions, and supporting socio-economic growth in resource-constrained areas globally.

Keywords: Reverse osmosis (RO); Photovoltaic (PV); Wind energy; Financial analysis

PT 86

Innovative RO membrane for enhanced boron rejection and cost-effective desalination

Arwa Alsaggaf, **Isam Aljundi***

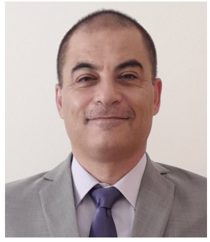
King Fahd University of Petroleum & Minerals, CHE Department, Dhahran 32161, Saudi Arabia
aljundi@kfupm.edu.sa

Boron removal remains a significant challenge in desalination, as its presence in treated water at elevated concentrations can harm human health and restrict water reuse applications. Conventional reverse osmosis (RO) membranes often fall short in effectively rejecting boron due to its small molecular size and neutral charge under typical desalination conditions, necessitating complex multi-pass systems. To address this, a novel RO membrane was developed by functionalizing the membrane with selective boron-binding ligands, tailored to enhance boron rejection without compromising water flux or salt rejection. The advanced modification enables strong interaction with boron, resulting in excellent rejection under standard conditions. This high efficiency allows for a simplified single-pass RO process, significantly reducing both operational and capital expenditures. The proposed solution demonstrates a transformative approach for boron management in desalination industry, offering a sustainable and cost-effective pathway to produce safe, high-quality water.

Keywords: Boron; TFC; Membranes

PT 87

Selective recovery of magnesium hydroxide from reverse osmosis reject brine via reactive crystallization



Qazi Iqra Shafi, **Isam Aljundi***

King Fahd University of Petroleum & Minerals, Dhahran 32161, Saudi Arabia, aljundi@kfupm.edu.sa

Recovering valuable resources from reverse osmosis (RO) reject brine is an essential step toward sustainable water treatment processes and brine management. This study focuses on the selective precipitation of magnesium hydroxide ($Mg(OH)_2$) via reactive crystallization from RO reject brine. The experimental work evaluates the effects of three critical parameters: temperature, pH, and seed concentration, on the efficiency and selectivity of magnesium recovery. Temperature was found to significantly influence both the precipitation rate and crystal morphology. Higher temperatures enhanced the solubility of competing ions, improving the selectivity for magnesium hydroxide. The pH was systematically varied to determine the optimal range for magnesium hydroxide precipitation while minimizing the co-precipitation of other salts. Results indicate that a pH range of 9.5 to 10.5 maximizes magnesium recovery while ensuring high purity. Seed concentration was also investigated as a means to control nucleation and growth dynamics. Higher seed concentrations reduced induction time and promoted larger crystal sizes, which are favorable for downstream separation processes. The interplay between these parameters was analyzed to establish optimal operating conditions for selective and efficient magnesium recovery. The findings demonstrate that selective precipitation of magnesium hydroxide from RO reject brine is feasible with proper control of process parameters, offering a pathway for valorizing brine while reducing its environmental impact. This approach supports the development of integrated water treatment and resource recovery systems that align with circular economy principles.

Keywords: Magnesium hydroxide; Brine valorization; Reject brine; Reverse osmosis

PT 88

3D printing of profiled cation-exchange membranes for harvesting salinity gradient energy from membrane distillation brines

Mekhna Venu*, Cláudia Galinha, João Crespo, Sylwin Pawlowski

Nova University Lisbon, Campus de Caprica, Caprica 2829-516, Portugal
m.venu@campus.fct.unl.pt

Reverse electrodialysis (RED) is a promising electromembrane technology that generates renewable energy from salinity gradients, such as mixing freshwater and membrane distillation brine, with an energy potential of 17 MJ/m³. The most common arrangement of RED stacks is 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 have advantages such as higher mass transfer and lower pressure drop, overcoming the limitations caused by concentration polarization, fouling and spacers shadow effect. However, the manufacturing of such membranes is challenging.

This study introduces a pioneering approach to preparing profiled 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, including chevron and stripe profiles. The electrical resistance of the prepared membranes and commercial alternatives (e.g., FUMASEP® FKB-PK-130) were very similar (10.7 vs 9.7 Ω·cm²). Furthermore, the electrical resistance of 3D-printed membranes increased much less than commercial alternatives after being submerged in a 5 M NaCl solution for 30 d, which demonstrates their promising potential for use when in contact with membrane distillation brines, which is one of the objectives of the EXBRINER project (https://exbriner.unical.it/) under which this research was conducted. 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 RED and other electromembrane processes.

Keywords: Ion-exchange membrane; Salinity gradient; 3D printing; Profiled membrane

PT 90

Pre-treatment of mine water for reverse osmosis by means of manganese dioxide filtration

Andrea Kassahun*, Harald Maedl

Wismut GmbH, Jagdschaenkenstrasse 29, Chemnitz 09117, Germany
Tel. +49 371 8120145, a.kassahun@wismut.de

Wismut GmbH is a state-owned company which performs the reclamation of the former East German uranium mine sites. A major task is mine water treatment to reduce pollutant and salt levels to regulatory limits. Mine water commonly contains iron and manganese in mg/l concentration ranges next to inorganic pollutants and high salt loads. Therefore, the application of membrane filtration for mine water treatment requires pre-treatment to reduce foulant concentration levels to about 50 µg/l. As part of a feasibility study for cleaning up a former uranium processing tailings management facility (TMF) drainage by membrane filtration, pre-treatment options for iron and manganese elimination were investigated. The pre-filtration of the TMF drainage, which contains up to 2 mg/l manganese and 0.5 mg/l iron, was tested in the laboratory. As filter material a natural manganese dioxide mineral (GAWU) was used. The material consists of a mixture of MnO minerals (about 70 wt %; X-ray fluorescence analysis), in particular of nsutite, ramsdellite, lithiophorite, pyrolisite, ferrihollandite, cryptomelane and todorokite (XRD analysis). Lab tests were performed in glass columns at different filtration and backflush velocities. Prior to the filter column passage, the original drainage water was adjusted in pH to optimize manganese speciation. During test periods of 6 weeks, total outflow manganese concentrations of 5 to 50 µg/l and total outflow iron concentrations of 30–100 µg/l were obtained. Dissolved manganese and iron concentrations amounted to <5 µ/l. The laboratory tests as well as the mineralogical investigations of the filtration materials prior and after the tests by REM analysis will be presented in detail. Based on the excellent performance of the manganese dioxide filter material, a pilot test was designed for upscaling the filtration flow rate to 1 m^3/h. Next to the manganese dioxide filters, an ultrafiltration unit will be operated in the pilot plant for further iron polishing prior to the reverse osmosis unit.

Keywords: Pre-treatment; Foulant elimination; Manganese and iron removal; Manganese dioxide filtration; Mine water desalination

PT 91

Enhancing productivity and energy efficiency in vacuum assisted air gap multistage membrane desalination

Ahmed Omera*, Mohammed Antar

**King Fahd University of Petroleum and Minerals, Dhahran 5051, Saudi Arabia*
g202313810@kfupm.edu.sa

In the 21st century, the shortage of freshwater is one of the most critical challenges around the world. Employing an environmentally friendly, cost-efficient, and energy-saving membrane distillation (MD) process offers a sustainable solution to address pollution from industrial and domestic waste sources. MD operates as a thermally driven separation process based on vapor–liquid equilibrium, utilizing a microporous hydrophobic membrane to facilitate separation. This work presents a detailed analysis of the multistage vacuum-air gap membrane distillation V-AGMD in two different configurations to establish the relationship between operational parameters and unit production cost (UPC). The parallel and series configurations are investigated using spiral-wound membranes. In the parallel configuration, the total feed flow rate fed to the system is divided equally among the modules, and the total flow is equal to that fed to the first stage of the series configuration. The membrane specifications are length, 1.5 m with six spiral envelopes in each evaporator and condenser channel. The study evaluates the effects of various factors, such as feeding temperature, vacuum pressure, coolant temperature, and the number of stages, providing valuable insights into the trade-offs between permeate production, energy efficiency, and cost-effectiveness. Performance metrics including Gained Output Ratio (GOR), permeate rate, and UPC are employed to assess the system's efficiency. The multistage MD systems outperform single-stage systems significantly, delivering higher permeate flow rates, improved GOR, and lower UPC values.

These results showed clearly that a system configuration with operational parameters greatly influences the viability of desalination technologies. The series configuration consistently exhibited higher permeate production compared to the parallel configuration. For the series configuration, permeate production was approximately 90 L/h at a feed temperature of 80°C, higher than the parallel configuration's steady output of 30 L/h. Similarly, applying more vacuum, the series configuration maintained higher production, although it dropped from 90 L/h at 20 kPa to 50 L/h at 100 kPa, reflecting a 44% decrease. In terms of energy efficiency, the parallel configuration outperformed the series configuration. Its GOR reached a peak of approximately 9, which was 200–300% higher than the series configuration's GOR of around 3. This behaviour is consistent across all operating conditions, including variations in feed temperature, vacuum pressure, and coolant temperature. The superior energy efficiency of the parallel configuration makes it particularly attractive for systems prioritizing reduced energy consumption. The UPC in parallel configuration decreased significantly with an increasing number of modules, stabilizing at approximately 6 $/m³ by the 30th module, compared to the series configuration, which exceeded 12 $/m³ with five modules. This represe

Keywords: Vacuum air membrane distillation; Multistage system; Parallel and series stage-connections; Economic analysis

PT 92

The distribution and prediction of liquid column velocity between horizontal tubes

Yiming Zhao*, Xingsen Mu, Shun Hu, Caixue Yang, Wenxu Qu, Shengqiang Shen, Zhe Tang

**Dalian University of Technology, Dalian 116024, China*
479819484@qq.com

The flow pattern of the liquid between horizontal tubes is one of the important factors affecting the heat and mass transfer efficiency of horizontal-tube falling-film flow process, and it is the most noteworthy part of optimizing the efficiency of horizontal-tube falling-film evaporators. The columnar flow is the most widely used flow pattern in the horizontal-tube falling-film evaporation device. In this paper, the velocity distribution of the liquid column between the tubes under different working conditions was analyzed by building a horizontal-tube falling-film flow experiment platform. At the same time, a machine learning model based on SCA-SVR is constructed to predict the velocity of liquid column. Results show that the velocity of the liquid column increases with the increase of landing distance and the increase of the spray density. When the spray density increased from 0.05 to 0.06 kg/(m·s), the liquid column velocity does not increase significantly and fluctuates greatly. The liquid column velocity in the area near the lower tube at low spray height is significantly lower than that at the same landing distance at high spray height. The SCA-SVR model can well predict the liquid column velocity between tubes. The average absolute percentage error is 7.0996%, and the root mean square error is only 0.0223.

Keywords: Horizontal-tube falling-film flow; Liquid column velocity; Machine learning; SCA; SVR

PT 93

LIFE ELEKTRA – Circular economy applied to nitrate removal, hydrogen generation and waste recovery in drinking water

Javier Sanchis-Carbonell, Bernardo Lliso, Jaume Cotolí, Miguel Capilla, Josep Ernest Escrivà, Marta Díaz, María Pedro-Monzonís*

Aguas de Valencia - Global Omnium, Gandía 46701, Spain
Tel. +34 674768437, mapemo@globalomnium.com

The presence of nitrates in water is a serious worldwide threat to human health and aquatic ecosystems and affects many EU countries. Water management needs sustainable solutions aligned with the circular economy approach to improve society and the environment. The main objective of LIFE ELEKTRA is to develop on an industrial scale a technology based on electrochemical denitrification that allows the removal of nitrates in concentrated streams. Moreover, the process will allow: (1) the use of different ionic compounds that can be used in other industrial processes and (2) the recovery of a hydrogen stream for energy use in the same process, which will be complemented with the installation of photovoltaic panels.

The electrochemical denitrification process takes place in a reactor in which water is subjected to a discharge of electric current which, together with specific catalysts, reduces the nitrate ion to nitrogen gas. For this purpose, a reactor capable of treating 50 L of water was designed and constructed with a Sn-Bi alloy cathode, a DSA-O2 anode and a membrane with an active geometric area of 3300 cm^2. The anolyte was a sulphuric acid solution and the electric current was set at 165 A for a period of three hours, the potential difference between the electrodes being set at 16.5 V. In order to optimise the process, a first softening stage was implemented using ion exchange resins, followed by a reverse osmosis stage that allowed to reach nitrate concentration around 1400 ppm. After the denitrification stage, a post-filtration stage was introduced to adapt the product water to the needs of its use. At the same time, a hydrogen capture and storage stage was designed and built using hydrides for subsequent use, capable of generating 0.45 kWh/m^3 of treated water. At the reactor outlet, the results show a reduction in nitrate concentration of more than 90%.

The results of the pilot plant obtained in Gandia demonstrate the feasibility of this process which will be replicated in Gran Canaria (Spain) and Mgarr (Malta), where the pilot plant will be transported for validation. Meanwhile, a third case study will be carried out in Gandía (Spain), where this technology will be scaled up to reach a higher treatment capacity.

Keywords: Nitrates; Electrochemical denitrification; Brine treatment; Circular economy; Salts recovery

PT 95

Synthesis of low-cost, high-performance ceramic membranes for efficient water treatment

Zakia El Bouhali*, Abdelaziz Atter, Rachid Benhida, Khaoula Khaless

**University Mohammed VI Polytechnic (UM6P), Hay El Matar,
EL Jadida 24000, Morocco
Tel. +212 669517546, Zakia.elbouhali@um6p.ma*

Water is a vital source of life for all living beings, covering around 75% of the earth's surface, The water sector is faced with several issues, including population growth and climate change, as well as dwindling water resources. To face these challenges, it is essential to find innovative solutions for the efficient management of water resources.In this context, membrane filtration technologies play a decisive role in managing water stress and are increasingly competitive with other technologies. Today, a variety of membranes are available, each with specific characteristics to suit the type of separation process required. Among these membranes, those made from ceramics are promising, with remarkable properties such as higher thermal and chemical stability, changeable micro-structure, reduced energy consumption at gentler conditions, raised cleaning efficiency, high permeability and low environmental impact are only a handful of its advantages. [1]

As a matter of fact, commercial porous ceramic membranes are made from oxides such as aluminum , zirconium , silicon, and titanium. However, their high cost has driven earlier research to investigate the use of more economical materials such as sand, fly ash, clay, pozzolan, phosphate, etc., for membrane manufacture.

In this respect, our study deals with the preparation of ceramic membranes from natural Moroccan resources, mainly phosphate and red clay. Such a choice is based on their excellent properties. Red clay, rich in aluminosilicates, has excellent thermal resistance and presents favorable characteristics for paste shaping due to its plasticizer and binder role. The latter, after hardening by firing, will contribute to stability and robustness of the membranes. Phosphate will be chosen because of its high CaO and P_2O_5 content; the high CaO/P_2O_5 ratio, higher than 1/3, confers on the final material high mechanical strength and makes it suitable for applications requiring robustness and durability.Tests conducted by mixing phosphate at various percentages relative to clay have revealed promising opportunities in terms of both resistance and performance.The synthesized membranes exhibit exceptional properties, combining high mechanical, thermal, and chemical resistance with a highly porous structure and an impressive retention capacity of 99%.

Keywords: Water treatment; Membrane technologies; Ceramic membranes; Moroccan phosphate; Red clay

[1] S.M. Samaei, S. Gato-Trinidad, A. Altaee, The application of pressure-driven ceramic membrane technology for the treatment of industrial wastewaters—a review, Sep. Purif. Technol. 200 (2018)

PT 96

A model for batch operation in vacuum-assisted air gap membrane distillation

Isabel Requena*, Juan Antonio Andrés-Mañas, Guillermo Zaragoza

**CIEMAT-Plataforma Solar de Almería, Plataforma Solar de Almería, Tabernas 04200, Spain,
isabel.requena@psa.es*

One of the current challenges for desalination is achieving zero liquid discharge (ZLD). For this purpose, it is necessary to properly manage the residue of the current desalination technologies, whose salinity limit is 75 g/L. Seawater also contains valuable minerals in low concentrations. Concentrating the brine facilitates its subsequent crystallization and valorization, as the volume of the brine is reduced and, in addition, more fresh water is produced. One of the alternatives for this objective is membrane distillation (MD), which can achieve high brine concentration and water recovery when operating in recirculation.

To date, the best performance in pilot-scale MD has been achieved with multi-envelope spiral-wound modules operating in vacuum-assisted air gap (V-AGMD) configuration. The best module to operate at high salinities is the one with 25.92 m^2 of membrane. With this module it is possible to concentrate the brine up to concentrations even higher than 245 g/L.

It would be very time-consuming to carry out many experiments in recirculation to optimize the process. To overcome this handicap, a dynamic model has been developed to simulate the operation. With this model it is possible to obtain the required operating time, the permeate productivity and the specific thermal energy consumption (STEC), depending on the initial and final salinity of the brine, the volume of brine to be treated, and the operating conditions: the inlet temperatures (of the evaporation and cooling channels) and the feed flow rate (FFR). Another function of the model is to simulate the operation and calculate the FFR (in a range between 400 and 1100 L/h) that minimizes the STEC, since its optimum value depends on the feed salinity.

For instance, to concentrate a volume of 1.5 m^3 of brine at 70 g/L to 245 g/L, and assuming optimal operating conditions for permeate production (TEI = 80°C, TCI = 20°C and FFR = 1100 L/h), the required time would be 21.7 h, resulting in a cumulative STEC of 172.4 kWhth/m^3. However, if the FFR varies with salinity, the cumulative STEC would decrease to 152 kWhth/m^3 but the time needed would be 47.4 h. This model is highly useful to make decisions regarding the brine volume to be treated and the operating conditions based on the thermal energy available and the desired final salinity or permeate volume produced. Different cases will be evaluated and discussed.

Keywords: Membrane distillation; Pilot plant; Vacuum-assisted AGMD; Dynamic model; Batch operation; Brine concentration

PT 97

Thermal parameters distribution and heat transfer deterioration in a horizontal tube falling film evaporator

Chao Li*, Dayuan Yuan, Liuyang Zhang, Qiang Meng, Shengqiang Shen

**Dalian University of Technology, Dalian 116000, China*
Tel. +86 18742021575, heatlichao@mail.dlut.edu.cn

In this study, the distributed parameter model of a horizontal tube falling film evaporator in the low temperature multi-effect distillation (LT-MED) desalination system is established. The process of falling film evaporation of seawater outside the tubes, the process of steam condensation and flow inside the tubes, and the process of secondary steam flow between the tube bundles are coupled. The distribution laws of saturation pressure between tube bundles, temperature inside and outside the tubes, total heat transfer coefficient, and effective heat transfer temperature difference are described. Two antagonistic mechanisms affecting the distribution of effective heat transfer temperature difference are proposed, and the heat transfer deterioration region and its moving law are identified, which can guide the selection of evaporator structural parameters and operating parameters.

Keywords: Horizontal tube; Falling film evaporator; Parameter distribution; Seawater

PT 98

Testing polymeric membrane resistance to ozone to extend membrane lifetime or promote their recycling

Bianca Zappulla Sabio*, Gaetan Blandin, Wolfgang Gernjak, Lide Jaurrieta

LEQUiA – UdG, C/ Pic de Peguera, 15, Porta B, Taller 14, Girona 17003, Spain
bianca.zappulla@udg.edu

Introduction

Water scarcity has driven the rise of desalination plants, increasing end-of-life (EOL) reverse osmosis (RO) membranes. With a 5–10-year lifespan, these membranes are often landfilled or incinerated, underscoring the need for sustainable recycling. Interest in recycling has grown, focusing on indirect methods (dismantling modules) and direct methods (modifying polyamide –PA– layer). Chlorine treatment is commonly used to convert RO membranes into NF or UF membranes, but more sustainable alternatives are needed. Ozone is known for being a strong oxidant used in water treatment process to disinfect water and eliminate organic contaminants. As for chlorine, remaining ozone may be present in water entering membrane modules but how ozone interacts with polymeric membranes remained poorly studied. The aim of this work is to evaluate how ozone is interacting with the polymeric membranes and establish if it can be toxic during membrane life operation or used to degrade the different layers of the membranes in EOL membrane recycling.

Materials and methods

RO (SW30 and BW30) and NF (NF90 and NF270) membranes were submerged for 1, 5, 15, and 30 min into a 3 L reactor filled with distilled water and enriched with ozone (20 ppm). Membranes characterization (permeability and salt rejection) and surface characterizations were performed to gain deeper insights into the changes occurring on the membrane. Results obtained were compared with the ones obtained with the membranes treated with chlorine.

Results and discussion

Initial tests demonstrated that ozone has an impact on polymeric membranes showing an increase in permeability and an exponential decrease in salt rejection after its contact. Also, results suggest that ozone is not only affecting the PA layer but is also leading to the polysulfone (PSf) layer degradation. SW membranes, compared to BW, exhibited greater resistance to ozone exposure, retaining partial functionality for a longer contact time with ozone. However, after 15 min of exposure, RO membranes were not able to reject salt anymore. NF270 demonstrated the greatest resistance to ozone maintaining its salt rejection capacity even after 30 min of ozone exposure and showing a much lower permeability increase.

Compared to chlorine, ozone exhibits a significantly higher oxidative capacity achieving faster conversion rates at lower doses. BW30 membrane reached a permeability of 225 $L \cdot m^{-2} \cdot h^{-1} \cdot bar^{-1}$ after 1 ppm·h, while with chlorine 300,000 ppm·h was necessary to achieve a slightly higher permeability of 275 $m^{-2} \cdot h^{-1} \cdot bar^{-1}$. The two methods showed a difference in degradation uniformity: chlorine caused uniform membrane degradation, while ozone created localized string damage with full removal of polymeric layers.

Conclusions

Overall, low tolerance of polymeric membranes to ozone was demonstrated showing the need to avoid remaining ozone in full scale operation and offering new way for EOL membrane transformation.

Keywords: Chlorine; Membrane degradation; Membrane reuse; Ozone; Polymeric membranes

PT 99

Optimising energy efficiency of seawater desalination plants with high-recovery by coupling OARO and RO processes

Jesús Montes-Sánchez*, David Sánchez, Lourdes García-Rodríguez

University of Seville, Seville 41008, Spain
Tel. +34 608356573, jmontess@us.es

This work focuses on the topic "Advanced techniques and processes" considering high recovery processes. This paper deals with optimising the energy efficiency of high-recovery seawater desalination. To this end, an innovative configuration is proposed aimed at enhancing energy efficiency by coupling osmotically assisted reverse osmosis (OARO) and Reverse Osmosis (RO) processes. The assessment presented includes energy efficiency along with estimations of product costs in comparison with other configurations reported in the literature based on the following concepts: multiple stages, closed circuit RO, ultra-high pressure RO, and other combinations of OARO and RO. Moreover, complementary technical aspects are discussed in comparison with conventional plants. Specifically, additional pretreatment requirements, preselection of main components, dependence of the specific energy consumption on the temperature evolution throughout the year, plant footprint, control strategies to operate driven by variable renewable energies, etc. The comparative analysis of different plant locations allows to identify the scenarios with the best market prospects. Besides, a wide range of energy costs is studied in order to assess the use of renewable energies with grid backup.

Keywords: Brine concentration; Seawater reverse osmosis desalination; Osmotically assisted reverse osmosis; Energy efficiency

PT 100

Simulation and modelling of a small-scale barometric desalination unit

Sami Own*, Adel Nasser, Hector Iacovides

The University of Manchester, Manchester M54EE, UK
sami9_9@ymail.com

This research introduces an innovative and sustainable approach to desalination, offering a more efficient and eco-friendly process. The method involves distilling freshwater from saline water at near-ambient temperatures and under near-vacuum pressures by exploiting a passive vacuum created by a barometric column. This setup allows for the use of solar energy or other low-grade energy sources to drive the process. The required vacuum pressures are naturally achieved within the headspace of water columns with a height equal to the local barometric head.

The configuration comprises an evaporation chamber inside which a flat plate solar collector, a condenser heat exchanger, and three ten-meter height columns serve as the saline water column; the brine withdrawal column; and the freshwater column, each with its own holding tank installed at ground level. These components are interconnected and managed via circulation pumps and control valves, forming a configuration that is not only cost-effective to construct, operate, and maintain but also easily integrable with other systems. By utilizing renewable energy sources, particularly solar power, the design ensures a low-temperature desalination process that is both environmentally friendly and economically viable.

By leveraging principles of thermodynamics, fluid mechanics, and heat transfer, this study develops a comprehensive simulation model in MATLAB to evaluate the potential of the Barometric Vacuum Desalination System (BVDS). Theoretical analysis demonstrates that this configuration is not only feasible but also highly efficient in producing high-quality freshwater. Moreover, it highlights the system's scalability, sustainability, and adaptability to resource-constrained environments, making it a promising solution for addressing global water challenges.

This research advances the field of sustainable desalination technologies, addressing critical global water challenges. The system demonstrates efficient operation under diverse conditions, delivering potable water with minimal environmental impact. Additionally, the findings emphasize the scalability and economic viability of BVDS, particularly for remote and arid regions.

Future research will focus on optimizing the system for large-scale applications and incorporating advanced energy storage solutions to enhance performance and reliability.

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

PT 101

Commissioning a solar-powered zero liquid discharge desalination pilot: Sol2H2O joint research

Frederico Felizardo*, Pedro Horta, Andrea Cipollina, Guillermo Zaragoza, Isabel Requena, Juan Antonio de la Fuente, Ángel Rivero Falcón

University of Évora, Largo dos Colegiais, 2, Évora 7004-516, Portugal
facf@uevora.pt

The commissioning phase of innovative water production systems is a crucial step in transitioning from theoretical design to practical application. Within the Sol2H2O project (Horizon Europe GA Nr. 101079305), a Joint Research Activity launched in late 2022 focuses on a high recovery rate solar desalination system employing a Zero Liquid Discharge (ZLD) approach. The developed pilot integrates photovoltaics-powered reverse osmosis (PV/RO), a multiple-feed plug flow reactor (MF-PFR), vacuum-enhanced membrane distillation (MD), and solar evaporation ponds to maximize freshwater recovery and brine valorization.

The system's modular design allows precise control of each stage, facilitating batch operation and ensuring water quality under varying conditions. Targeting up to 80% water recovery—exceeding the industry standard of 50%—the process begins with pre-treated Atlantic Ocean seawater (35 g/L salinity) stored in 100 m³ tanks. The PV/RO unit recovers ~50% of the water, with the remaining brine undergoing further processing to minimize waste.

In the second stage, the MF-PFR employs fractionated reactive crystallization for selective ion recovery. Magnesium hydroxide precipitates at a lower pH, while calcium hydroxide requires a higher pH (>12). Adjustments in Sodium hydroxide (NaOH) dosing were critical to optimize ion recovery. The clarified effluent is neutralized with hydrochloric acid (HCl) and directed to the MD unit, which concentrates the brine (>220,000 ppm), producing freshwater and a retentate for final treatment.

The final stage utilizes solar evaporation ponds to harvest high-purity NaCl, achieving complete brine valorization. This eliminates liquid effluents, aligning with circular water management principles.Early commissioning observations highlight promising system integration, focusing on energy efficiency and operational stability under real-world conditions: - initial trials with RO systems enabled due regulation of water inlet pressure to mitigate cavitation in the RO pump after fine-tuning of pump settings and pre-treatment conditions to ensure consistent operation; - Adjusting NaOH concentration in the MF-PFR was key for selective ion recovery. Magnesium hydroxide precipitated at lower pH, but calcium precipitation requires a pH >12. Increasing NaOH ensures sufficient hydroxide ions for calcium. These results underscore the importance of precise dosing and pH control for optimizing MF-PFR performance.

Following commissioning, experimental trials will assess water recovery, brine valorization, and energy efficiency. Future work will optimize system scalability and include techno-economic and environmental evaluations to advance sustainable water production technologies. This article focuses on pilot commissioning, highlighting component adjustments, system integration findings, and initial experimental data.

Keywords: Photovoltaics-powered reverse osmosis (PV/RO); Demonstration pilot; Multiple-feed plug flow reactor (MF-PFR); Vacuum-enhanced membrane distillation (MD); Zero liquid discharge desalination

PT 102

Utilization of a pilot-scale electrochemical unit for the treatment of spent caustic and oil-based produced water streams

Bassam Tawabini*, Abdullah Basaleh, Saleh Al-Aqeel

**KFUPM, Geosciences Department, Box 189, Dhahran 31261, Saudi Arabia*
Tel. +966 502145429, bassamst@gmail.com

Spent caustic and oil-based produced waters are two examples of difficult industrial waste streams that are generated from operations in the petrochemical and petroleum industries. Disposal of such waste streams imposes great challenges to industrial sector treatment due to their serious negative health and environmental impacts. Treatment of these streams is adding to the challenges because of their complex physiochemical nature. The recent strict Saudi regulations for the discharge of these two streams make it necessary to search for more advanced treatment methods. For instance, spent caustic is characterized by high pH and elevated levels of carbonates and sulfides (odorous), while oil-based produced water contains large amounts of salts, heavy metals, and dissolved hydrocarbons. Spent caustic is mainly treated by a wet-air oxidation (WAO) process that brings the COD levels down to around 1000 ppm, and an extra post-treatment method is needed to reach the allowable disposal limit of 50 ppm. On the other hand, basic physical treatment is applied to produced water before it is reinjected into the subsurface oil field, leaving it with a high COD. In this study, pretreated authentic ethylene plant spent caustic effluents and synthetic produced water samples were further treated using an advanced oxidation (AOT) batch-mode pilot unit in a two-separate set of experiments. The AOT unit consists of anodic oxidation (AO) and in-situ generation of strong oxidants (i.e., hydrogen peroxide) in the electrolytic cell. A boron-doped diamond (BDD) and a gas diffusion electrode (GDE) were used for this purpose. The results of the spent caustic treatment part showed a maximum COD removal of 90% at pH 4,150 mA/cm^2 electric current density and circulation rate 0.2 L/min within 3 h. The results also showed that for the produced water stream, a COD removal of 84% at pH 12, 200 mA/cm^2 electric current density, and circulation rate of 0.2 L/min within 4 h. This work clearly demonstrated that electrochemical posttreatment is an efficient, cost-effective, and environmentally friendly technique for the treatment of both pretreated spent caustic and oil-based produced water.

Keywords: Industrial wastewater; Spent caustic; Oil-based produced water; Electrochemical; COD

PT 103

Accurate bench scale measurement of mass transfer in RO

Bastiaan Blankert*, Santiago Cespendes, Ratul Das, Thomas Altmann, Johannes Vrouwenvelder, Cristian Picioreanu

**KAUST, Thuwal, Saudi Arabia*
Tel. +966 544700692, bastiaan.blankert@kaust.edu.sa

In order to measure salt permeability, it is crucial to properly account for concentration polarization. The required mass-transfer coefficient (k) can in principle be obtained from characteristic mass-transfer relations (Sh vs Re), which are available in literature. However, it can be unclear whether those relations are adequate for a particular bench-scale test-cell. It appears straightforward to experimentally determine k instead. However, such procedures are extremely sensitive to measurement errors, artefacts, and (unnecessary) simplifications – thus measurement errors are amplified in the observed k. The non-linear relation between measured variables and the observed k also introduces a bias. This bias is proportional to the square of the measurement error, and leads to over-estimation of k. Bias can be reduced by using a harmonic mean on multiple observations of k, it is nevertheless imperative to minimize the impact of measurement errors. The sensitivity of mass transfer (k) measurements for measurement errors can be expressed as a function of the dimensionless Peclet number (Pe) and the 'osmotic number' (Pi). Ideally, both these numbers should be large, however, due to the relation between Pe, Pi , and JW this is not possible and an optimal trade-off needs to be found. We optimize experimental conditions to obtain more reliable observations of k. We found that by critically addressing various common practices, and improved understanding of the effects of measurements errors, many error sources can be reduced by an order of magnitude. Mass transfer coefficients determined in this way are presented and will be compared to CFD models (with spacer) and theory (without spacer).

Keywords: Mass transfer; Bench scale testing; Error propagation; Optimization

PT 104

Steps for optimizing energy and water consumption in the operation of reverse osmosis systems with a focus on chemical treatment

Dan Freeman*, Liana Kunzler, Rodrigo Cadihna, Marck Solla, Leonardo Kuhn, Fiona Finlayson, Raul Gonzalez

**Kurita Europe GMBH, Theodor-Heuss-Anlage 2, Mannheim 68165, Germany*
dan.freeman@kurita-water.com

Water shortages have not been perceived as a major issue in most of Europe other than certain southern areas until recent decades. Steadily growing concerns regarding water availability became reality however, during the drought of 2022. In that year even

areas which had rarely experienced such issues became profoundly affected, prompting governments and policy makers throughout the region to reconsider the value and availability of water supplies. There is, consequently, an increasing requirement for water users to improve water efficiency and seek reuse and reclamation schemes.

Over the same period, geopolitical events have highlighted the requirement to move away from legacy energy sources, focusing attention on the energy consumption associated with industrial processes.

Reverse osmosis is one technology that is widely used to provide purified water for municipal and industrial applications and is also increasingly used in water purification and wastewater reclamation schemes. The growing need to optimize the performance of reverse osmosis systems from an energy, emissions and water recovery perspective is apparent.

This paper will focus on the chemical treatment in this context, highlighting the need to consider often overlooked areas which, when taken cumulatively, can have a significant impact. A case study example will be presented demonstrating how a proper understanding of system dynamics, water chemistry and water waste across the whole system can help operators to minimize the monetary and environmental cost of the process.

Keywords: Reverse osmosis; Chemical treatment; Water efficiency; Energy efficiency; Environmental emissions; Process optimisation

PT 105

Use of concentration polarization (CP) to predict and control membrane biofouling potential

Harvey Winters*, Eli Oklejas

Fairleigh Dickinson University, 704 Four Seasons Dr, Wayne NJ 07470, USA
Tel. +1 2016914766, harvey@fdu.edu

Membrane biofouling in seawater reverse osmosis (SWRO) desalination is the greatest impediment towards successful operation and its efficiency. Two of the most used indicators for predicting membrane fouling potential are the silt density index (SDI) and modified fouling index-UF (MFI) which have proved unsuccessful in predicting membrane biofouling potential. While these indicators may measure the biofouling potential in the feedwater before the RO membrane, they do not take into consideration the effect of membrane hydrodynamic conditions (flux and crossflow velocity) that controls deposition of biological foulants from the feedwater onto the RO membrane.

It has been shown that hydrodynamic conditions can be expressed as the membrane concentration polarization (CP) and in reality, the CP controls membrane biofouling. The CP of bacterial foulants is defined as the ratio of the concentration of the rejected bacteria near the membrane surface (boundary layer) to concentration of bacteria in the bulk flow.

There exists a critical CP value in the membrane boundary that determines whether the bacterial foulants will aggregate and then will deposit onto the RO membranes surface (cake layer). The greater, that the bacterial foulant concentration is present in the feedwater to the RO membrane, the lower is the critical CP. This critical CP reflects the separation from a planktonic form of bacteria (nohn-attached) and a periphytic form of an attached biofilm to the membrane surface.

The critical CP is controlled by the concentration of bacterial foulants in RO feedwater and hydrodynamic conditions which are the membrane flux and membrane crossflow velocity (recovery). As the recovery increases, the critical CP values in single-stage SWRO decreases. In SWRO, when the permeability of the membrane used increases, the critical CP decreases and higher the membrane biofouling potential becomes. In addition, the first element in a pressure vessel has the highest CP and it is the most susceptible to membrane biofouling.

Most SWRO operating plants are single-stage facilities with each pressure vessel ranging from 6-8 elements. Because of the membrane biofouling issues, single-stage SWRO plants are limited to recoveries of less than 40% to stay within the critical CP limits. Since most SWRO plants are designed to operate from 40 to 50% recoveries, membrane biofouling potential increases. In contrast to single-stage SWRO, brine-stage SWRO can operate in recovery range of 60–70% without excessive cleanings because each of the two stages stays within the limits of their critical CP. Since the specific energy consumption (SEC), using the bi-turbo energy recovery (FEDCO) in brine-stage technology, and biofouling potential both decrease as the recovery increases, it is apparent that the future innovation in SWRO in controlling membrane biological fouling and lowering the SEC is with brine-staging bi-turbo technology.

Keywords: Critical concentration polarization; Membrane biofouling potential; Brine-stage SWRO

PT 106

Three-dimensional model of ion transport in composite membranes: effect of the internal structure and equivalent thickness

Fernan David Martinez Jimenez*, Bastiaan Blankert, Cristian Picioreanu

**KAUST, Thuewal 23953, Saudi Arabia,
Tel. +966 0566577157, fernan.martinez@kaust.edu.sa*

RO composite membranes contain an ultrathin polyamide active layer (AL) on top of polysulfone support. Most current theoretical models (solution-diffusion and solution-friction) assume ions and water transport through a uniform and homogenous AL. Nevertheless, a recent 2D model proved that AL's irregular morphology affects ion and water permeability 4. However, the internal structure and morphology, e.g., voids, channels, etc., and their effects are still debated. 3D reconstruction of the polyamide AL is arduous and challenging due to its length scale (nano), hampering image processing. Though, some works 5–9 have presented 3D structures for polyamide. For instance, Pacheco et al. (2016)6 claim that voids have diameters ranging from 15 to 35 nm. They reported voids that can connect with outer domains, which is contradictory because voids must be enclosed by material. On the other hand, Culp et al. (2018)7 studied the internal structure and suggested that the void fraction in AL is below 0.2% (v/v), disagreeing with Pacheco et al. (2016), who reported ca. 16%. Though those studies present relevant insights, their main goal was to characterise the AL, neglecting its impact on water and ion transport. Besides the internal features of the AL, its equivalent thickness is a topic broadly discussed due to its role in ion and water permeability 4,6,8,10, with reported values ranging from 15 to 700 nm.

This work presents the newly developed solution-friction 3D model to describe the NaCl transport through an RO composite membrane, considering a 3D TEM structure of polyamide AL. The model considers AL internal morphology (i.e., voids and channels), all transport mechanisms, membrane charge and the water-membrane partition effects. We aim to investigate the effect of the internal morphology of the polyamide AL on the transport of water (JW) and salt (JNa and JCl). Finally, we look to answer the following questions: 1) what are the effects of the internal features on the ions and water permeability? 2) What is the difference between ions and water permeability when applying a two- and three-dimensional solution-friction model? Finally, 3) Is it possible to obtain an equivalent thickness considering the internal structures of the AL that can reproduce the obtained results in 3D? Our results suggest that apparent voids in 2D can also be connected channels to outer domains. Concentration polarization affects the salt concentration in the channels, while the Na^+ concentration inside voids lies between the feed bulk and the current density inside the AL. Simulations show that void fraction doesn't significantly affect salt permeability, and the 2D model underestimates salt permeability by an error of 50% compared to the 3D model. Finally, we observed that the equivalent AL thicknesses reported in the literature are overestimated, and we propose a method to compute it considering internal features and the shortest path, allowing a 1D model to match 3D results.

Keywords: RO membranes; 3D active layer; Voids; Channels; Solution-friction; Solution-diffusion; Equivalent active layer thickness

PT 107

Analysis of crystallization fouling growth and heat transfer on horizontal tube surfaces under constant heat flux

Boyu Wang*, Shengqiang Shen, Xingsen Mu

**Dalian University of Technology, No. 2 Linggong Road, Ganjingzi District, Dalian 116024, China, wangboyu@mail.dlut.edu.cn*

Based on the numerical simulation of the fouling growth on the surface of horizontal tube falling film evaporation under constant heat flux conditions, this paper studies the circumferential distribution and growth characteristics of fouling thickness under different spray densities, salinities, and evaporation temperatures. Additionally, the study compares the distribution of heat transfer coefficients (HTC) before and after fouling, analyzing the variation of heat transfer performance of the horizontal tube falling film evaporation system as fouling growth. The study found that the growth rate of fouling thickness in the lower half of the tube is higher than that in the upper half, and the growth rate of fouling at the bottom of the tube is about twice that of the top. As the spray density increases, not only does the accumulation rate of fouling decrease but also the final thickness of the fouling layer becomes thinner; as the solution salinity increases, the increase in the accumulation thickness of fouling linearly increases; as the evaporation temperature linearly increases,

the average accumulation thickness of the fouling layer increases in the form of a proportional multiple. In addition, during the initial growth stage of the porous fouling layer, its influence on the surface morphology is beneficial for heat transfer. However, as the thermal resistance of fouling increases further, it will lead to a decrease in HTC.

Keywords: Fouling growth; Seawater desalination; Heat and mass transfer; Saltwater thermal treatment

PT 108

Numerical simulation of falling film flow characteristics on a horizontal tube under vibration conditions

Qinggang Qiu, **Wei Zeng***, Yali Guo, Xingsen Mu, Shengqiang Shen

Dalian University of Technology, Dalian 116024, China
Tel. +86 15879842567, weiceng702@gmail.com

This study conducted three-dimensional numerical simulations of falling film flow outside a horizontal tube under vibrational conditions. The periodic cosine vibration of the tube was implemented using a user-defined function (UDF) in combination with dynamic mesh technology. The effects of periodic vibration on the liquid film thickness and flow velocity were investigated. The study primarily analyzed the fluctuation patterns of liquid film thickness and velocity, as well as the variation in average flow velocity, under vibration frequencies ranging from 15 to 35 Hz and amplitudes of 0.35 to 1 mm.

The simulation results showed that vibration frequency and amplitude have different impacts on the fluctuations in liquid film thickness and flow velocity. At an amplitude of 0.5 mm, the amplitudes of fluctuations in liquid film thickness and flow velocity significantly increased when the vibration frequency rose from 15 Hz to 20 Hz. When the vibration frequency exceeded 20 Hz, the fluctuations in liquid film thickness and flow velocity slightly decreased in the dimensionless axial range of 0 to 0.2, but they rapidly declined in the range of 0.3 to 0.5. The fluctuations in liquid film thickness and flow velocity peaked at a vibration amplitude of 0.5 mm and a frequency of 20 Hz. At a vibration frequency of 20 Hz, the fluctuations in liquid film thickness and flow velocity increased with vibration amplitude at different axial positions. Along the axial direction of the horizontal tube, the farther from the incoming liquid column, the greater the influence of vibration amplitude on liquid film fluctuations. The average liquid film flow velocity increased with rising vibration amplitude and frequency.

Keywords: Seawater desalination; Horizontal tube falling film evaporation; Vibration; Numerical simulation

PT 110

Liquid gap membrane distillation: optimal use of residual heat

Paul Buijs*, Radjesh Nidhansing, Tijmen van Heukelingen

**RN Solutions BV, Handelsweg 2A, St Oedenrode 5492NL, The Netherlands
Tel. +31 615937341, paul.buijs@1stwater.org*

Membrane distillation (MD) was patented already in 1963 (Bodell, 1963), only shortly after the first reverse osmosis (RO) desalination membrane (Loeb, 1960). MD however, is not widely applied for desalination, despite a substantial amount of research into design and optimization of MD membranes and modules, which is continuing. MD provides a unique opportunity to use residual heat from processes like hydrogen generation, power generation and other exothermal processes, or to use solar power. Scale up was limited by both Temperature and Concentration Polarization. A new air gap MD module has been developed (Nidhansing, 2018) that has unique thermal and hydrodynamic properties, maximizing the net water flux. The bespoke membranes are strongly hydrophobic, and the spacer can be adapted to the application.

Advantages RN solutions module design

- Diamond 2.5 mm spacer prevents both temperature polarisation and concentration polarisation
- Optimised heat transfer through rectangular design
- High flux (10 LMH) at low feed temperature (50°C) and low delta T (17°C)
- Proprietary gluing process for leak free operation
- Competition spiralwound design: flux 2 LMH at high feed temperature (80°C) and high delta T (30°C) sustainability
- Waste heat contributes strongly to global warming (Bian, 2020)
- Reverse osmosis power consumption 3-5 kWh/m^3, MD 0.1–0.5 kWh/m^3
- Low pressure operation, no need for chlorine tolerant stainless steel (Duplex, Hasteloy, SMO 254)
- No chemicals needed (reverse flow cleaning)

Keywords: Membrane distillation; Spacer; Flux; Green hydrogen; Waste heat

PT 111

A new approach to reverse osmosis pressure vessel design

Mike Sinfield*, David Jiménez, Amit Sankhe, Daniela Vidal,
Paul Choules

**H2O Innovation, 3 Aston Way, Middlewich CW10 0HS, UK*
Tel. +44 1606837605, mike.sinfield@h2oinnovation.com

In conventional reverse osmosis (RO) systems, feed water enters through the front end of the pressure vessel and permeate water is extracted in each membrane element. This process means that the flow entering the last element is significantly less than the flow entering the first. The uneven flow distribution places a disproportionate load on lead elements, increasing the fouling index for lead elements and ultimately resulting in higher than necessary operation and maintenance costs, compared to if the fouling index was more evenly distributed between each element in the length of the pressure vessel.

The authors present a commercially viable pressure vessel design which addresses these challenges by incorporating (i) a novel feed flow distribution mechanism and (ii) a significant increase in the size of the pressure vessel. Unlike current industry standard design, the presented system enables controlled bypass of feed water to the front end of membrane elements in position 2, 3, 4, 5, 6 and 7, facilitating more uniform water flux down the length of the pressure vessel. The larger vessel diameter permits the positioning of 49 conventional 8x40" membrane elements, reducing the need for piping, couplings and auxiliary equipment, which lowers both capital and operational costs.

This presentation compares the performance of the novel system against conventional RO vessels by computational simulations of flow rate, pressure, concentration, and fouling resistance. Additionally, preliminary findings for a single-stage seawater RO (SWRO) system are presented with benefits attributed to the novel system's stable water flux across the pressure vessel.

Keywords: Reverse osmosis; Pressure vessel; Mega vessel

PT 112

Flow electrode capacitive deionization: a path toward scalable and sustainable desalination solution

Hafiz Muhammad Saif Saleem*, Joao Crespo, Sylwin Pawlowski

**Nova University of Lisbon, Largo da Torre, Caparica, Lisbon 2828-516, Portugal
Tel. +351 920359958, h.saleem@campus.fct.unl.pt*

Flow electrode capacitive deionisation (FCDI) is an emerging electromembrane desalination technology that operates at room temperature and pressure. However, its widespread use is hindered by challenges related to flow electrode flowability, channel design, system configuration and the choice of activated carbon, which significantly impact desalination efficiency and operational stability.

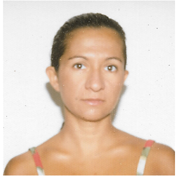
The impact of flow electrode channel geometry on FCDI performance was assessed through experimental and computational fluid dynamics (CFD) studies [1]. FCDI stacks with horizontal serpentine channels worked better than vertical ones by minimising clogging and increasing the internal shear rate, thus enhancing the flowability of the shear-thinning activated carbon flow electrodes. Furthermore, the shift from traditional CNC-milled graphite plates to 3D-printed flow electrode gaskets significantly improved FCDI performance [2]. Especially the use of conductive filaments made of a mixture of polylactic acid (PLA) and carbon black enabled the formation of micro-corrugation inside the flow electrode channels, which increased internal mixing and resulted in a 25% enhancement in desalination efficiency. A comparative evaluation of FCDI configuration modes revealed that the single-cycle separate concentrate (SCSC) mode was the most energy-efficient and stable configuration, which also allowed for on-site regeneration of flow electrodes. Also, in contrast to other tested modes, minimal pH fluctuations were observed, which makes it suitable for scalable and long-term continuous desalination. Finally, we demonstrated that lab-made activated carbons with smaller particle size (1–10 μm), higher surface area, and hydrophilic surface chemistry are essential for enhancing FCDI performance and can surpass commercial alternatives such as YP80F, YP50F and Norit.

These findings emphasise a comprehensive strategy for enhancing FCDI performance by incorporating advanced manufacturing, customised designs, and material optimisation to provide a scalable and sustainable desalination solution. The outcome of this work provides a strong footing to produce next-generation FCDI systems that can efficiently help address global water scarcity.

Keywords: Desalination; Flow electrode capacitive deionization (FCDI); Activated carbons; Computational fluid dynamics (CFD); Additive manufacturing

PT 114

Development of reverse osmosis technology and opportunities for renewable energy integration in the Greek islands



Eftihia Tzen*, Evagelos Rikos, Ifigenia Karga, Panagiotis Papadopoulos, Nikolaos Stefanatos, Dimitris Theofiloyiannakos

**CRES, 19th klm Marathonos Ave., Pikermi 19009, Greece, etzen@cres.gr*

The Greek islands, particularly those in the Aegean and Ionian seas, benefit from strong winds and abundant sunshine, especially during the summer months when water demand is highest. The reduction in available natural water resources and the explosive growth of tourism in the Greek islands have led even those islands traditionally known for their natural water sources to be concerned and seek alternative solutions, such as desalination. Over the last two decades, reverse osmosis, primarily of seawater, has become the main source of water on many Greek islands. Small to medium-sized reverse osmosis plants, with average water capacities ranging from 250 m³/d to around 2000 m³/d, serve the public, with a few exceptions of larger plants. The full automation of these systems, the use of energy recovery devices to reduce energy consumption, and the modularity of reverse osmosis technology, which accommodates with the seasonal variations in water demand, make this technology an ideal solution for the islands. Additionally, combining wind energy, solar energy, and energy storage with reverse osmosis technology can minimize carbon emissions and significantly reduce the environmental impact on islands' sensitiveenvironments and water resources. Despite these advantages, only a few desalination plants powered by renewable energy currently exist on the Greek islands.

This paper presents the current status of desalination in the Greek islands and analyses two case studies on the combination of wind and solar energy to power reverse osmosis plants on two Aegean islands. Additionally, it analyzes the current barriers to integrating renewable energy on non-interconnected islands, which lack connections to the mainland's electricity network, and on the opportunities of the expected electrical interconnection, as it will increase the potential for electricity generation from renewables.

Keywords: Wind energy; Solar energy; Reverse osmosis; Islands

PT 115

Desalination without chemicals: Bonaire's modular plant and the application of direct osmosis cleaning

Iris Sutzkover Gutman*, Irena Zaslavschi

**IDE Technologies, Expert Process Engineer, Israel*
irisg@ide-tech.com

The drinking water in the Caribbean Island of Bonaire is supplied by the HATO desalination plant that was designed to supply a constant high-quality and sustainable drinking water to the residents and the numerous tourists, while minimizing any environmental impact.

The Bonaire Island is surrounded by a marine national park and therefore, the desalination plant aims to operate without the use of any chemicals returning into the sea.

This paper reviews the performance and operational aspects of the WEB Bonaire desalination plant (5,600 m^3/d), operating as a chemical free plant.

Seawater salinity is of standard salinity and amounts to ~3.6%. The SWRO system is designed to operate at a relatively low water recovery level of ~40%. Under these operating conditions, the use of antiscalant to control the formation of scaling is not required.

However, as for the formation of fouling, the seawater composition is characterized by a low load of particulate matter but also with a very high load of organic matter. A remarkable phenomenon of a TOC concentration equaling a dissolved organic carbon concentration, suggests that the filtration system, will not be able to reduce the organic load and that this large load, shall, inescapably, heavily foul the RO membranes.

To mitigate the high rate of organic fouling accumulation on the membrane surface, IDE included a unique feature in the SWRO system design – a direct osmosis cleaning (DOC) system.

Two independent observations aiming to evaluate the effectiveness of this DOC cleaning are presented: its effect on the SWRO system DP pattern and a presentation of evidence for a local organic matter removal.

The HATO chemical-free desalination plant in Bonaire, demonstrates the successful implementation of the DOC technology, that provides a sustainable and environmentally friendly solution for water production on an island while maintaining a high operational efficiency.

Keywords: SWRO; DOC; Fouling; Cleaning

PT 116

Advanced ion-exchange membranes for enhanced performance in membrane capacitive deionization (MCDI) technology

Othman Thayfi*, Yassine Koumya, Rachid Benhida, Khaoula Khaless

**Mohammed VI Polytechnic University,*
10 rue Iliya Abou Madi Qu Najah Elamir, Safi 46000, Morocco
Tel. +212 663263337, othmane.thayfi@um6p.ma

Water scarcity is increasingly becoming a significant issue, particularly in arid and semi-arid regions. This situation necessitates the urgent development of effective solutions, including water treatment and desalination technologies. Among these, desalination processes, such as membrane capacitive deionization (MCDI), stand out as highly efficient methods for addressing water scarcity, particularly for brackish water. Conventional capacitive deionization (CDI) technologies face several limitations, notably the undesired adsorption of co-ions and the accumulation of divalent ions on the electrode surfaces[1,2]. This accumulation leads to the formation of layers on the electrodes, ultimately reducing the desalination efficiency. To address these challenges, we have developed three approaches that incorporate both anion and cation exchange membranes into the CDI system. The first approach involves integrating the synthesized ion exchange membranes adjacent to the electrodes within the CDI system. The second approach focuses on directly incorporating the membranes onto the electrode surfaces, effectively covering them. The third approach involves placing a membrane upstream that selectively retains bivalent ions[3].

In this study, we synthesized a series of anion-exchange membranes (AEMs) starting from a polymer backbone that undergoes a series of chemical modifications. These modifications include chloromethylation followed by quaternization, using varying fractions of the quaternization agent, dimethylethanolamine (DMEA). This approach allows for the fine-tuning of membrane properties by controlling the degree of quaternization, which directly impacts the ion-exchange capacity and overall performance of the membranes in membrane capacitive deionization (MCDI). The synthesis procedure was optimized to achieve membranes with enhanced anion conductivity, permselectivity, and dimensional stability. Fourier transform infrared spectroscopy was used to confirm the functional groups in the membranes. The morphology of the membranes was examined using scanning electron microscopy. The physicochemical and electrochemical properties of the membranes were studied in detail, including their ion exchange capacity, water uptake, volume expansion ratio, tensile strength, electrical resistance, and transport number[4]. This work aims to enhance the efficiency of CDI systems by overcoming the limitations associated with co-ion adsorption and the presence of divalent ions, thereby improving desalination rates.

Keywords: Desalination; Ion exchange membrane; Capacitive deionization (CDI); Membrane capacitive deionization (MCDI); energy consumption; Chloromethylation; Quaternization

PT 118

Assessment of an ultrafiltration module with an integrated pre-filter as seawater desalination pre-treatment

Daniel García-Huertas, Michael Hoffmann, Christian Staaks, Jan Rädel, Harith Alomar, Guillem Gilabert-Oriol, Martin Heijnen, **Olga Ferrer Mallén***, Jorge J. Malfeito

**Acciona S.A.U., Avda. de les Garrigues, 22, Prat De Llobregat 08820, Spain*
Tel. +34 607193608, olferrer@acciona.com

Ultrafiltration (UF) and microfiltration (MF) membrane processes are used in various water filtration applications, including seawater desalination, surface water potabilization, wastewater treatment/reclamation and industrial use. Due to its design and material stability, a previous stage to avoid the entrance of solids that could clog or damage its fibers/capillaries is needed. Typically, strainers or ring filters, whose mesh size commonly ranges between 100 and 300 μm, are used. A new concept has been recently developed, integrating the abovementioned pre-filter within the MF/UF module itself, leading to a compact process. Previous experiences assessing the integrated UF system have already been reported dealing with surface water in Germany [1], reporting a stable performance as well as lower energy consumption. However, up to now this system has not been assessed with raw seawater continuously, under different influent water qualities. The objective of this work has been the assessment of a pre-filter integrated within a UF as a pre-treatment for seawater desalination, avoiding the need of the above-mentioned pre-filters. For such purpose, a 4.5 m^3/h nominal capacity UF pilot plant fed by raw seawater from the Mediterranean Sea (only pre-filtered by 2–5 mm grids, without any pre-filter) has been tested in continuous operation. A full-scale DuPont™ IntegraTec™ Ultrafiltration Module made out of polyether sulphone ultrafiltration (PES-UF) module equipped with a prototype of the integrated Pre-Filter is employed. This integration avoids the need of an additional fiber protection (e.g. ring filters, mesh filters), leading to space savings and less complexity. Moreover, it enables a regular cleaning since it is washed when an UF backwash (BW) or chemical enhanced backwash (CEB) is applied, enabling long term low pressure drop. The system has been able to deal with raw seawater (average influent turbidity pH 8, 0.4 NTU, SDI15 4.3, total suspended solids (TSS) 5.6 mg/L), working up to 90 L/(m^2·h) (LMH) with a stable transmembrane pressure (TMP) around 0.25 bar, without any coagulant dosage and performing a BW every 40 min and 1 CEB per day, as shown in Fig. 1. In particular, the pressure drop of the pre-filter has been 5 mbar along 4 days when working at 90 LMH. The average filtrate turbidity has been 0.017 NTU, SDI15 1,24. In these conditions, the water recovery has been 94.8% and the chemical consumption 1.27 mL NaOH 30%/m^3, 0.98 mL NaOCl 15%/m3 and 2.64 mL H2SO4 98%/m^3 of permeate. In order to assess the integrated system performance under more challenging scenarios in terms of raw seawater physical-chemical characteristics, tests continuously spiking solids (TSS up to 20 mg/L) and algae (up to 20 Mcel/L) are under progress.

Keywords: Seawater desalination; Ultrafiltration; Pre-filter; Reverse osmosis

PT 119

Biofouling monitoring in SWRO systems through microbial loading quantification

Núria Zamorano-López, Raquel Escorihuela, Olga Ferrer Mallén*, Jorge J. Malfeito

Acciona S.A.U., Avda. de les Garrigues, 22, Prat De Llobregat 08820, Spain
Tel. +34 607193608, olferrer@acciona.com

Introduction

Desalination is contributing to a more resilient scenario worldwide against hydric stress, especially in coastal areas in which water resources are scarce. Fouling prevention during seawater pretreatment and specially in reverse osmosis (SWRO) systems is needed to reduce the treatment costs, estimated in ~15 billion$ per year worldwide (Azis et al., 2001). These costs include higher reagents consumption for membrane cleaning and greater membrane replacement rates. Despite the relevance of microbial dynamics of biofouling in these processes, little is known about the link between microbial load in seawater, operational parameters and fouling indicators such as silt density index (SDI15), adenosine triphosphate (ATP) levels, etc. In this work, microbial loading is monitored at demonstration scale in a pilot plant which comprises different pretreatment stages, as well as a SWRO unit. In situ quantification of this parameter during different episodes with seawater quality drop episodes provides further information about the application of new microbial-based methods to improve the operation of desalination systems. This work contributes to a better understanding of fouling behaviour beyond standard water quality parameters and hence, improves desalination systems operation.

Materials and methods

Automatized flow cytometer (BactoSense, bNovate) for microbial (bacteria) loading quantification has been coupled to a demonstrative SWRO pilot plant located in a full scale SWRO plant in the Mediterranean area. The pilot includes two different dual media filters (pretreatment 1 and 2) and the RO system itself. Water quality analysis (total organic carbon (TOC), ATP, turbidity...) and operational process (differential pressure, backwash frequency...) data have been retrieved and contrasted with cytometry results in a statistical multivariable approach.

Results and discussion

Microbial loading detected on the intake ranges 250.000-360.000 cell/mL with a 55-75% removal after pre-treatment stages. Higher removal was observed in pretreatment 2 than in pretreatment 1 (Fig. 1). On-going work is being performed to analyse the link between all data retrieved, including changes in normalized differential pressure in both pre-treatment and RO units. Fig. 1. Cytogram analysis for microbial loading quantification in (a, b) intake, (c, d) pretreatment 1, and (e, f) pretreatment 2 sampling points.

Conclusions

Automatized cytometry techniques can provide fast detection of episodes of high microbial loads that might affect seawater desalination process. Despite the high removal of the pre-treatments here analysed, the remaining microbial load may have an effect over RO process due to biofilm formation over membrane surfaces. The data analysis of the trends in between changes in microbial load and RO operational parameters is on-going.

References

Azis P.K.A., Al-Tisan I. and Sasikumar N. (2001)

Keywords: Biofouling; Microbial load; Desalination; Pre-treatment; Water quality

PT 120

Harnessing membrane distillation for sustainable water supply in concentrated solar power plants

Bartolomé Ortega Delgado*, Juan Antonio Andrés-Mañas, **Patricia Palenzuela**, Lourdes García-Rodríguez, Guillermo Zaragoza

**University of Seville, Seville 41980, Spain, ortega-bartolome@us.es*

The global electricity demand will increase during the next decades following the rise of the world population. This high demand must be met using clean, reliable, affordable, and sustainable power production technologies. Concentrating Solar Power (CSP) has the potential to meet part of the demand because of its capability to store energy and its dispatchability, which also contributes to grid stability. CSP plants need high-quality water for power cycle cooling, power cycle make-up water and mirror cleaning. Thermal distillation technologies, such as membrane distillation (MD), have the potential to meet these water demands with minimal loss of power cycle efficiency. This work presents a performance assessment of the integration of a vacuum-assisted air-gap MD unit into the power cycle of a 50 MWe CSP plant, using thermal energy from the feedwater heaters and condenser to avoid the penalty in the cycle efficiency. The components of the CSP+MD plant have been modelled to develop a simulation tool that allows assessing annual water and electricity yields. The solar field has been modelled and implemented in Matlab, based on [1]. The power block has been modelled and implemented in Engineering Equation Solver, considering nominal and part load operation. For the MD unit, the permeate productivity and condenser outlet temperature were modelled empirically using the Response Surface Methodology [2]. The condenser outlet temperature is used to determine the thermal efficiency (specific thermal energy consumption) of the MD.

Keywords: Desalination; Membrane distillation; CSP+D; Solar desalination; Parabolic trough; Simulation

PT 121

Cutting-edge technology for the selective separation of monovalent salts from seawater brine

Noura Chehab*, Nikolay Voutchkov, Moahmmed AlSindi

**NEOM, NEOM Camp, Tabuk 32143, Saudi Arabia*
Tel. +966 547047066, noura.chehab@neom.com

NEOM views brine as a valuable by-product and is shifting focus toward environmentally sustainable solutions for brine management. This project introduces a revolutionary technology for brine valorization aimed at extracting individual minerals from brine without the conventional separation of monovalent and polyvalent minerals. The ENOWA Water Innovation Center (WIC) has developed a process utilizing selective seawater reverse osmosis (SWRO) membranes to directly extract targeted minerals from seawater. This process is complemented by a membrane-based crystallization technology that replaces traditional thermal evaporation methods, enhancing efficiency and sustainability. The selective RO membranes facilitate the extraction of a wide range of minerals from seawater or brackish water, with a focus on potassium chloride (KCl). The methodology involves using innovative SWRO membranes embedded with active ingredients to selectively transport potassium ions while rejecting other salts. The extracted potassium chloride achieves a purity of 95% or higher, allowing it to be directly used as liquid fertilizer. The system recovers over 90% of the potassium chloride naturally present in seawater. Additionally, the membrane crystallizer unit employs forward osmosis (FO) principles to crystallize the mineral, significantly reducing energy consumption compared to conventional methods. The advantages of this potassium selective membrane technology include ease of installation, low membrane and energy costs, and high-value product generation without the need for expensive mineral separation systems. Most existing desalination plants utilize a two-pass process configuration, enabling the integration of this brine mining system with minimal capital investment. The final product, a low-volume, high-value chemical feedstock, creates an additional revenue stream for desalination plants. The membrane crystallizer offers several benefits: it prevents scaling, promotes small crystal formation, and features an osmotically assisted reverse osmosis (OARO) system that reconcentrates the diluted draw solution for reuse. The energy associated with this membrane crystallization is significantly lower than that required for thermal evaporation. This novel brine processing technology contributes to more sustainable desalination practices by improving water recovery, enhancing energy efficiency, and facilitating the extraction of valuable minerals from brine. The financial implications are substantial, as the production costs for potassium chloride are estimated to be between $45 and $60 per ton, significantly lower than the market price, which ranges from $250 to $1,100 per ton. The scalability of the system allows for flexibility in production based on market demand, enabling the adjustment of mineral production by modifying the number of selective membrane racks in operation. This adaptability ensures that brine mining remains profitable and commercially viable.

Keywords: Selective membrane; Membrane crystallizer; Brine mining; Zero liquid discharge (ZLD); Water desalination

PT 122

Cost optimization of ultrafiltration and reverse osmosis systems using the Operations Advisor software

Guillem Gilabert Oriol*, Gerard Massons, Leaelaf Hailemariam, Zach Jensen, Joey Liao, Sylvia Insogna

**DuPont Water Solutions, Tarragona, Asturias 33469, Spain*
guillem.gilabertoriol@dupont.com

Reverse osmosis (RO), protected with an ultrafiltration (UF) pretreatment, has been identified as the most effective technology to desalinate water. Therefore, the optimized operation of a reverse osmosis membrane system, with its ultrafiltration pretreatment, is of utmost importance to decrease the total cost of water and achieve a seamless operation. The Operations Advisor is a software platform that analyzes ultrafiltration and reverse osmosis plant operating data. This application allows a plant operator to identify the hydraulic and the chemical enhanced backwashes (CEB) and clean-in-place (CIP) cleaning cycles, as well as identify the type of fouling, if any, that the membranes are experiencing. The types of fouling this software can detect are biofouling, organic fouling, particulate fouling, scaling, and membrane integrity failures. Once the fouling types have been identified, the DuPont™ Operations Advisor predicts when the next cleaning cycle will be performed and provides a recommended schedule for when and how to clean the elements to maximize operating cost savings. These cost savings come from energy savings, chemical savings, downtime savings and an increase in water production. The software is also capable of quantifying the total amount of savings in dollars per year that an installation can achieve thanks to the optimization proposed by the Operations Advisor. This paper will also showcase two real installations based on UF and RO systems, where the Operations Advisor has been used to decrease the total cost of water. These savings are quantified in dollars per year to provide a meaningful impact on total operating cost.

Keywords: Reverse osmosis; Ultrafiltration; Desalinate water; Optimized operation; Cost of water; Software; Simulation

PT 123

Concentrating high-salinity brines using low salt rejection reverse osmosis membranes

Guillem Gilabert Oriol*, David Arias, Claudia Niewersch, Tirtha Chatterjee, Caleb Funk, Harith Alomar

**DuPont Water Solutions, Tarragona, Valle del Tamón s/n Nubledo, Tamón, Asturias 33469, Spain, guillem.gilabertoriol@dupont.com*

Reverse osmosis has been established as the most effective technology to produce water of drinking water quality, as it enables significant energy savings compared to thermal processes. As water is desalinated, a concentrate, or brine, is also produced. Brine concentration has emerged as a technology that enables to recover more water from it, and also obtain valuable minerals from it. The process of concentrating salts from the brine is limited by the maximum available pressure. The Low-Salt-Rejection Reverse Osmosis (LSRRO) membranes provide a solution to this physical limit, by offering a membrane that is capable to concentrate salts up to 220 g/L, while operating within the typical operating ranges of desalination reverse osmosis membranes. The use of LSRRO membranes enable avoiding the evaporator thermal process, offering significant energy savings. This paper showcases how DuPont™ FilmTec™ Reverse Osmosis elements that uses LSRRO membrane can concentrate salts at these higher salinities through real experimental results. The use of this membrane is also proposed to assess its impact in a real desalination plant by analyzing its energy consumption and comparing it to current alterantives using advanced modeling software. This case study can be replicated by other desalination plants to study the feasibility of implementing the LSRRO technology for concentrating brine and valorizing its most valuable minerals.

Keywords: Reverse osmosis; Brine recovery; Energy savings; LSRRO; OARO

PT 124

Robust ultrafiltration-based pretreatment to secure long term sustainable operation

Guillem Gilabert Oriol*, Blanca Salgado, Gerard Massons, Harith Alomar, **Oliver Neumann**, Jan Radel

DuPont Water Solutions, Tarragona, Valle del Tamón s/n Nubledo, Tamón, Asturias 33469, Spain, guillem.gilabertoriol@dupont.com

Ultrafiltration (UF) membranes have been identified as a proven effective solution to remove suspended solids and turbidity from water and wastewater, as well as significantly reduce the amount of virus and bacteria present. This ensures an excellent and consistent water quality, which can be used to produce drinking water, feed industrial processes, or regenerate water for agricultural irrigation. The UF membranes can therefore be used as stand-alone solutions, or as a pretreatment to the downstream reverse osmosis. When used as standalone application, removal of suspended solids and bacteria removal are its core

advantages. When used as a pretreatment to the reverse osmosis (RO), it enables the RO to operate efficiently and smoothly. UF as a pretreatment to RO is as well implemented in seawater desalination contexts. For that application, UF membranes are understood to have the capability to deal with algae blooms. Algae blooms lead to biofouling in the RO units, when bio-degradable byproducts of algal matter pass the primary and secondary pretreatment, compromising the production output of RO desalination plants dramatically. This paper aims to showcase how UF can effectively deal with algae bloom, presenting a real case study. Additionally, it intends to present a novel DuPont™ Ultrafiltration membranes that can contribute to sustain a long-term operation. This novel membrane is characterized by reducing capital expenses (CAPEX), as it enables to operate a UF membrane with a higher active area, while keeping the whole module dimensions the same. This leads to a reduction in CAPEX, with ultimately helps reducing the total cost of water..

Keywords: Ultrafiltration; Algae bloom; Long-term operation; CAPEX; Water cost

PT 126

Research on horizontal tube condensation flow and heat transfer in MED systems

Minle Bao, Luyuan Gong, Qinggang Qiu, Shengqiang Shen, **Yali Guo***

**Dalian University of Technology, Dalian 116024, China*
Tel. +86 13019489176, ylguo@dlut.edu.cn

The heat exchange characteristics of pure steam flow inside horizontal vacuum tubes has been experimentally studied to improve the heat transfer efficiency of MED system. The effects of steam mass flow rate, saturated temperature, and total temperature difference ?Ts,c on the flow process are analyzed. Based on the analysis of the heat exchange mechanism associated with stratified flow condensation, a calculation model for the thermal partition angle is developed. The experimental results demonstrate that the thermal partition angle increases with both the mass flow rate and the rise of the heat transfer temperature difference. The saturated temperature has minimal influence on the local heat transfer coefficient and the thermal partition angle of condensation in the tube. By taking the thermal partition angle as the partition boundary, an empirical correlation is proposed for calculating the local heat transfer coefficients, which proves the prediction accuracy of the coefficients.

On the other hand, due to issues such as the experimental tube diameter and material, it was not possible to measure parameters such as the liquid film thickness and flow velocity on the tube wall. However, their impacts on heat transfer performance cannot be ignored. Therefore, a three-dimensional mathematical model of steam condensation flow inside a smooth tube was established to investigate the condensed liquid film thickness inside the tube using the Eulerian wall film model in ANSYS FLUENT software. The simulation conditions include a tube length of 500 mm and an inner diameter of 38 mm. The simulation results indicate that the liquid film thickness at the bottom of the tube increases with the flow distance, while at the top of the tube, the film thickness first increases and

then stabilizes. Higher steam inlet velocities lead to higher liquid film thicknesses. The liquid film flow velocity at the bottom of the tube increases with the flow distance, while at the top of the tube, it first increases and then gradually decreases. Higher steam inlet velocities result in higher liquid film flow velocities. At the 0°, 90°, and 180° positions on the tube wall, the local heat transfer coefficient of the liquid film flow decreases along the direction of steam flow as the flow distance increases. Due to the larger liquid film thickness at the bottom of the tube, the local heat transfer coefficient at the 0° position on the tube wall is lower than that at the 90° and 180° positions. The highest local heat transfer coefficient on the tube wall is found at the tube inlet.

Keywords: Condensation; Heat transfer coefficient; Thermal partition angle; Film thickness

PT 127

Antiscalants in seawater desalination: impacts on microbial growth and environmental fate

Graciela Gonzalez Gil*, Marian Castrillon Tobon, Camila Albarracin Ruiz, Johannes Vrouwenvelder

KAUST, Saffron Lane G-3209, Thuwal 23955, Saudi Arabia
graciela.gonzalezgil@kaust.edu.sa

Antiscalants are chemicals added to the feed water prior to reverse osmosis seawater desalination, playing a crucial role in improving membrane performance by reducing scale formation and membrane fouling. However, it has been demonstrated that the selection and monitoring of antiscalants requires careful consideration, as some can inadvertently promote bacterial growth, increasing the risk of membrane biofouling. In this presentation, the mechanisms by which antiscalants such as phosphonate and polymer-based compounds enhance bacterial growth and how this relates to their fate is explored. Certainly, the fate of these chemicals when discharged into the environment remains a concern. While some bacteria can break down natural phosphonates, the biological degradation, and photodegradation of synthetic phosphonates in real-world conditions remain poorly understood. This knowledge gap is troubling as antiscalants will ultimately enter marine ecosystems, potentially causing adverse ecological impacts.

Keywords: Phosphonates; Co-polymers; Scale inhibitors; Seawater bacteria

PT 128

Solar-driven evaporation system for high-salinity wastewater desalination using 3D chitosan-based interfacial evaporators

Hyeong Woo Lim*, Sang Joon Lee

**Pohang University of Science & Technology, Pohang 37673, Korea*
Tel. +82-10-9424-9770, hyeongwoo@postech.ac.kr

Global water scarcity has become a critical global issue, further intensified by the environmental degradation associated with conventional seawater desalination technologies. Simultaneously, the rapid growth of industries, particularly in sectors like secondary batteries and semiconductors, has led to an increased discharge of industrial high-salinity wastewater. While post-treatment processes for handling such wastewater exist, they often incur significant environmental harm, necessitating the development of sustainable alternative approaches.

In this study, we developed an interfacial solar steam generation technology for environmentally friendly seawater desalination. This approach harnesses solar energy to heat the interface via photothermal effects while compensating for insufficient input energy by utilizing wind as an auxiliary driver. A robust and highly efficient water-absorbing and transporting 3D chitosan interfacial evaporator serves as the heating layer, with graphene nanoplatelets employed as the photothermal material. The polymer-based membrane used in this system reduces the enthalpy of evaporation and allows for aspect ratio optimization through density control within the evaporator. These innovations enabled a maximum evaporation rate of 2.1 kg m^{-2} h^{-1}.

Additionally, we explored evaporation enhancement using convective effects on the 3D interfacial solar evaporator. Under solar irradiation of 1 kW m^{-2} with wind speeds of 6 m s^{-1}, the system achieved an exceptional evaporation rate of 6 kg m^{-2} h^{-1}. Even under these harsh conditions, salt accumulation was prevented due to rapid water replenishment, with the system sustaining performance over seven cycles. To further optimize the utilization of convective environments, we designed a blade-shaped 3D evaporator, demonstrating significantly accelerated evaporation through rotational effects compared to a traditional standstill model.

Our method achieves highly efficient evaporation without salt accumulation, significantly outperforming conventional bulk water evaporation systems. Moreover, this technology offers a sustainable alternative to environmentally destructive practices, aligning with zero-liquid-discharge (ZLD) strategies commonly employed in salt lakes. It presents a transformative advancement in selective ion harvesting, combining rapid operation, minimal environmental impact, and exceptional adaptability for diverse resource recovery applications.

Keywords: Interfacial solar steam generation; Solar energy; Evaporation; Rotation; Wind enery

PT 129

Electrothermal-based hanging type evaporator for effective seawater desalination

Younghoon Suh*, Sangjoon Lee

**POSTECH, Pohang 37673, Korea*
Tel. +82 1088399819, suh9819@postech.ac.kr

The global demand for freshwater is increasing due to global warming and explosive population growth. Conventional desalination methods, such as reverse osmosis (RO), have been widely used but rely heavily on fossil fuels, limiting their sustainability. Solar-based photothermal desalination has emerged as a promising alternative owing to its renewable energy source. However, its efficiency is low and heavily depends to weather conditions. To overcome these limitations, electrothermal-based desalination using Joule-heating is gaining large attention due to its ability to achieve high evaporation rate with less energy input and independence from weather conditions.

In this study, a hanging type evaporator made of carbon fabric as the electrothermal material was utilized. Due to hydrophobic nature of untreated carbon fabric, a thiolation process was applied to enhance its wettability, making it more suitable for efficient water transport. The hanging model design provides several key advantages such as utilization of both sides of the fabric for evaporation, improved water supply to the central area through a sloped configuration, and localization of salt crystals. Experimental comparison between hanging type and flat type was conducted using a solar simulator. As a result, the hanging type exhibited better evaporation performance compared to the flat type. Furthermore, the hanging type desalination system was optimized with varying the hanging distance to identify the optimized distance for maximizing evaporation performance.

The evaporator of 6 cm × 2 cm in physical dimension at a hanging distance of 3 cm achieved an evaporation rate of 7.81 $kg/m^2 \cdot h$ for deionized (DI) water and 7.23 $kg/m^2 \cdot h$ for artificial seawater under 1 sun and 3 V input voltage. These results demonstrate the potential of the hanging type electrothermal evaporator for a scalable and practical solution for freshwater production.

This research underscores the feasibility of electrothermal-based desalination as a sustainable and efficient approach to address global water scarcity. By leveraging all-day, all-weather technology with high energy efficiency, this study paves the way for developing a new desalination system that can meet the growing demand for freshwater.

Keywords: Electrothermal; All-day; All-weather desalination; Hanging type

PT 130

Evaluating combined cooling technologies for inland solar MED systems

Juan Miguel Serrano, **Patricia Palenzuela**, Bartolomé Ortega-Delgado, Lidia Roca*

**Plataforma Solar de Almería - CIEMAT - CIESOL, Spain*
lidia.roca@psa.es

The typical cooling method in Multi-effect Distillation (MED) is Once Through (OT), in which cooling water flows through the tubes of a shell-and-tube condenser, absorbing latent heat of condensation from the final-stage vapor. Part of this cooling water is usually used as feedwater for the MED process, being then preheated during this process. The cooling water flow rate is typically 2–3 times higher than the feedwater flow rate [1], leading to increased pumping demands, higher auxiliary energy consumption, and a large volume of warmer reject water.

In case seawater is used as cooling water, the discharge of warmer water (7–10°C above ambient) may be high enough to have a negative effect on aquatic life [2]. Additionally, in the case of MED plants located far from the coast, the altitude has a strong impact on economic cost of water due to the energy required by the pumping system [3]. In offshore locations, the use of Air Cooled Condense (ACC) type dry cooling systems is a possible option, but they limit the cooling temperature and therefore the MED performance.

This paper evaluates the use of a combined wet and dry cooling (CC) technology as cooling system for a commercial MED plant with a capacity of 1000 m^3/d and located in Borg El Arab (Egypt). The model of the CC technology, validated with data from a pilot plant located at the Plataforma Solar de Almeria (Spain) [4], has been scaled up for the commercial MED case. The annual simulations show the distillate production and electricity consumption obtained considering different configurations of the CC system.

Keywords: Solar thermal desalination; Cooling system; Modelling

References

[1] Elsaid, K., Kamil, M., Sayed, E. T., Abdelkareem, M. A., Wilberforce, T., Olabi, A. (2020). Environmental impact of desalination technologies: A review. Science of the total environment, 748, 141528.
[2] Madden, N., Lewis, A., Davis, M. (2013). Thermal effluent from the power sector: an analysis of once-through cooling system impacts on surface water temperature. Environmental Research Letters, 8(3), 035006.
[3] Mata-Torres, C., Zurita, A., Cardemil, J. M., Escobar, R. A. (2019). Exergy cost and thermoeconomic analysis of a Rankine Cycle+ Multi-Effect Distillation plant considering time-varying conditions. Energy Conversion and Management, 192, 114-132.
[4] Serrano, J. M., Navarro, P., Ruiz, J., Palenzuela, P., Lucas, M., Roca, L. (2024). Wet cooling tower performance prediction in CSP plants: A comparison between artificial neural networks and Poppe's model. Energy, 131844.

PT 131

Wastewater treatment membranes: main issues and failures

Nuria Peña Garcia*, Javier Rodriguez, Mike Sinfield,
Fernando Del Vigo Pisano

**H2O Innovation, c/ Londres 38, Las Rozas 28232, Spain
nuria.pena@h2oinnovation.com*

Conventional wastewater treatment methods are well established and widely used, as they provide effective removal of pollutants. Nevertheless, the scarcity of freshwater and evolution of membrane technologies has significantly increased the interest and use of advanced treatment technologies as a means to achieve a potable-grade product water and address emerging contaminants. In fact, the use of membrane technologies has allowed the treatment of wastewater for reuse with a significant reduction in the size of equipment, energy requirements, and capital cost versus conventional treatment methods.

The application of membranes for wastewater treatment is not a recent development, as the first membrane bioreactors (MBRs) were developed during the ’70s. During the early 2000s, membrane technologies became more integrated into municipal wastewater plants. Today, membrane technology is a key component of advanced wastewater treatment processes in North America, and growing popularity in Europe and is widely used in both industrial and municipal settings to produce high-quality effluent and meet stringent water quality standards.

Although industry has made commendable efforts to improve membrane technology, it is also important to understand the challenges that may arise in some cases when dealing with complex wastewaters.

In addition to operational issues within the facilities, the identification of the foulant that may occur on membranes provides valuable information to minimize or correct fouling in the most effective way.

In the last 20 years, H2O Innovation laboratories have autopsied more than 2000 water treatment membranes, including more than 200 wastewater RO and NF membranes. This paper gathers information on characteristic wastewater membrane foulants, their impact on membrane operation, and other relevant details detected during the study of wastewater membranes.

Keywords: Wastewater; Reuse; Membrane; Autopsy; Foulant

PT 133

Preliminary design of a novel CSP+ORC desalination system equipped with a ZLD unit based on direct contact evaporation

Néstor M. Santana-Hernández*, Agustín M. Delgado-Torres

**University of La Laguna, La Laguna, Tenerife 38200, Spain*
nsantana@ull.edu.es

This work deals with the preliminary analysis of a novel concentrated solar power and desalination technology which incorporates a heat-driven Zero Liquid Discharge system (ZLD). A solar thermal plant composed of a solar field and a thermal energy storage drives an Organic Rankine Cycle (ORC) based on the dual-pressure configuration. Compared to the single ORC case, that option presents several advantages such as lower solar field's operating temperature and less heat storage volume needed. Regarding the ZLD system, a hot gas flow is produced with the heat rejected by the cycle. The brine from the desalination unit is concentrated by direct contact evaporation within a bubble chamber. The bubbling process is generated by the injection of the hot gas inside the brine fluid. To enhance the global efficiency, the brine preheating before it enters the bubble chamber is considered throughout the heat recuperation from the downstream gas.?

Keywords: Solar ORC; Brine concentration; Solar desalination; Seawater reverse osmosis desalination

PT 134

NADES as green cleaning agent for control of biofouling in RO membrane systems

Andreia Farinha*, Kees Theo Huisman, Lamya Al Fuhaid, Caroline Crisel, Geert-jan Witkamp, Johannes Vrouwenvelder, Bastiaan Blankert

**KAUST, Thuwal 23955, Saudi Arabia*
Tel. +966 5424760, andreia.farinha@kaust.edu.sa

Biofouling prevention and control remains one of the most significant problems of membrane-based water treatment systems for desalination and water reuse. Membrane module cleaning is carried out at full-scale reverse osmosis (RO) installation to restore membrane performance. However, current strategies for cleaning, which rely on alkaline and acid solutions, have proven to fail in removing the biofilm entirely from the surface and out of the modules. Furthermore, the use of such chemicals raises environmental concerns due to its hazardous nature. Developing new, sustainable and more effective cleaning strategies that reduce or eliminate the use of hazardous chemicals is essential for advancing towards more sustainable desalination processes. This study evaluates the potential of natural deep eutectic solvents (NADES) as green cleaning agents for biofilm

removal. NADES are new class of green solvents formed by the interaction of natural non-hazardous organic compounds, such as sugar, polyalcohols, organic acids and bases. These solvents present unique physicochemical properties that distinguish them from conventional solvents.

In this study, membrane fouling simulators were used to mimic the biofouling growth in membrane systems under well-controlled conditions. NADES at different concentrations were tested as cleaning agents to disrupt, dissolve and remove biofilm structures. Results demonstrated that NADES achieved cleaning efficiencies comparable to those of conventional cleaning methods. Our findings highlight the potential of NADES as environmentally friendly alternatives for biofilm removal.

Keywords: Green solvents; Biofouling control; NADES; RO

PT 136

Thermal driven ultrapure water production for water electrolysis with membrane distillation

Rebecca Schwantes*, Yair Morales, Eric Pomp, Jan Singer, Kirtiraj Chavan, Florencia Saravia

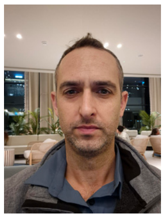
**Fraunhofer Institute for Solar Energy Systems, Heidenhofstrasse 2, Freiburg 79110, Germany, rebecca.schwantes-chavan@ise.fraunhofer.de*

This study evaluates the techno-economic feasibility of membrane distillation (MD) as an alternative to reverse osmosis (RO) for UPW production. Utilizing waste heat from a 5 MW proton exchange membrane electrolyzer, the proposed MD system employs permeate gap membrane distillation to treat feedwaters with brackish and seawater salinities. The study incorporates numerical simulations to analyse system design parameters and energy consumption of MD and RO systems designed to produce 1 t/h of distillate, as well as experimental data on distillate water quality. Results demonstrate that MD systems achieve high-quality distillate (<3 μS/cm) under the tested salinities and at competitive costs. Unit costs per ton of produced distillate for MD ranged from €2.17 to €2.85 for either brackish or seawater feed at electricity prices of €0.10–€0.40/kWh, while RO costs ranged from €2.53 to €5.51 under comparable conditions. The annual costs also reflect the cost advantage, especially for seawater desalination with MD costs, approx. 40% lower than RO. MD shows advantages in energy efficiency with thermal energy provided as low-grade heat. The results show that MD can be a cost- efficient and versatile solution for UPW production powered by PEM electrolyzer waste heat.

Keywords: Ultrapure water; Membrane distillation; Electrolysis; Heat coupling; Techno-economic evaluation

PT 138

Advanced methods for electrochlorination: Applied in mega desalination plants



Elad Barak

All e Water, Plitei-Hasfar 32, Tel Aviv, Israel, elad@allewater.com

Traditional chlorine disinfection methods for water treatment have proven to be costly, time-consuming, and potentially hazardous due to the health risks associated with chlorate by-products. In contrast, electrochlorination offers a safer and more economical alternative, utilizing salt solution electrical energy into electrolysis cell (electrolyzer) to produce hypochlorite disinfectant.

In recent years, many mega-desalination plants, power stations, industrial facilities and other water supply infrastructures have adopted electrochlorination, recognizing its significant benefits over conventional methods.

This presentation at the EDS Conference in Porto 2025 will showcase a case study of an advanced, containerized electrochlorination system designed for large-scale applications. We will focus on the innovative strategies used to manage hypochlorite temperature, which is essential for mitigating health risks while also achieving much lower operational costs.

Traditional electrochlorination systems often rely on chillers to maintain lower temperatures, which can be expensive and energy-intensive. The presented system's unique approach eliminates the need for chillers, leading to a more efficient and stable operation.

In addition, the system employs an eco-friendly cleaning method that align with sustainable and environmental goals. By tackling the challenges of hypochlorite stability and reducing the formation of chlorates, this advanced electrochlorination system serves as an improved practical solution for effective water disinfection in mega desalination processes, reflected by a positive experience by the end users.

PT 140

First evaluation of a concentrated solar power and desalination system using a double-stage organic Rankine cycle configuration

Néstor M. Santana-Hernández*, Agustín M. Delgado-Torres, Lourdes García-Rodríguez

University of La Laguna, La Laguna, Tenerife 38200, Spain
nsantana@ull.edu.es

This work focuses on desalination using renewable energy, co-generation and solar energy use within the topic "Sustainability and energy". A novel solar Organic Rankine Cycle (ORC) scheme based on a double-stage configuration is presented for seawater reverse osmosis desalination. That ORC configuration is driven by line-focus solar collectors along with a thermal energy storage system to extend the electricity and desalinated water output throughout the year. Benefits of the double-stage ORC for the solar desalination application are analyzed, as the improvement in the global efficiency and the size of the needed energy storage. Different reverse osmosis configurations are considered to optimize the global configuration of the concentrated solar power and desalination system. Finally, the yearly assessment of the optimal proposed design is presented for a few interesting locations.

Keywords: Solar ORC; Brine concentration; Solar desalination; Seawater reverse osmosis desalination; CSP-ORC+D

PT 141

Waste to Value — A pilot demonstration and economic analysis of vaterite calcium carbonate production using brine, CKD, and CO_2

Seungwon Ihm*, Abdallatif Abdalrhman, Mohammed Al-Talibi, Omar Al-Raqibah, Eslam Alwaznani, Youngho Lee, Kichul Park, Jinuk Heo, Won Jo, Sehun Kim, Myoung-Jin Kim

**Saudi Water Authority, Dhahran 34232, Saudi Arabia, swihm78@daum.net*

SWRO brine is currently being discharged as waste without any value. In Saudi Arabia, a significant portion of waste from the cement industry, specifically Cement Kiln Dust (CKD), is not recycled. Although there are many carbon dioxide (CO_2) capture projects aimed at reducing greenhouse gas emissions, the captured CO_2 is often injected underground without being utilized. Many extraction solvents used in indirect carbonation technology — such as acids, ammonium salts, and various chelating agents — have demonstrated technical feasibility, still, commercialization has been challenging due to the high costs of these solvents.

This study introduces a novel approach that employs SWRO brine as an effective solvent for the reaction between calcium oxide (CaO), which constitutes 40–60% of CKD, and CO_2. The goal is to produce vaterite, a spherical-shaped crystal form of calcium carbonate ($CaCO_3$), at a pilot scale, presenting a promising and economically viable method for indirect carbonation.

Vaterite is not thermodynamically stable and readily transforms into more stable forms, such as calcite or aragonite, when in contact with water. The research team has recently explored favorable conditions for producing vaterite at a pilot scale. For the first time in the world, actual SWRO brine from Jubail and CKD from a local cement factory were combined with CO_2 to produce vaterite $CaCO_3$ over a three-month demonstration period in a facility designed for 50 tons per year vaterite $CaCO_3$ production (with the capacity to store 22 tons of CO_2 per year) in Jubail, Saudi Arabia. Analysis results confirmed the successful production of high-quality vaterite, meeting the targets of $CaCO_3$ purity greater than 97%, vaterite content exceeding 80%, whiteness over 99%, and particle size below 3 micrometers.

Due to the unique characteristics of vaterite — such as its high specific surface area, dispersibility, and porosity — using vaterite as a raw material can yield products with superior performance compared to conventional calcite. This type of $CaCO_3$ can be utilized not only in traditional industries such as paper, plastic, rubber, coatings, sealants, and adhesives as a premium product, but also in emerging fields like cosmetics, pharmaceuticals, and medical applications (e.g., drug delivery systems and bone fillers).

A techno-economic analysis indicates a potential return on investment (ROI) of less than one year, but establishing a market remains the major challenge, as vaterite is a new product. This paper outlines an economic and environmentally friendly pathway for utilizing SWRO brine, recycling CKD, and storing CO_2, while also addressing the challenges associated with the mass production of vaterite due to its meta-stability.

Keywords: Indirect carbonation; Beneficial use of desalination brine; Vaterite calcium carbonate; Carbon utilization and storage; Brine utilization

PT 142

Selective recovery of lithium from geothermal brines by means of a membrane-based electrochemical system

Clara Roggerone*, Asnakech Lass-Seyoum, Fabio La Mantia, Julia Kowal

**HTW Berlin, Berlin 12459, Germany*
Tel. +49 15204083226, roggero@htw-berlin.de

The current global energy crisis further accelerates the world energy transition towards renewable energies. The demand for lithium raw materials, which are used to make batteries, is expected to grow exponentially in the next years, leading to a potential supply shortage.[1] For this reason, much effort has recently been invested in developing technologies for direct lithium extraction (DLE) from brines. One of the new DLE technologies that is under development is the electrochemical ion pumping method, which is particularly attractive due to its low energy consumption and the avoidance of the use of chemicals.[2] This method has been tested using intercalation materials as the positive electrode that show outstanding selective properties towards lithium, especially $LiMn_2O_4$ (LMO).[3] In this work, a membrane-based continuous flow-by reactor for the electrochemical extraction of lithium from geothermal brine with a $LiMn_2O_4$/?-MnO_2 system is studied. A zoned reactor is proposed in which the current density and electrode mass loading gradually decrease along with the depletion of lithium in the brine.[4] Based on an initial lithium concentration equal to 30 mM, the average energy consumption of a complete extraction cycle for three different reactor sections is determined for an output lithium concentration of 3 mM.

Keywords: Lithium recovery; Geothermal brines; Electrochemical lithium ion pumping

[1] C. B. Tabelin, J. Dallas, S. Casanova, T. Pelech, G. Bournival, S. Saydam, I. Canbulat, Miner Eng 2021, 163, DOI 10.1016/j.mineng.2020.106743.
[2] L. Baudino, C. Santos, C. F. Pirri, F. La Mantia, A. Lamberti, Advanced Science 2022, 9, DOI 10.1002/advs.202201380.
[3] G. Zhou, L. Chen, Y. Chao, X. Li, G. Luo, W. Zhu, Journal of Energy Chemistry 2021, 59, 431–445.
[4] C. Roggerone, F. La Mantia, J. Kowal, A. Laß-Seyoum, ChemElectroChem 2024, 11, DOI 10.1002/celc.202400160.

PT 143

Optimizing pretreatment for reverse osmosis desalination through simultaneous media filter monitoring

Yasmeen Nadreen*, Graciela Gonzalez-Gil, Johannes Vrouwenvelder, Ratul Das, Thomas Altmann

**KAUST - King Abdullah University of Science and Technology, Thuwal 23955, Saudi Arabia*
Tel. +966 542402688, yasmeen.nadreen@kaust.edu.sa

Seawater desalination using reverse osmosis (RO) technology is a critical solution to alleviate global freshwater scarcity. However, the performance of RO systems is often hindered by (bio)fouling, a prevalent issue linked to the accumulation of particles, microbial cells, and organic material on membranes. Effective pretreatment is essential to minimize these challenges, with media filtration being a widely used conventional method. A variety of traditional and novel media materials are available on the market, but comprehensive studies evaluating their comparative performance under identical operational conditions are limited.

This study investigates the performance of six different filter media used in pretreatment for a full-scale RO desalination plant, alongside a conventional sand filter for benchmarking. Over a six-month monitoring period, weekly assessments are conducted to capture seasonal variations and evaluate the filters' efficiencies over time in removing impurities. The monitored parameters include particle counts, microbial cells, organic carbon, turbidity, silt density index (SDI), and modified fouling index (MFI). Notably, the filters were evaluated simultaneously using the same feedwater, enabling direct and comparative analysis under uniform conditions.

Preliminary results reveal distinct performance differences among the media. While some filters demonstrated high efficiency in particle removal but were less effective in reducing microbial cells, others showed greater microbial cell reduction despite lower particle removal efficiency. Furthermore, while SDI and turbidity values for all media remained within recommended limits, the parameter provided limited differentiation compared to the detailed insights gained from microbial and particle analysis.

Ongoing monitoring aims to uncover the seasonal and operational factors that influence the performance of media filters. The insights gained will guide the selection of optimal filter media for varying seawater conditions, enabling more focused and effective pretreatment strategies. Ultimately, this work aims to enhance the sustainability and operational efficiency of RO desalination systems, contributing to longer membrane lifespans and improved overall performance.

Keywords: Pretreatment; Microbial quality; Media filtration; Biofouling; Alternative media

PT 144

Membrane cascades for enhaced rejection of organic pollutants in RO of brackish and sea water

Fatima Zohra Charik*, Saad Alami Younssi, Murielle Rabiller-Baudry

**Hassan II University of Casablanca, Casablanca 50069, Morocco*
Tel. +212 652122181, fz.charik@enscasa.ma

Organic pollutants found in seawater became an increasing challenge to be faced during the desalination process, given the increasing demand for freshwater to overcome water scarcity. RO is a more energy efficient process than distillation, however this last one is able to produce pure water. What about the micropollutants in RO brackish and sea waters treated waters? In our previous study, small organics (MW ˜ 300 g mol^{-1}) were evidenced to be only partially rejected by two RO membranes, especially in complex media where multiple solutes co-exist, and to date neither the upper size limit of potentially transmitted solutes nor the fundamental understanding of this transfer through the membrane are known.

In this work, a set of azo-dyes, vitamin and antibiotics with MW ranging from 254 to 916 g.mol^{-1} and different properties (charges, hydrophobicity…) were filtered in brackish and sea waters aiming at this understanding. A systematic study of RO performances has been achieved to investigate the transfer mechanisms by assessing the impact of the affinity in the solute-membrane-solvent system; discussion is provided using the Hansen Solubility Parameter (HSP). Moreover, as the organic pollutants were not fully rejected, we investigated the potential of membrane cascades in the enhancement of their rejection by simulating the performance for RO of binary mixtures containing an organic pollutant added to brackish water, following our approach of the use of membrane cascade with internal recycling. RO experiments of solutes, conducted in binary and ternary mixtures, were performed with the SW30 RO membrane (Filmtec) in brackish and sea waters, in the 30–40 bar applied pressure range in cross-flow conditions.

Aiming at a first evaluation, several configurations up to 3 stages of membrane cascades with internal recycling of the permeate and the retentate were evaluated. Their efficiency was mainly assessed based on the water recovery and quality, and the required membrane area. Regardless of their MW and the presence or absence of salts, all the organic solutes were transmitted (Tr= 0.09–0.01) through the membrane.

Correlation between the HSP and solutes rejection was evidenced and showed that the interactions in the solute/membrane/solvent significantly impacted the transmission. The more the affinity of the solute for the membrane is decreasing, the more the solute is transmitted, despite its MW.

By using membrane cascades, the performance at 40 bar was simulated to be better than that of single stage filtration. An enhancement in the water recovery of up to 10% with the cascade arrangement could be obtained, and the concentration of the organic solute in the permeate could be divided by 100, while maintaining a high rejection of salts (98%). The additional filtering area and energy consumption will be discussed.

Keywords: RO membrane; Desalination; Membrane cascade; Micropollutants

PT 145

Optimization of time-variant, solar-powered electrodialysis desalination architectures

Melissa Brei*, Jimmy Tran, Amos Winter

**Massachusetts Institute of Technology, 70 Vassar St, Cambridge, MA 02139, USA , Tel. +1 2488843219, mbrei@mit.edu*

With the rise of water scarcity around the world, desalination is serving as an additional source of potable water. The dominant technology, reverse osmosis, is energy intensive, therefore presenting challenges for cost-effective, renewable-powered desalination. Recent work has shown the potential of a novel control scheme for electrodialysis, an electrically-driven desalination process, that significantly reduces the required energy storage. This control scheme modulates flow rate and applied current to maximize desalination rate while tracking a variable power source. It has been successfully demonstrated on a small, community-scale pilot (5–10 m^3/d) treating brackish groundwater in a batch process. This study explores the application of this control scheme for brackish water desalination using a simulated continuous, batch, or hybrid architecture. A multi-objective optimization was conducted to determine the optimal number of stacks in series, cell pairs in each stack, solar array size, and battery capacity for each architecture to maximize production volume while minimizing capital cost of the system. The resulting pareto fronts for each architecture were then compared to map the design space for time-variant electrodialysis desalination. This parametric-driven framework allows practitioners to assess different electrodialysis desalination architectures for a variety of feedwater salinities, power profiles, and other relevant inputs.

Keywords: Electrodialysis; Renewable-powered desalination; Cost optimization

PT 146

Comparison of minimal and zero liquid discharge systems using multi-criteria analysis

Hiba Chebli*, Philip A. Davies, Nicola Bellantuono, Francesco Fornarelli

**University of Foggia, Via Francesco Figliolia 6, Foggia 71121, Italy
Tel. +39 3513995063, hiba.chebli@unifg.it*

Freshwater reserves have been under high threat, mainly due to anthropogenic causes such as population growth, industrialization, and climate change. Seawater desalination is one of the technologies used to meet the global demand for freshwater. However, it has several negative environmental impacts, particularly related to brine discharge, that harm sealife and the ecosystem if not properly managed. The Minimal and Zero Liquid Discharge (MLD/ZLD) approach has recently emerged to remove all the liquid waste from the desalination system. It consists of three stages: concentration, crystallization, and disposal.

MLD/ZLD systems have different pros and cons. Therefore, selecting the right MLD/ZLD system requires the utilization of multi-criteria decision making (MCDM) methods that can integrate qualitative and quantitative criteria into the decision-making process effectively. In this context, this study aims to apply the MCDM method to analyze four treatment trains: multi-effect distillation (MED), membrane distillation (MD), osmotically assisted reverse osmosis (OARO), and multistage nanofiltration (NF). Each treatment train was assessed in two configurations: disposing of the brine in evaporation ponds (EP) or crystallizing the brine. Unlike the MED system, which represents a commercial thermal-based system and includes the concentration and crystallization stages of the MLD/ZLD systems, the MD, OARO, and multistage NF are considered emerging thermal and membrane-based systems developed to treat the brine produced by the reverse osmosis desalination. Several criteria are considered in the analysis and categorized into three aspects: economic, technical, and environmental. These include investment and operation costs, land requirements, carbon dioxide emissions, specific energy requirements, recovery rates, maturity, and lifetime. The analytic hierarchy process (AHP) and technique for order preference by similarity to ideal solution (TOPSIS) methods were used to weigh the criteria and rank and select the best MLD/ZLD system, respectively. The preliminary results show that the most important criteria influencing the ranking of the alternatives are recovery rate, maturity, SEC, and CO_2 emissions, with priority vectors of 0.257, 0.207, 0.201, and 0.191, respectively. Additionally, they indicate that the MLD/ZLD treatment trains have the highest ranking, particularly the MED with EP.

Keywords: Zero liquid discharge; Minimal liquid discharge; Multi-criteria decision making; Membrane distillation; Osmotically assisted reverse osmosis; Multi-stage nanofiltration; Multi-effect distillation

PT 147

Optimizing brine management through solar membrane distillation and thermal energy storage: a techno-economic analysis

Alejandro Bueso Sánchez*, Cristobal Valverde López,
Juan Diego Gil Vergel, **Guillermo Zaragoza del Águila**

**CIEMAT-Plataforma Solar de Almería, Almería 04005, Spain*
Tel. +34 637163753, alejandro.bueso@psa.es

Currently, the valorization of brine from desalination is a key strategy in the circular economy, aiming to transform this waste into valuable resources. This requires the implementation of zero liquid discharge (ZLD) or minimum liquid discharge (MLD) strategies, which aim to eliminate or minimise liquid waste by recovering all the water and producing only solid waste. In this context, Membrane Distillation (MD) emerges as an excellent option for concentrating brines from various desalination techniques, utilizing a hydrophobic and microporous membrane to transfer vapor at low temperatures and obtain a highly concentrated brine. These lower temperatures can be easily achieved using a solar thermal field, supplemented by a Thermal Energy Storage (TES) tank to mitigate the impact of cloud cover or to maintain operation briefly without sunlight, depending on operational

and ambient conditions. An innovative trend in the research of TES tanks and materials is the use of packed-bed systems, which offer high energy storage densities, particularly when storing energy at lower temperatures. This study investigates the impact of utilizing packed bed materials in TES tanks to enhance the efficiency of an MD system within a simulation framework, through a techno-economic analysis that evaluates several case studies. The results of the techno-economic analysis demonstrate that the use of packed bed material significantly improves system efficiency, reducing the levelized cost of water and providing a more sustainable and economically viable solution for brine management.

Keywords: Solar desalination; Brine management; Membrane distillation; Thermal energy storage; Packed bed material

PT 148

Harnessing inspection technology and AI in order to understand and predict pipeline cleaning frequency of sea water intake pipes

Pilar Vera-Rodriguez*, Simon Bell, Barry Ritchie, **Paul Newbury**#

iNPIPE PRODUCTS, Brompton on Swale DL10 7JH, UK
**Corresponding author Tel. +44 01748 813270, pilar@inpipeproducts.co.uk*
#Presenter paul.newbury@inpipeproducts.co.uk

This paper discusses typical launching and receiving options, as well as cleaning frequency, for seawater intake pipeline systems. It explores the use of innovative inspection techniques harnessed through AI technology to provide predictive debris modelling, along with post-cleaning validation.

The paper presents practical examples demonstrating the payback on capital investment for new systems, as well as retrospective options for pipeline intervention in existing, older water pipeline systems.

Established in 1984, iNPIPE PRODUCTS™ has nearly four decades of expertise in pipeline cleaning and isolation. The company has developed an integrated, systematic approach to mechanical cleaning of pipelines ranging from 10 mm to 3000 mm in diameter. This includes bespoke designs and cost-effective methods for tool introduction, specific tool designs for removing problematic organisms and deposits, and solutions for integrating pigging into seawater intake pipeline systems. Additionally, the paper covers outlet options for the environmentally safe removal of debris and cleaning tools into the sea.

Key points discussed in the paper include:

- Cost-effective, seamless introduction of cleaning tools into pipelines without disrupting production, with practical examples.
- Seawater intake design considerations, with historical examples to ensure easy and trouble-free exit for cleaning tools and debris.
- Visual inspection techniques for pipelines up to 3000 mm in diameter, with typical examples of debris accumulation.
- Pipeline joint integrity measurement, visual inspection, and accurate location tracking along the pipeline.

- AI-based predictive deposition mapping software to optimize pipeline performance throughout the life of desalination plants.
- Pipeline mapping software for existing pipelines without system drawings.

Keywords: Intake pipe cleaning; Biofouling removal; Pipeline cleaning; Pipeline pigging; Marine growth inspection; Marine growth measurement; AI predictive debris accumulation and resultant cleaning frequency

PT 149

Numerical assessment of membrane intrusion in permeate channels of reverse osmosis units

Giuseppe Battaglia*, Andrea Sireci, Luigi Ranieri, Bastiaan Blankert, Giorgio Micale, Cristian Picioreanu

**Università di Palermo, Palermo 90128, Italy*
Tel. +39-3271715211, giuseppe.battaglia03@unipa.it

Seawater reverse osmosis (RO) desalination is currently the most adopted process for supplying fresh water in arid regions. RO units employ semipermeable polymeric membranes that allow passage of water under applied pressure, while rejecting ions and other compounds. In the units, membranes are wound around feed and permeate spacers made of plastic nets that keep the membranes apart, creating the channels where water flows. Numerous studies investigated the flow in feed channels, aiming at reducing the pressure drop and enhancing mass transfer of solutes. Conversely, the flow in permeate channels has received less attention. In 2021, Kleffener et al. [1] performed computational fluid dynamics simulations in undeformed permeate channels of seawater RO units, finding pressure drops almost 4 times lower than those experimentally recorded. This was attributed to membrane intrusion phenomena, i.e., membrane deformation around the spacer into the permeate channel upon applied pressure, leading to extensive flow constriction and heightened pressure loss. This study motivated us to investigate the mechanical basis of membrane intrusion and its effects on hydrodynamics.

Recently, we developed a 3-D simulation framework coupling mechanics and fluid dynamics to investigate membrane intrusion in RO permeate channels [2]. Simulations were conducted at the small scale of several periodic units of membrane-permeate spacer assembly. A one-sided intruding system made of one membrane placed above a permeate spacer (side A) supported by a non-deformable wall was first studied. Compared with experimental data from [3], membrane deformation and flow in the deformed permeate channels were very well described numerically. The present work aims at studying the closer-to-reality double-sided configuration, with membranes above and below the permeate spacer. To this aim, values for the mechanical characteristics of membrane and permeate spacer were adjusted based on novel experimental data, collected in one-sided configurations with the membrane placed above (side A) and below (side B) the asymmetric spacer [3]. After tuning of mechanical parameters, the water flow in each single-sided configuration was very well predicted by numerical fluid dynamics simulations. For the double-sided configuration, pressure drop along the spacer-filled permeate channel was found to increase from ~0.5 to ~3.8 bar/m (760%) under an applied transmembrane pressure of 20 bar, at 5 cm/s permeate superficial velocity.

Our results mark the strong impact of membrane intrusion in permeate channels and the need for better understanding of these phenomena for improved design procedures and optimized performance of RO units.

Keywords: Membrane intrusion; Structural mechanics; Computational fluid dynamics; Brackish water

[1] C. Kleffner, et al., Chemie-Ingenieur-Technik. 93 (2021).
[2] G. Battaglia, et al., Desalination. 587 (2024).
[3] L. Ranieri, et al., Desalination. 591 (2024).

PT 150

Integrated production of $Mg(OH)_2$ powders and high valuable salts from seawater desalination brines through evaporative ponds

Giuseppe Battaglia*, Lorenzo Ventimiglia, Fabrizio Vicari, Alessandro Tamburini, Andrea Cipollina, Giorgio Micale

**Università di Palermo, Palermo 90128, Italy*
Tel. +39-3271715211, giuseppe.battaglia03@unipa.it

Concentrated saline solutions, referred to as brines, are the by-product of the desalination industry. These solutions have been treated as waste, posing environmental concerns. However, seawater contains almost all the elements in the periodic table, such as sodium, magnesium, calcium, and sulphate ions [1]. The concentration of these species almost doubles in desalination brines. The valorisation of desalination brines represents, therefore, an appealing opportunity for the supply of crucial chemical elements. In this context, the REWAISE project proposes the use of evaporation ponds as an effective step to valorise desalination brines by producing chemicals, such as NaCl or calcium-based compounds, and Ca^{2+}-free highly concentrated Mg^{2+} solutions, called bitterns. Bitterns are suitable for the production of highly pure magnesium hydroxide solids [2], a chemical compound widely adopted in several industrial fields. The present work investigates the performance of the integration of evaporation ponds for the treatment of desalination waste brines at the pilot scale. To this aim, an extensive experimental campaign was conducted at the WAVE innovation centre at Adeje (Canary Island). Evaporative ponds were built and adopted to treat (i) a reverse osmosis (RO) brine solution collected from the la Caleta-Adeje RO plant and (ii) a retentate solution, enriched in bivalent ions, from a nanofiltration unit testing the same RO brine. At the end of the evaporative process, two bittern solutions were collected. The RO brine, the NF retentate and the corresponding bitterns were then adopted for $Mg(OH)_2$ production through a pilot scale magnesium crystallizer prototype, named Multi Feed-Plug Flow Reactor, MF-PFR. The prototype was developed by ResourSEAs and the University of Palermo, two partners of the Rewaise project. Tests were carried out at a pH value of 10.8 by adopting sodium hydroxide solutions as the alkaline reactant. Mg^{2+} concentration was found to increase up to 10 and 15 times in bitterns with respect to the corresponding concentrations in the RO brine and the NF retentate. Calcium concentration was reduced by more than 50%, due to the precipitation of calcium carbonate and calcium sulfate compounds in the evaporative ponds. $Mg(OH)_2$ production was = 45 kg/d, moreover, thanks to the Ca removal in the evaporative ponds, $Mg(OH)_2$ solids extracted by the bitterns had a purity >95%.

Keywords: Mineral recovery; Magnesium hydroxide; Critical raw material; RO brine; Evaporative ponds

Acknowledgements

The Authors would like to 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.

References

[1] A. Kumar, et al., Metals Recovery from Seawater Desalination Brines: Technologies, Opportunities, and Challenges, ACS Sustain. Chem. Eng. 9 (2021) 7704–7712.
[2] G. Battaglia, et al., Evaluation of the Purity of Magnesium Hydroxide Recovered from Saltwork Bitterns, Water. 15 (2023).

PT 151

Membrane deformation in reverse osmosis: In-situ quantification and impacts on pressure drop in permeate channel

Luigi Ranieri*, Luca Fortunato, Johannes Vrouwenvelder, Cristian Picioreanu, Bastiaan Blankert

**King Abdullah University of Science and Technology, Thuwal 23952, Saudi Arabia, Tel. +966 540603094, luigi.ranieri@kaust.edu.sa*

Reverse osmosis (RO) is currently the most used technology for brackish and seawater desalination. RO is pressure-driven, requiring the transmembrane pressure (TMP) to exceed the osmotic pressure of the feed solution (brackish or seawater). The applied pressure used in RO can cause deformation of the membrane and flow-channel, due to membrane intrusion into the permeate spacer, and membrane displacement. Membrane intrusion or permeate spacer embossing occurs due to the feed pressure pushing the membrane into the permeate spacer, changing the system geometry and, therefore, with negative impacts on the permeate flow pressure drop [1]. Hereby, it is worth noting that the monitoring and characterization of membrane deformation assume a fundamental role for the assessment of process performance. Currently, direct observations of membrane deformation in RO modules can be obtained ex-situ (i.e., in autopsies). However, ex-situ techniques require sample preparation (drying, etc.) and can only observe irreversible deformation, and require different membrane sample for each condition to be tested. For a better understanding of involved dynamics, reversibility, and the impact of process conditions, acquiring quantitative information in real-time during operation is highly required. Therefore, the objective of this study was to introduce OCT as an in-situ non-invasive tool to quantify membrane deformation as function of TMP (5–55 bar) and evaluate its impact on pressure drops in permeate channel. In-situ monitoring of membrane surface geometry in a lab-scale flow-cell revealed the formation of specific patterns with ridges and valleys. The deformation became more pronounced with increasing applied pressure (5–55 bar), due to membrane intrusion into the permeate spacer. Moreover, by alternating between high (pressurized) and low (relaxed) TMP, we observed that the membrane deformation is partially reversible [2]. Herein, in the pressure range investigated, the deformation (relaxed and pressurized) was linear with applied TMP (5–55 bar). Thereby, the measured dependency of membrane displacement (?z - ridge and valley) and membrane intrusion on TMP is reasonably well described by a straight line, where we are interested in the slope (μm/bar) [2]. Interestingly, the asymmetric structure of the permeate spacer causes a clear distinction in (i) the magnitude, (ii) the reversibility and (iii) the spatial distribution of the deformation (i.e., ridges and valleys), depending on which side faces the membrane [2]. This led to different impacts on the permeate channel pressure drop, highlighting the importance to link the in-situ quantification of membrane deformation with the RO process performance during operating conditions.

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

References

[1] C. Kleffner, et al., Chemie-Ingenieur-Technik. 93 (2021).
[2] L. Ranieri, et al., Desalination, 591,118037 (2024).

PT 154

Novel insights into biofouling growth on reverse osmosis membranes through in-situ microscopic visualization

Noshin Karim*, Louise Ratel, Nitish Sarker, Catherine Charcosset, Amy Bilton

University of Toronto, 5 King's College Road, Toronto, ON M5S 3G8, Canada
Tel. +1 4039261504, noshin.karim@mail.utoronto.ca

Escalating global water scarcity highlights the critical need for sustainable desalination technologies and wastewater treatment solutions. Reverse osmosis (RO), including photovoltaic-powered systems (PVRO), has become a predominant choice in achieving these goals and realizing Sustainable Development Goal (SDG) 6 in off-grid communities (Greenlee et al., 2009, Bian et al., 2016, Islam et al., 2018). While inorganic scaling has been widely studied (Sarker et al., 2025), biofouling remains a persistent challenge for PVRO, reducing system performance and increasing operating costs (Wang et al., 2011). Most biofouling analysis techniques in literature are classified as ex-situ (Wilson et al., 2017). Despite their importance, real-time assessment of biofouling growth on RO membranes can provide new insights, leading to breakthroughs on the effectiveness of different mitigation strategies. Thus, the goal of this research is to develop a RO visualization flow cell for in-situ observations of biofilm growth using confocal laser scanning microscopy

(CLSM). In compliment to this, we are also analysing the effect of UVC-LED pre-treatment on biofouling growth as a mitigation measure in off-grid PVRO applications.

A custom-built high-pressure crossflow cell with a visualization window was designed, manufactured and commissioned to fit under a CLSM and operate at realistic seawater RO filtration conditions. A commercial SEPA® CF II filtration unit was also used for controlled experiments and ex-situ analyses of biofilm morphology and composition via scanning electron microscopy (SEM). Pseudomonas biofilms were cultivated on RO membranes under controlled hydrodynamic conditions using synthetic seawater, allowing in-situ observation of biofilm growth. Preliminary findings highlight the value of pairing in-situ imaging with ex-situ analysis to gain better insights into biofilm growth. Another custom-built crossflow cell was prepared to simulate brackish water RO systems and study the effect of UVC-LED pre-treatment on biofilm development. Results demonstrated that >18 mJ/cm2 UVC-LED pre-treatment of an Escherichia coli water source can delay biofilm formation, as confirmed through ex-situ crystal violet assays and fluorescent microscopy; the delay could be attributed to a lag in bacterial attachment to the membrane. Building on these insights, we are integrating in-situ CLSM visualization to evaluate the UVC-LED pre-treatment efficacy, aiming to cross-validate the functionality of both and ultimately enhancing the efficiency and reliability of RO operations across diverse sectors.

Keywords: Biofilm; In-situ microscopy; UVC-LED; Cross-flow filtration

PT 155

Effect of increasing top brine temperature on the performance of a solar powered MED system

Patricia Palenzuela*, Mohammed Abdelkarim Antar, Juan Miguel Serrano, Lidia Roca, Guillermo Zaragoza

**CIEMAT-Plataforma solar de Almería, Almería 04007, Spain*
Tel. +34 669423044, patricia.palenzuela@psa.es

Minimal or Zero Liquid Discharge processes allows on one hand to reduce the brine discharge to the sea by brine concentration and on the other hand, the extraction of added value elements present in seawater by brine valorization [1]. Among large-scale desalination technologies, reverse osmosis is the one that has experienced the most rapid growth in recent years, accounting for up to 66% of current installed capacity [2]. However, this technology is currently limited by the osmotic pressure to concentrate and valorize brines and here is where thermal desalination technologies have great opportunities, with multi-effect desalination (MED) being the most widely implemented at industrial level. The operation of these plants is limited at a maximum temperature of 65–70°C to avoid the risk of precipitation of divalent salts present in seawater, which could lead to scale deposits on the heat exchanger tubes, thus decreasing the heat transfer of the process. This restriction limits in turn the thermal efficiency of the process since it increases with the temperature because it allows to increase the number of effects. In addition, it allows to reduce the investment costs as less heat exchange area is required due to the increased temperature difference between effects. It is especially relevant when the process is powered by solar energy since the higher the efficiency of MED plants the lower the required area of the solar field, which would lead to a substantial decrease in the investment costs. The temperature limitation can be avoided by the use of pretreatments, such as nanofiltration (NF) [3].

This work evaluates the effect of temperature rise on a solar MED unit located at Plataforma Solar de Almería, operating with seawater previously pretreated by a NF plant. To this end, an experimental campaign has been carried out at a temperature range between 65°C and 89°C. The experimental results have been then used to evaluate the effect of the temperature increase on the Recovery Ratio (RR) and to adjust the overall heat transfer coefficient [4] to higher operation temperatures. Finally, the plant model (originally published in [4]) has been modified to use the new heat transfer coefficient correlation and to evaluate the effect of temperature increase on plant efficiency and exchange area when increasing the number of effects.

Keywords: Brine concentration; Multi-effect distillation; Nanofiltration; Top brine temperature

PT 157

Waterfountain: Sub-sea desalination with easy maintenance

Paul Buijs*, Kyle Hopkins, Rolf Bendiksen, Per Olsen

FirstWater Consultancy FZ-LLC, RAKEZ, Ras Al Khaimah, UAE
Tel. +971 509767302, paul.buijs@1stwater.org

Waterfountain is a submerged desalination system based on standard reverse osmosis membranes that has been developed by Oisann Engineering, Norway. Using the deep-sea pressure, an energy saving of around 30% can be achieved. Since Waterfountain is running at a low recovery, no antiscalants or other chemicals need to be used. As the deep-sea water quality is superior to the surface quality (algae, turbidity), just a minimal pretreatment is required. Since the recovery is low, the local increased salinity effects are minimal. Waterfountain only extracts water from the sea, leaving minerals behind. Waterfountain's unique design requires no subsea maintenance, only the filters and membranes are submerged, and the critical moving components float above the surface.

Waterfountain offers 3 products: Waterfountain 10, with a capacity from 50–3,000 m^3/d, Waterfountain+, with a capacity of 50,000 m^3/d and Waterfountain Max, with a capacity of up to 200,000 m^3/d. Waterfountain is an agile approach, fitted for emergency and disaster relief, transported and deployed on location swiftly.

Keywords: Subsea desalination; Airlift; Reverse osmosis; Barge; Mobile

PT 159

Operation and maintenance considerations of an innovative 1200 m³/d brine valorization system

Stasinos Chiotakis*, Nikolay Voutchkov, Noura Chehab

**ENOWA – NEOM, Neom Community 1, NEOM 49643, Saudi Arabia*
Tel. +966 532709673, stasinos.chiotakis@neom.com

This study focuses on the development of a Zero Liquid Discharge (ZLD) system for desalination brine management at NEOM, an independent economic zone in Saudi Arabia. Located in a relatively desert region, NEOM relies on desalination, producing brine as a byproduct, which can harm the local environment if not managed correctly. Traditional ZLD technologies are costly and produce mineral waste with low commercial value. In contrast, NEOM's innovative ZLD system, developed by the Water Innovation Center (WIC), integrates brine mining to extract commercially viable minerals like magnesium and lithium. The system, implemented at the Duba desalination plant, uses advanced filtration and evaporation techniques to produce potable water and mineral products while reducing environmental impact. The study also highlights operational challenges, emphasizing the importance of effective plant design, operation, and maintenance (O&M) for continuous, reliable performance. Key factors for O&M success include proper staff training, coordination with suppliers, and rigorous safety protocols. The system's efficiency and sustainability rely on optimized processes and a detailed preventive maintenance schedule, contributing to long-term operational success and minimizing production costs.

Keywords: Seawater; Brine; Brine mining; Zero liquid discharge; Operation; Maintenance; System; Plant

PT 160

Resilient marine works: survey and marine modeling strategies for successful coastal desalination

Mario Valente*, Filipe Vieira

**ATM - a Geosyntec Company, Dubai, UAE*
Tel. +971 508459336, mario.valente@appliedtm.com

The successful design of coastal desalination plants depends on comprehensive marine field data collection surveys and marine modelling of marine works. These surveys and numerical models provide essential insights into site conditions, enabling informed decision-making and minimizing risks throughout the project lifecycle. This article will review the key surveys required for designing intake and outfall structures, pipelines, and coastal protection systems, with a focus on early-stage surveys that establish a strong foundation for project success. The article will also review the key numerical models required at early stages. Marine surveys and numerical models in the early project development stages provide critical inputs for sustainable and efficient designs, reducing risks and ensuring regulatory compliance. This article intends to serve as a guide for prioritizing and integrating surveys and numerical models, promoting a data-driven approach that enhances project outcomes and long-term success.

Keywords: Seawater intake; Seawater outfall; Hydrodynamic modelling; Marine surveys; Data collection

PT 162

Raising awareness of air-related issues in seawater pipelines: a practical review

Mario Valente

ATM - a Geosyntec Company, Dubai, UAE
Tel. +971 508459336, mario.valente@appliedtm.com

Air entrainment in seawater pipelines is often overlooked yet can have significant implications for both short- and long-term marine outfall pipeline performance. This presentation provides a brief review of air accumulation mechanisms in submerged outfall systems, focusing on how air pockets can impede flow capacity, induce instabilities, and increase the risk of pipe failure. Key factors contributing to air entry—such as onshore hydraulic structures and pipeline geometry—are highlighted, as well as the consequences of trapped air on pipe weight and buoyancy. Emphasis is placed on practical design considerations and operational strategies to minimize air intrusion and mitigate its effects, thereby enhancing pipeline reliability and extending service life. By raising awareness of these potential issues, contractors and engineers will be better equipped to develop robust solutions and ensure safe, efficient operation of seawater outfall systems.

Keywords: Marine outfall; Outfall systems; Air entrainment; Seawater pipelines

PT 163

Blue energy: renewable energy production from desalination brine

Patricia Terrero Rodriguez

Sacyr Agua, Madrid 28027, Spain
Tel. +34 618103386, pterrero@sacyr.com

Salinity Gradient Energy (SGE) capture by Reverse Electrodialysis (RED) is a promising technology to harvest the energy available in the salinity of the reject stream from the desalination process generating electrical energy and reducing the global energy consumption of the desalination process.

The present study presents the LIFE HyReward Project European project, which aims to demonstrate the technical and economic feasibility of a new more sustainable desalination process combining Reverse Osmosis (RO) and Reverse Electrodialysis (RED). The integration of the RED process with the conventional RO process allows to improve the

energy efficiency of the desalination process, thanks to the recovery of the electrical energy contained in the seawater reverse osmosis (SWRO) brine before its discharge into the sea through the generation of electrical energy, reducing the global energy consumption and, therefore, the greenhouse gas (GHG) emissions.

This paper will present the experimental results obtained during the pilot plant experimentation, where an energy production of up to 0.3 kWh/m^3 of brine has been achieved.

Keywords: Blue energy; Brine valorization

PT 164

Challenges and opportunities for the use of non conventional water resources for agriculture

Patricia Terrero Rodriguez

Sacyr Agua, Madrid 28027, Spain
Tel. +34 618103386, pterrero@sacyr.com

According to United Nations, food production should double by 2050 and we should meet the 2nd Sustainable Development Goal (SDG) by 2030, which is to end hunger in the world.

This is a major challenge, according to the data and conclusions from UN and FAO, taking into account the scenario we face: the uncertainty generated in agriculture, livestock farming and fishing due to extreme weather events caused by climate change, the loss of biodiversity and a progressive degradation of the soil, which is less productive, and water scarcity as a result, primarily, of human action.

For this reason the role that unconventional resources (desalination and reuse) must play in the coming years is crucial to be able to meet these objectives.

In this paper, the challenges of the use of non conventional water resources will be analyzed, from different point of views (economic, technical, legal and social).

In the freamework of the R&D project SOS AGUA XXI, developed by Sacyr, 2 of the main challenges will be analyzed scientifically by means of experimentation both at laboratory scale and pilot plants:

1. Effect of irrigation of different crops with desalinated water (effects over crops and soils)
2. Detection of the presence and elimination of Compounds of Emerging Concern (CECs) in reclaimed water used for agriculture

Keywords: Desalination for agriculture; Reuse

PT 165

Green desalination project for resource recovery from brine

June-Seok Choi*, Linitho Suu, Jonghun Lee, Joowan Lim,
Youngkwon Choi, Hojung Rho, Saeromi Lee

**KICT, 283, Goyangdae-ro, Goyang-si 10223, Korea
Tel. +82-31-910-0759, jschoi@kict.re.kr*

With climate change exacerbating water scarcity issues, seawater desalination technology has become widely adopted worldwide as a solution. However, the large volumes of brine generated during desalination processes are anticipated to significantly impact marine ecosystems. As a result, research efforts to utilize brine have been growing, particularly in the Middle East and Europe.

The Green Desalination Project addresses these challenges by developing membrane-based process technologies to recover valuable ions from brine generated during seawater desalination and wastewater treatment.

This study employs Membrane Crystallization (MCr) technology to develop crystallization and recovery techniques for valuable ions in brine, aiming to reduce brine volumes while recovering useful ions. Additionally, process optimization has been pursued by integrating various standalone and coupled processes.

The MCr process experiments were conducted using a reactor designed with submerged hollow-fiber membranes, and research is also underway to design reactors utilizing flat-sheet membranes.

Keywords: Resource recovery; Membrane crystallization; Brine; Desalination

PT 166

Control biofouling through membrane flux balance by interstage boosting

Haytham Abdelfatah*, Eli Oklejas

**FEDCO Pump, 800 Ternes Drive, Monroe, MI 48162, USA
Tel. +1 7346297352, hahmed@fedco-usa.com*

The main problem in increasing recovery systems is membrane flux as you need to increase the pressure to get product from last element but in reality, all this extra pressure provided to the 1st element which increase the flux and recovery for this element because this element works on feed water and don't need all this pressure. At the same time the rear elements work with high TDS water (high osmotic pressure) but with lower pressure compared with front elements.

Sea water desalination Membrane manufacturing design guidelines indeed recommended element recovery of around 8% and an element flux lower than 24 LMH (liters per square meter per hour), These guidelines are designed to optimize the performance and longevity of the desalination membranes.

Regarding biofouling, which is a significant challenge in membrane processes, research has shown a tight relationship between element concentration polarization and biofouling. Element polarization can exacerbate biofouling by creating conditions that favor the growth of biofilms on the membrane surface. This, in turn, can lead to a phenomenon known as biofilm-enhanced concentration polarization (BECP), which can degrade water quality and reduce membrane lifetime.

To mitigate biofouling, it is recommended to keep the element polarization below 13%. This helps in maintaining the quality of the permeates and the efficiency of the membrane process. By controlling element polarization, it is possible to reduce the risk of biofouling and extend the operational life of the desalination membranes.

In paper we will compare the single stage design, each element boost pressure, 3-stage design and 2-stage design to see the best technical result and balance between technical result and capital cost so we can get the optimum design.

Keywords: Driven pressure; Flux balance; Interstage boost; 2-satges; Biofouling and membrane lifetime

PT 167

Multiscale modeling of ion transport in IEMs and polyamides: bridging microscale and macroscale insights

Nasser Al-Hamdani, Giorgio Purpura, **Giorgio De Luca***, Giuseppe Costanzo, Javier Luque Di Salvo, Andrea Cipollina, Giorgio Micale

**Tecnologia delle Membrane, ITM-CNR, Via P. Bucci cubo 17/C, Rende 87030, Italy, Tel. +39 0984 492080, g.deluca@itm.cnr.it*

Membrane separation processes cover a broad category of techniques widely applied in desalination for the production of freshwater, recovery of valuable products and energy production. The performance of the desalination technologies strongly depends on the specific characteristics of the membranes employed and their behavior under varying operative conditions. The development and synthesis of innovative, tunable membranes would be greatly beneficial for optimizing such processes. Achieving this goal requires a comprehensive understanding of the physical phenomena governing the mass transport of different species across desalination membranes. However, despite substantial research efforts, a detailed understanding of these mechanisms remains elusive. Furthermore, the usage of simplified tunable models to describe these complex phenomena often risks misrepresenting the underlying physics of separation. This study presents an ab initio multiscale approach to model ion transport across polymeric membranes, including ion exchange membranes (IEMs), as well as polyamide thin-film composite (TFC) membranes. IEMs are essential in green technologies, but reliance on adjustable parameters in traditional models limits predictive accuracy. Our research introduces an approach eliminating the need for such parameters. Molecular dynamics (MD) simulations were used to calculate key properties such as water uptake, water volume fraction, and the membrane dielectric constant, which inform analytical models for ion diffusivity and transport ensuring the avoidance of numerical artifacts associated with direct MD calculations. Partition coefficients were derived by calculating the chemical potentials at the membrane interfaces, accounting for the concentration-dependent variations during ion transitions from solution to membrane. The improved procedure showed good agreement between theoretical and experimental water uptake and water volume fraction. Ionic diffusivities predicted using the Mackie-Mears model matched experimental data. While analytical corrections for condensed counterion mobility in the Donnan-Manning model slightly reduced agreement. Likewise, the results obtained for the partition coefficients matches those of the experimental results. This framework enhances predictive accuracy and provides valuable insights into transport mechanisms in polyamides, AEMs, and CEMs without relying on tunable parameters. This approach offers valuable insights into the physics of separation by elucidating the relationship between intrinsic atomic-scale membrane properties and engineering-scale mesoscale parameters. Ultimately, this work lays the foundation for a novel framework for the modeling and development of desalination membranes.

Acknowledgments

The work is funded by the European Union – Next Generation EU. Action financed with PRIN-PNRR funds, project Prot. P20225HTWF COSMO

Keywords: Ab-initio multiscale modelling; Ion-exchange membrane; Polyamides; molecular modelling; Analytical models

PT 168

Sustainable production of lithium compounds: a key element towards the energetic transition

Ana Beatriz Teixeira*, Lícinio Ferreira, Sylwin Pawlowski, Marisa Rodrigues

**Bondalti, Avenida Jorge Lemos 94 1D, Coimbra 3045-232, Portugal
ana.teixeira@bondalti.com*

Under the current scenario of transitioning towards a low-carbon economy, lithium has taken a central stage due to its use in lithium-ion batteries. The need for lithium has drastically risen in recent years, resulting in a threefold increase in lithium production in the last decade [1].

Such scenario has created extreme pressure in the battery industry, leading to the scarcity of raw materials, such as lithium compounds. Moreover, the production of these compounds is known for their negative environmental impacts.

As the demand for lithium increases, industries are focused on ensuring high-purity lithium that meets the high purity requirements (>99.5 wt%) needed for lithium battery applications, a fast-evolving field. Consequently, additional purification steps involving both novel and traditional techniques play a crucial role in meeting the high standards, which are vital for the battery performance and safety of lithium-battery technologies [2]. Boron is an impurity present in most lithium brines that needs to be removed from concentrated brines in order to produce high-purity lithium salts [3].

Novel, sustainable, and low-cost deep eutectic solvents (DESs) have gained attention as eco-efficient "designer solvents" due to their unique mix-and-match properties [4].

Here, a preliminary study for boron removal from concentrated brines using liquid-liquid extraction is presented. Upon careful review of many conventional solvents for boron extraction, the active boron extractant 2,2,4-trimethyl-1,3-pentanediol (TMPD) was chosen as the primary hydrogen bond donor to formulate novel hydrophobic DESs with five different alcohols.

Preliminary results have demonstrated promising boron removal from lithium chloride and boroncontaining streams via liquid-liquid extraction. Among the five DESs under study, the highest single-stage boron extraction efficiency (84%) was achieved using DESs composed of TMPD dissolved in 1-Pentanol, whereas the lowest lithium loss (2%) was observed with the DESsformed by TMPD dissolved in 2-ethylhexanol, and kerosene.

Keywords: Lithium rich brine; Boron; Solvent extraction; Hydrophobic deep eutectic solvent; Green chemistry

PT 169

Selection of pre-RO cartridge filters

Oren Heymans

Entegris, Kiryat-Gat 8202276, Israel
Tel. +972 73 2210010, oren.heymans@entegris.com

Reverse osmosis (RO) desalination is an essential technology for producing potable water. In this process, cartridge filters (CF) are often used as the last stage of pretreatment to polish remaining suspended solids from the water to reduce fouling of the RO membranes. These filters are often considered mere protection devices but can in practice significantly impact operational efficiency and cost management of the desalination process.

This study investigates the performance of cartridge filters of different media types, ratings and models in the desalination process. The aim is to establish the optimal pre-RO filtration strategy that minimizes total costs for desalination plants by balancing Pre-RO cartridge filter costs against energy and chemical savings.

Media types: The filtration media type the filter uses, like melt-blown depth filtration media or pleated media, has an impact on the filter's critical performance attributes like dirt holding capacity, particle removal efficiency and pressure drop. Depth Filters provide a larger media amount and trap particles throughout their thickness. Pleated Filters have large surface area from a folded design that enhances flow rates and minimizes pressure drops.

Particle retention: Tighter CF filtration can reduce fouling of the RO membranes, moderating the RO Differential Pressure (DP) increase and lower the pump energy consumption. Additionally, it can decrease the need for clean-in-place (CIP) of the RO membranes by maintaining a moderate DP curve. However, tighter pre-RO filters come with ownership costs, including lifetime and filter element expenses.

Filter models: Even filter models on the market of nominally same media type and material, construction and retention rating, like a "5 µm melt-blown polypropylene depth filter", but from different makes, can show a large difference in the critical performance parameters.

Cartridge filtration represents a substantial cost element in SWRO treatment plants. Optimization of cartridge filtration can result in significant cost savings.

Keywords: Cartridge filtration; CF; Energy; Cost

PT 170

Hydraulic design of marine intake systems: optimizing performance and reliability

Mario Valente*, Hugo Costa

**ATM - a Geosyntec Company, Dubai, UAE*
Tel. +971 508459336, mario.valente@appliedtm.com

The hydraulic design of marine pipeline systems is critical to the efficient operation of coastal infrastructure, including desalination plants, power stations, and offshore industries. A key parameter in these projects is the hydraulic roughness, which directly influences frictional losses, energy requirements, and long-term system performance. This paper explores the complex factors affecting hydraulic roughness in marine environments.

Recommendations are presented for selecting initial design roughness values for common projects, incorporating allowances for aging and environmental impacts, and implementing risk mitigation strategies to manage fouling and wear. Case studies highlight the practical implications of roughness variability, emphasizing its role in operational efficiency and lifecycle cost optimization. This paper aims to provide desalination plant developpers with actionable insights and guidelines for robust hydraulic design of marine pipeline systems, ensuring sustainable and reliable operation.

Keywords: Intake system; Seawater intake; Marine fouling; Hydraulic roughness; Intake pipelines

PT 171

Intake and outfall systems — Middle East experience and lessons learned

Hugo Costa*, Ian Willoughby

HR Wallingford, Dubai, UAE
Tel. +971 569452579, h.costa@hrwallingford.com

The Middle East has witnessed the rise of some of the world's largest desalination plants, driven by the region's arid climate and growing water demands. Designing intake and outfall systems for these mega-projects presents unique challenges that require careful consideration and innovative solutions. This article draws upon valuable lessons learned from these projects, highlighting key challenges and outlining best practices to mitigate risks. One of the paramount considerations is the environmental impact. Minimizing the effect on marine life, maintaining water quality, and preserving the surrounding ecosystems are crucial. Careful design and implementation of mitigation measures are essential to ensure minimal disruption to the delicate marine environment. The influence of currents, waves, and sedimentation on system performance and stability must be carefully assessed. For instance, the design of intake structures must account for the prevailing currents and wave patterns to ensure adequate water flow and prevent the ingress of debris, whilst being structurally safe.

Operational constraints also play a crucial role in the design process. The intake and outfall systems must be designed to meet the stringent operational demands of the desalination plant while ensuring long-term reliability and efficiency. This includes considerations such as the required flow rates, the quality of the intake water and redundancy are essential to minimize the risk of operational disruptions and ensure the continued supply of desalinated water.

Construction and maintenance in the harsh marine environment present unique challenges. Corrosion, biofouling, and extreme weather conditions can significantly impact the longevity and performance of the systems The selection of appropriate materials for the construction of intake and outfall structures is critical to ensure structural integrity, durability, and cost-effectiveness. Pipe sizing and selection are also crucial considerations, impacting both the hydraulic performance of the system and the overall project cost.

In conclusion, the design and implementation of marine intake and outfall systems for large-scale desalination plants in the Middle East require a multidisciplinary approach that considers a wide range of factors. By carefully addressing the environmental, hydrodynamic, operational, and engineering challenges, it is possible to design and construct robust and sustainable systems that meet the growing demand for water while minimizing the environmental impact. In the absence of design guidelines in this critical structures, this experience will hopefully guide the industry in the implementation of successful design considerations.

Keywords: Mega desalination projects; Intake and outfall marine systems; Seawater intake; Intake pipeline; Outfall pipeline; Intake towers; Outfall diffusers

PT 172

Sustainable membrane distillation desalination for hydrogen production

Alba Ruiz-Aguirre*, Alejandro Bueso, Antonio Atienza-Márquez, Guillermo Zaragoza

CIEMAT-Plataforma Solar de Almería, Carretera de Senés, Tabernas 04200, Spain, alba.ruiz@psa.es

Over the last 15 years, membrane distillation (MD) technology has come a long way in terms of robustness, energy efficiency, production and permeate quality. However, it still needs less thermal energy consumption to be competitive and sustainable. One solution is the use of waste heat, which amounts to 20 % and 50 % of the total energy consumed in industrial processes. This waste heat can be used as a sustainable source of energy to drive different processes, mainly thermal ones such as thermal desalination.

An example of an industrial process that generates waste heat is the electrolysis of water. Some of the electricity is lost as heat during the process, reducing the efficiency by 60–80%. To avoid overheating and the associated decrease in efficiency, cooling systems are usually installed that dissipate that waste heat with its corresponding loss of exergy. Alternatively, its use in a thermal desalination plant would valorise it. On the other hand, electrolysis needs high quality water. This limits the implementation of hydrogen production, since water treatment for purification can be expensive and difficult in areas where clean water is scarce. Thus, the coupling of an electrolysis system to a MD system would remove the needs of an external heat source for the MD and of a cooling system for the electrolyser, as well as the need for a natural source of water, since the MD process can produce pure water from practically any water sources.

In this study, the modelling of the integration of a proton exchange membrane (PEM) electrolyser and a MD system is carried out. The heat needed for the latter is provided by the waste heat of the PEM and, in turn, the water required in the PEM is supplied by the MD. The simulation of the PEM calculates the hydrogen production, the waste heat generated and the water requirements. In turn, for the MD-based desalination system two different modules are chosen and compared: i) high productive capacity but low energy efficiency; and ii) low productive capacity but high energy efficiency. For both cases, the integration of the MD with the PEM is satisfactory, with the waste heat being sufficient to feed several MD modules resulting in a total permeate production greater than that necessary for the PEM to produce hydrogen under the study conditions. Thus, in industries where the cogeneration of purified water and energy is required, such as petrochemicals and pharmaceuticals, these integrated systems can be very useful contributing to achieving carbon neutrality.

Keywords: Sustainable desalination; Membrane distillation; Water-energy nexus; Hydrogen production

PT 173

Hydrophobic PVDF flat sheet membrane modified using hybrid structure nanomaterial of (TiO_2/GO) for air gap membrane distillation

Hamad Alromaih*, Patricia Gorgojo, Krishnaprasad Manoj, Maria Perez-Page

**The University of Manchester, Manchester M13 9PL, UK*
Tel. +44 7765563926, hamad.alromaih@postgrad.manchester.ac.uk

Introduction

The global challenges of increasing demand, pollution, and diminishing resources are stressing freshwater supplies, leading to the necessity of innovative solutions for freshwater production [1]. Water desalination by membrane process is a sustainable alternative to produce fresh water. Among different membrane technologies, membrane distillation (MD) is a promising process because of its high efficiency and environmental friendliness, characterized by lower operating pressures and temperatures than traditional methods such as reverse osmosis. MD has the ability to completely reject solutes, less demanding membrane requirements, and suitability for high salinity water [2,3]. It operates on a thermal separation principle, where vapor from heated salty water passes through a porous membrane to condense as fresh water on the other side. While MD is promising for applications like desalination, it faces challenges in the fouling and wetting of membranes [4]. Developing new membranes to avoid these challenges is crucial because it would enhance the efficiency and reliability of water purification processes, making clean water more accessible and sustainable.

Experimental/methodology

The project aims to improve the MD polymeric membrane by coating a thin layer of different materials such as titanium dioxide (TiO_2), graphene oxide (GO), and hybrid structure nanomaterial (HSN) containing TiO_2/GO on a porous polymeric support, polyvinylidene fluoride (PVDF). Vacuum filtration has been used to prepare the thin-film membrane. Different concentrations from 1 to 5 mg and various layers of 1H,1H,2H,2H-perfluorododecyl trichlorosilane (FTCS) as crosslinking have been used to prepare thin-film membranes (TFM) and evaluate the effect on the membrane performance and properties. To effectively address the challenges of fouling and wetting, the prepared membrane utilizes the synergistic effects of the coatings to create a surface that is not only hydrophobic but also resistant to the adherence of contaminants, thus maintaining high performance in MD applications.

Results and discussion

Performance evaluation in a custom-designed air-gap membrane distillation (AGMD) setup revealed that membranes modified with TiO_2/GO nanocomposites exhibited superior flux stability, enhanced antifouling properties, and high salt rejection rates compared to pristine PVDF membranes, due to the synergistic effects of TiO_2 and GO which enhance membrane hydrophobicity and resistance to wetting. Our findings suggest that the incorporation of TiO_2/GO into PVDF membranes is a promising approach to overcoming current limitations in desalination technologies, potentially addressing the global water crisis. The flux and rejection performance of PVDF membranes, with TiO_2 and GO modifications exhibiting improved flux due to antifouling properties, while (HSN) modification greatly enhances rejection to nearly 100%. HSN also shows significant flux imp

Keywords: Membrane distillation; Desalination; Nanoparticles; Graphene oxide

PT 174

Modular GRP intake towers for desalination plants

Gregory Gleetus

Global Composites LLC, Ras Al Khaimah 29722, UAE
Tel. +971 504570283, gregg@global-composite.com

Global Composites LLC (GC) has established itself as a pioneer in providing innovative GRP intake tower solutions for desalination plants across the Middle East (MENA) region since 2015. Collaborating closely with experienced marine and structural consultants, GC develops project-specific solutions that address critical design and operational considerations, ultimately saving time and cost on the overall marine component of the project.

GRP is widely recognized as the preferred material for seawater pipelines due to its resistance to seawater and its lightweight nature. This proven track record of successful installations worldwide has encouraged us to extend its application to Seawater Intake Towers, particularly in the challenging marine environments of the Middle East.

Recognizing the crucial importance of intake towers in operational efficiency and the potential for maintenance deficiencies in other materials, , this article focuses on the use of GRP intake towers as an alternative to traditional materials like concrete and steel in various MENA region projects.

GRP offers several key advantages:

- Excellent corrosion resistance: It exhibits exceptional resistance to seawater, making it an ideal material for marine applications.
- High durability: GRP structures withstand wear and tear, pressure, and damage, ensuring long-term performance.
- Lightweight and modular: This facilitates easy transport and on-site assembly with minimal lifting requirements.
- Cost-effectiveness: GRP offers a competitive alternative to stainless steel, with minimal ongoing maintenance costs.
- Versatility: It allows for precise and customized shapes to fit diverse site conditions.

This innovative design of the GRP intake tower presents a unique and modular product, designed for easy on-site assembly and installation with minimal resources.

Our current experience in using modular GRP intake towers for offshore marine applications has revealed a positive impact on the program of works on site, from fabrication and delivery to assembly and installation. In some projects, the fully assembled GRP structure weighed less than 10 tonnes, a significant reduction compared to reinforced concrete structures with similar dimensions and flow capacities.

We are confident that this solution has the potential for further development and application in different geographies.

Keywords: Intake structures; GRP; Modular solutions; Desalination plant

PT 175

Advancing circular desalination: photothermal membranes to overcome membrane distillation limits for brine valorization

Sergio Santoro*, Roviel Berhane Zegeye, Tsotne Dadiani, Efrem Curcio, Marco Aquino, Antonio Politano

**University of Calabria, Via P. Bucci Cubo 44A, Rende 87036, Italy*
Tel. +39 3894727435, sergio.santoro@unical.it

The initial approach involved the incorporation of silver nanoparticles (AgNPs) into mixed matrix membranes. The use of these AgNPs in a polyvinylidene fluoride (PVDF) membranes demonstrated significant improvements in transmembrane flux, achieving values of 32.2 L/m²·h for pure water and 25.7 L/m²·h for a 0.5 M NaCl solution—approximately 11- and 9-fold higher, respectively, compared to unloaded PVDF membranes [1]. Despite these promising results, the high cost of AgNPs posed a barrier to large-scale implementation. To address this, AgNPs were localized in a coating rather than being dispersed throughout the membrane matrix. This modification reduced the overall cost while maintaining enhanced photothermal properties [1]. However, these membranes still relied on UV light to activate the photothermal effect, which limited their practicality for sustainable,large-scale applications.

To further reduce costs and improve scalability, the focus shifted to materials that respond to sunlight, offering a more accessible and sustainable energy source. Graphene-based materials were investigated for their superior light-to-heat conversion properties ensuring the extraction of minerals (es. NaCl, KCl) from hypersaline solution [2,3]. Initially, plasma-based methods were explored to develop vertically aligned graphene membrane, but these methods proved difficult to scale [2]. As a result, the embodiment into the polymer became the preferred approach, allowing for a more scalable incorporation of graphene oxide (GO) into the PVDF matrix [3]. These graphene-based mixed matrix membranes demonstrated improved photothermal performance, significantly enhancing the water evaporation rate and allowing for more efficient mineral extraction from brine under solar irradiation.

Despite the progress with graphene, the scalability of this approach remained a challenge. To overcome this, other photothermal materials were explored, including tungsten disulfide (WS_2) and, more recently, nickel selenide (NiSe) and cobalt selenide (CoSe) [4]. These materials offered exceptional photothermal properties, with NiSe and CoSe embedded in thin coating, in particular, showing impressive increases in evaporation rates—up to 690% greater than that of AgNP-based membranes [4]. Additionally, these materials are less expensive than Ag, making them more suitable for large-scale applications. The ultimate result was that NiSe and CoSe facilitated the recovery of the water from SWRO brine above the supersaturation ensuing NaCl crystallization. These innovations not only address the critical challenge of temperature polarization in MD-MCr but also provide a sustainable, cost-effective solution for desalination intensification and mineral recovery.

Keywords: Brine valorization; Membrane distillation-crystallization; Photothermal membranes; Temperature polarization; Solar radiation

PT 176

Reference class forecasting as a tool for planning RO desalination mega-projects

Mohammed Haroon Siyech

Acwa Power, G14, Al Majdiah 113, Boreidah Street, Riyadh 13244, Saudi Arabia, hsiyech@acwapower.com

Mega-projects, including RO desalination plants, are prone to cost overruns and schedule delays due to inherent uncertainties and biases in traditional forecasting methods. This study investigates the applicability of Reference Class Forecasting (RCF), as developed by Bent Flyvbjerg, to address these challenges in desalination projects. Through an exploratory review, we assess whether RCF has been previously utilized in the desalination sector and propose a structured framework for its implementation. By leveraging historical data from desalination plants and analogous infrastructure projects, the study outlines a step-by-step approach to define reference classes, establish probabilistic outcomes, and calibrate project forecasts. Key adaptations are proposed to address the unique characteristics of desalination projects, including energy cost variability and environmental compliance. Findings reveal gaps in RCF application to desalination and highlight opportunities to improve forecasting accuracy. This paper provides a roadmap for integrating RCF into the planning of large-scale water projects, emphasizing its potential to enhance decision-making and mitigate risks.

Keywords: Reference class forecasting; Data driven planning; Project planning

PT 177

Integration of $Mg(OH)_2$ production in a real industrial scale reverse osmosis desalination plant

Lorenzo Ventimiglia*, Fabrizio Vassallo, Giuseppe Lo Burgio, Antonino Campione, Fabrizio Vicari, Alessandro Tamburini, Giuseppe Battaglia, Andrea Cipollina, Giorgio Micale

**Università degli Studi di Palermo, Palermo 90146, Italy*
lorenzo.ventimiglia@unipa.it

Since 2011, the European Union has drawn up a list of critical raw materials, whose reliable and unhindered access is a growing concern [1]. In this context, it is essential to find new and sustainable supply sources to satisfy the EU demand. In current desalination technologies, the recovery of raw materials from the salty solution rejected by the plants (brine) is gaining a lot of interest. Specifically, the recovery of magnesium, the most valuable element present in the brine, has a particular potential [2]. In this work, the recovery of high-purity magnesium hydroxide, $Mg(OH)_2$, powders from desalination units rejected brines has been investigated at the pilot scale. The rejected brines were the waste stream of the industrial seawater reverse osmosis (SWRO) desalination plant located on the island of Lampedusa (Italy). $Mg(OH)_2$ solids were synthesized within a fully integrated circular treatment chain aimed at producing, aside from marketable $Mg(OH)_2$ powders, all the required chemicals for process operation and the SWRO permeate stream remineralization. The SWRO brine, rich in magnesium ions at concentrations of about 2 g/L, was treated in a pilot-scale reactive crystallizer (called "multi-feed plug flow reactor", MF-PFR). The pilot plant was tested for one year in the industrial environment, thus demonstrating the achievement of a TRL between 6 and 7 for the MF-PFR technology. In the reactor, Mg ions reacted with hydroxyl ones (provided by an alkaline species, namely a sodium hydroxide, NaOH, solution) forming magnesium hydroxide solids. Several operating conditions and brine pre-treatments were analyzed and their influence on the features of produced $Mg(OH)_2$ powders was assessed. Among these, the effect of (i) the feed flow rate, (ii) the use of an excess of the alkaline reactant, (iii) the fluid dynamic regime in the reactor, and (iv) the pre- treatment efficiency were found to be the most relevant ones. Sedimentation and filtration rates of magnesium hydroxide suspensions, along with the purity of $Mg(OH)_2$ solids, were the performance parameters. Magnesium hydroxide suspensions exhibited excellent performance. In particular, the highest sedimentation velocity was >200 mm/h, the highest filtration rate was > 7 kg/($m^2 \cdot h$) and the highest purity of $Mg(OH)_2$ solids was >98%. Note that, values of 100, 6.5, and 96% are reported in the literature [3].

The future perspective is to test the whole treatment chain and improve some characteristics of synthesized magnesium hydroxide solids such as their morphology and granulometry.

Keywords: Mineral recovery; Magnesium hydroxide; Pilot scale; Critical raw material, Seawater mining

References

[1] European Commission. Study on the EU's list of Critical Raw Materials (2020).
[2] A. Kumar, N. Gayathri, H. Fukuda, F. Du, V. Saravanamuth, E. Drioli, and J. H. Lienhard V. Metals Recovery from Seawater Desalination Brines: Technologies, Opportunities, and Challenges, ACS Sustainable Chem. Eng.2021.
[3] M. Turek, W. Gnot, Precipitation of magnesium hydroxide from brine, Ind.Eng.Chem.Res.34(1995)

PT 178

Assessment of the performance of a pilot scale reverse electrodialysis stack equipped with segmented electrodes

Francesco Volpe*, Emanuela Mangiaracina, Giuseppe Battaglia, Andrea Cipollina, Giorgio Domenico Maria Micale, Alessandro Tamburini

**University of Palermo, Via Rocco Jemma, 64, Palermo 90127, Italy*
Tel. +39 3319540725, francesco.volpe03@unipa.it

Reverse electrodialysis (RED) is a promising technology to produce green energy from the controlled mixing of two solutions with a different salinity level. Cation and anion exchange membranes (CEMs and AEMs) allow ions dissolved in the solutions to selectively migrate across the membrane according to their charge. The research for intensification of RED process aims to achieve high power densities and energy conversion [1] and, in this regard, electrode segmentation, i.e. each electrode is composed by multiple segments, is one of the strategies that can be adopted. This feature allows to connect more electric circuits to the RED plant and, therefore, to optimize power output by adjusting external loads and tuning current density to specific sections of the stack. In this work, the performance of a RED pilot scale stack (active membrane area 10 cm × 80 cm) equipped with segmented electrodes has been investigated through an extensive experimental campaign. Moreover, in contrast to previous works on electrode segmentation [1], high solutions more concentrated than seawater were employed.

The stack studied was equipped with (i) segmented electrodes constituted by 4 parts, each one covering 20 cm of the total channel length, (ii) Fujifilm® type 10 membranes and (iii) Deukum® 270 μm woven spacers. Solutions flowed in co-current configuration. In the present study, 4 electrode configurations were analyzed: Configuration C1, where only the first electrodes pair was connected to an external circuit and configuration C2, C3, C4 where all 80 cm were exploited by connecting respectively one, two and four circuits. The influence of flow velocity, from 0.5 to 2 cm/s, was investigated and the effect of unbalanced flowrates was studied. The concentration of dilute streams was kept equal to 0.17 M, while the high stream concentration varied from 1 to 5 M NaCl.

As expected, maximum corrected power density values were reached in configuration C1, by exploiting the maximum salinity gradient of the solutions but, considerably higher power outputs and efficiencies were achieved in configurations using the total membrane area, proving the benefits of scale-up for RED process. The use of electrode segmentation, i.e. multiple circuits connected in configuration C3 and C4, increased, on average, the power output of 15% in comparison to equivalent tests performed in configuration C2, where a single circuit was connected, showing an improvement respect to previous similar works on electrode segmentation [1].

Keywords: Salinity gradient energy; Reverse electrodialysis; Electrode segmentation

Acknowledgments

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 869467 (SEArcularMINE). This output reflects only the author's view. The European Health and Digital Executive Agency (HaDEA) and the European Commission cannot be held responsible for any use that may be made of the information contained therein.

References

[1] Veerman, J. Environ. Sci. Technol. 2010, 44, 9207–9212.

PT 179

A novel numerical modelling tool for the study of colloidal fouling in electrodialysis units

Francesco Volpe*, Giuseppe Battaglia, Andrea Cipollina, Giorgio Domenico Maria Micale, Alessandro Tamburini

**University of Palermo, Via Rocco Jemma, 64, Palermo 90127, Italy*
Tel. +39 3319540725, francesco.volpe03@unipa.it

In membrane-based technologies, fouling is described as the attachment of undesired substances on membranes or spacers. The physics of fouling is distinguished by complexity and several mechanisms, one of which is colloidal fouling. Colloidal fouling, referred as the deposition of suspended charged particles, colloids, on membranes' surface, is one of the main phenomena affecting the performance of electro-membrane processes. However, despite its importance, only few works have numerically investigated colloidal fouling phenomena.

De Jaegher et al. [1] presented an interesting hybrid model for the description of fouling phenomena in which a mechanistic model was combined with neural-network based approach to complement the limits of mechanistic parts. However, the authors did not study the fluid flow in the channels.

The present work introduces a novel two-way Computational Fluid Dynamics (CFD) and fouling modelling tool aiming at investigating colloidal fouling phenomena in Electrodialysis (ED) systems. Steady state CFD simulations were coupled with a Matlab® code to numerically solve colloids deposition rates. Colloidal fouling deposition was therefore predicted through an in-house script developed performing a transient simulation.

The numerical domain consisted of a periodic unit of a fluid channel encompassed between two membrane surfaces. Fluid dynamics and mass transfer in the channel were computed by adopting the "unit cell approach" [2]. Computed wall shear stresses and concentration fields were the input data for the fouling model. Wall shear stresses defined whether the attachment of colloids on solid surfaces could happen, while through the concentration field colloids deposition rates were quantitatively calculated.

The distribution of colloidal fouling was then adopted in the CFD model as a pseudo-solid phase to compute the impact of growing fouling layer in the channel.

In order to test the developed modelling tool, ED tests conducted by Guo et al.[3] were simulated.

Specifically, the influence of different current densities, from 20 to 30 A/m2, and the concentration of a foulant species, namely the anion polyacrylamide (APAM), up to 300 mg/L, were investigated.

Numerical simulation fairly well predicted the increase of ohmic resistance of the ED unit at low current density values, while a very good agreement was observed at high current densities.

Finally, the model's prediction of resistance and pressure drop increase due to fouling provides insights into the impact of fouling on operating costs. Therefore, the coupled model serves as a valuable tool for analyzing fouling effects and providing useful hints for process optimization.

Keywords: Computational fluid dynamics; Colloidal fouling; Ion-exchange membranes

References

[1] B. De Jaegher, W. De Schepper, A. Verliefde, I. Nopens, Sep. Purif. Technol. 2021, 259, 118028.
[2] L. Gurreri, A. Tamburini, A. Cipollina, G. Micale, M. Ciofalo, J. Membr. Sci. 2014, 468, 133–148.
[3] H. Guo, L. Xiao, S. Yu, H. Yang, J. Hu, G. Liu, Y. Tang, DES. 2014, 346, 46–53

PT 180

Optimised preliminary design of seawater desalination with zero liquid discharge driven by solar micro-gas turbines

Rafael González-Almenara*, Agustín Delgado-Torres, Jesús Montes-Sánchez, Néstor Santana-Hernández, David Sánchez, Lourdes García-Rodríguez

University of Seville, ETSI, Camino de Los Descubrimientos, s/n, Sevilla 41092, Spain
Tel. +34 649640536, rgalmenara@us.es

This work focuses on the topic "Sustainability and energy", considering "Desalination using renewable energy". Specifically, this paper tackles the optimisation of the design of a seawater desalination system with Zero Liquid Discharge (ZLD) driven by solar micro gas turbines. This work relies on experimental assessments of main components since no integrated pilot system has been developed so far. In previous works by the authors, the synergies between the ZLD process and solar micro gas turbines have been described. This new evaluation builds upon lessons learned from the previous experimental work, during which some flaws were identified. Besides, the electricity production of the solar micro-gas turbine drives an optimised seawater desalination system based on a high-recovery design that provides the brine input of the ZLD subsystem. Furthermore, in order to characterise the performance of the full system, dedicated modelling has been developed. This study on design optimisation considers three different power ranges namely, <30 kW, 30–200 kW and >200 kW. A single solar parabolic-dish collector with the micro gas turbine installed at its focal point covers the lowest power range. This technology was experimentally assessed throughout an European project (OMSoP, FP7-ENERGY-2012-308952). Besides, the parallel coupling of several units competes with other concepts of solar micro-gas turbines at higher power outputs, including additional heat recovery by Organic Rankine Cycles prior the ZLD unit.

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

PT 181

Retrofitting assessment of reverse osmosis desalination plants based on energy diagnosis

*Juan I. Pinaglia-Villalón**, María Gutiérrez-Valcarce, Rolando Bosleman, Lourdes García-Rodríguez

**University of Seville, ETSI, Camino de Los Descubrimientos, s/n, Sevilla 41092, Spain*
Tel. +34 601436207, juapinbel@alum.us.es

This work focuses on the topic "Sustainability and energy", specifically on "energy efficiency", dealing with energy diagnosis of desalination plants as an useful tool for retrofitting assessments. To this end, this paper develops an innovative methodology of energy diagnosis of reverse osmosis desalination plants in order to identify potential improvements attributable to quite different causes of inefficiency. The energy diagnosis of a desalination plant normally considers only the thermodynamic limit. On the contrary, the proposed methodology identifies five contributions that amounts the total specific energy consumption (SEC) of the plant, namely: 1) The thermodynamic limit, depending on ambient conditions of salinity and temperature along with the recovery rate of the plant. 2) The additional SEC resulting of implementing the best configuration identified for a given reverse osmosis plant at its working conditions under the hypothesis of ideal plant components. This contribution indicates potential improvements on plant efficiency due to further research on plant configurations. 3) The contribution to the SEC directly attributable to the inefficiency of the existing plant configuration. The plant retrofitting overcomes this contribution. 4) The additional SEC due to the use of obsolete plant components that relies on the sum of individual contribution of main components of the plant namely, membrane elements, high pressure pump, energy recovery devices along with booster pump and low-pressure pump if any. This part of the SEC corresponds to the energy saving achievable by means of the upgrade of main components. 5) The contribution to the SEC of non-ideal plant components, according to the state-of-the-art. This contribution identifies potential improvements of the energy efficiency of the plant associated to the future development of advanced components. Results of the proposed methodology of energy diagnosis of different plant designs are presented covering a wide range of feed salinity, recovery rate and product quality.

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

PT 183

Symbiosis of water electrolysis and membrane distillation

Markus Wenzel

EvCon GmbH, Gewerbestraße 7, Pliening-Landsham 85652, Germany
Tel. +49 1702136290, mwe@evcon-water.com

The objective of this presentation is to display the beneficial applicability of vacuum-membrane-distillation (VMD) for the water purification of water electrolysers. The production of green hydrogen from water electrolysis requires mainly electric energy from renewable sources, purified water and re-cooling. Electricity drives the electrolysis and the installation of systems for renewable electric power comes along with large investments. This underlines the need of high electric efficiency at electrolyser and periphery like water purification and cooling. The availability of excessive waste heat opens the door for thermal water treatment processes. VMD is a thermal separation process with very low electric energy demand. The temperature level of the required heat fits well to the temperature level of the electrolyser cooling what allows the synergetic connection of electrolysis and membrane distillation.

The heat flow that must be cooled from the electrolysis exceeds the thermal demand of a one stage distillation process, even when using a highly efficient electrolyser. This means that thermal efficiency has a minor role for the symbiotic connection.

VMD can separate highly purified water from aqueous feed solutions at all salinities up to saturation in just one process step.

The used hydrophobic and vapor permeable membrane works like an ideal droplet catcher. Saline water droplets from a potential membrane leakage can further be separated from the vapor flow before mixing with the purified water. Both features lead to a very high degree of separation sharpness. The key point for the competitive connection of VMD and electrolysis is the existence of cost-efficient re-cooling for the distillation process.

The optimum integration of VMD-technology in single- or multi-effect-design (VMEMD) is an ongoing working topic at EvCon. The company has an automatized production line for its membrane modules and its engineering team is ready to develop specific projects from pilot to hundred-megawatt scale.

Keywords: Green hydrogen; Water purification; Re-cooling of electrolysis

PT 184

Desalination technology conversion: GCC case study. Part 1: Overview and key drivers

Sergio Casimiro*, Hugo Costa, Hassan Almsaeed, Justin Robert

**ACWa Power, 41st Floor, The One Tower, Sheikh Zayed Road, Dubai 30582, UAE, Tel. +971 559441578, scasimiro@acwapower.com*

The desalination industry is undergoing a rapid and unprecedented technological transformation, characterized by the replacement of operational plants well before the end of their contractual lifetimes. This shift is driven by the emergence of newer, more efficient, and environmentally sustainable technologies. In this series of papers, we present a detailed case study from the ACWA Power fleet in the GCC, where a mega-scale desalination plant, originally designed within a cogeneration scheme, was decommissioned ahead of schedule and converted to make way for a state-of-the-art facility. This transition underscores a pivotal moment in the industry, demonstrating the alignment of environmental sustainability and economic feasibility.

This paper consists of part one of this series, were we explore the primary factors that contributed to the success of this project, including key drivers from both the offtaker's and developer's perspectives, the resolution of contractual challenges, and the realization of significant financial benefits. The discussion delves into the technical advancements that facilitated the replacement, focusing on innovative solutions that reduced power consumption and enabled the direct integration of renewable energy sources. These advancements exemplify the critical role of cutting-edge technology in transforming desalination into a more efficient and sustainable industry.

In part two of this series of papers, we shift the focus to the marine environmental impacts of the project, providing an in-depth analysis of the measures taken to minimize ecological disruption. This includes the recirculation study and the design and optimization of intake and outfall systems, which significantly reduced thermal pollution, brine discharge, and chemical byproducts. These steps were pivotal in mitigating adverse effects on marine biodiversity and fostering the restoration of sensitive ecosystems. By addressing these challenges through advanced engineering and environmental planning, the project sets a benchmark for minimizing the ecological footprint of desalination facilities.

By analyzing the case study's outcomes across these two interconnected dimensions, this series of papers aims to provide valuable insights into the strategic planning, decision-making, and implementation processes required to modernize desalination infrastructure while managing risks and maximizing benefits. The lessons learned serve as a blueprint for stakeholders navigating the complexities of early decommissioning, greenfield development, and sustainable operations. Ultimately, this work contributes to the ongoing discourse on sustainable water solutions by emphasizing the dual importance of technical innovation and environmental stewardship in addressing the growing global demand for potable water.

Keywords: Re-conversion; Desalination; Mega projects; Environmental impacts; Optimization; Paradigm shift; GCC

PT 185

Desalination technology conversion: GCC case study. Part 2: Offshore design and environmental impact reduction

Hugo Costa, Sergio Casimiro*, Hassan Almsaeed, Justin Robert

**ACWa Power, 41st Floor, The One Tower, Sheikh Zayed Road, Dubai 30582, UAE, Tel. +971 559441578, scasimiro@acwapower.com*

This is part two of a series of papers exploring the transformation of desalination practices towards greater efficiency and environmental sustainability. In this paper, we focus on offshore design and environmental impact reduction through a case study of a major desalination project in the GCC, where a conversion of technologies was undertaken. This conversion involved replacing traditional shallow-water discharge methods with an innovative deep-water brine diffuser system, positioned 40 m below sea level. By utilizing advanced multi-port diffusers, the system achieved high initial mixing, significantly enhancing the dilution and dispersion of brine in the receiving waters while reducing the ecological impact on marine environments.

The technological conversion in this project brought substantial environmental benefits. The deep-water discharge approach minimized thermal pollution, brine concentration, and chemical byproducts nearshore, thus preserving ecologically sensitive habitats and reducing stress on marine biodiversity. The conversion also addressed challenges associated with recirculation and brine plume management, ensuring effective dispersion and safeguarding marine ecosystems. This paper provides a comprehensive analysis of the engineering design, hydrodynamic modeling, and environmental studies that informed the implementation of the offshore intake and outfall systems, emphasizing their role in achieving sustainability.

Beyond environmental benefits, this case study highlights how the conversion of technologies aligns with the industry's shift towards greener and more sustainable practices. By adopting cutting-edge solutions, the project serves as a benchmark for addressing the dual priorities of operational efficiency and ecological responsibility. This paper aims to provide actionable insights for stakeholders, showcasing how technology conversions in desalination can balance industrial requirements with the imperative to reduce environmental impacts. Ultimately, it contributes to the ongoing discourse on sustainable water solutions, offering a pathway for future projects to integrate innovation and environmental stewardship effectively.

Keywords: Conversion; Desalination; Mega projects; Offshore design; Environmental impacts; Paradigm shift; GCC

PT 187

Towards sustainable desalination: weighing environmental and economic outcomes of a hybrid CSP/PV membrane distillation system

Varinia Felix*, Jeb Shingler, Reema Shinh, Kerri Hickenbottom

**The University of Arizona, 11596 W Granville Dr, Marana, AZ 85653, USA*
Tel. +1 9157047674, variniafelix@arizona.edu

A techno-economic and life cycle assessment (LCA-TEA) was conducted for a hybrid optical system combining concentrated solar power (CSP) and photovoltaic (PV) collectors with air gap membrane distillation (AGMD) to evaluate its feasibility for standalone desalination and brine management. A pilot-scale CSP/PV-AGMD system located in Tucson, AZ was used to inform the CSP/PV-AGMD inventory. Simulations were conducted across different feed salinities ranging from 2.5 to 140 g/L and operating conditions such as system capacity and circulating flow rate to represent various industries and identify operating conditions resulting in the lowest cost and environmental impact. Additionally, sensitivities were performed to compare the stand-alone CSP/PV system to various solar configurations and conventional energy sources for MD (electric grid and/or steam). The environmental impact was measured with the ReCiPe 2016 Endpoint (H) version 1.08 as a single score (pts/m^3). Cost estimations are presented as Levelized Cost of Water (LCOW - USD/m^3). The construction phase of the CSP/PV system is the main stressor for the LCA and TEA. The environmental impact for a full-scale CSP/PV-AGMD system ranges from 0.07 to 0.57 pts/m^3, while the LCOW ranges from 2.33 to 11.38 USD/m^3 for best scenarios of feed salinities of 2.5 and 140 g/L. While the hybrid system has an environmental impact up to 13 times lower than a conventional electric gris and steam-based AGMD system, its LCOW is 1.4 to 3.5 times higher. The divergence in environmental and cost impact for the hybrid system underscores the need to align desalination system selection with specific goals, such as sustainability, cost, and availability of energy infrastructure.

Keywords: Membrane distillation; Off-grid desalination; Brine management; Water Reuse; Life cycle assessment; Techno-economic assessment; Hybrid solar desalination; Waste to resource

PT 188

Impact of fouling on the performance of solar-driven multi-effect desalination systems

Jawaher Hajaji*, Patricia Palenzuela, Mohamed Abdelkarim Antar

**King Fahd University of Petroleum and Materials, Dhahran 34463, Saudi Arabia
Tel. +966 538830778, g202320170@kfupm.edu.sa*

The global problem of water scarcity remains a pressing challenge, which drives the adoption of desalination as a crucial solution to meet the growing demand for water. Multi-effect distillation (MED) is an important desalination technology due to its efficiency, adaptability, and compatibility with sustainable energy sources such as solar energy. MED systems are able to treat high-salinity water and improve brine concentration, which provides significant environmental benefits by reducing saline discharges. Furthermore, when combined with solar energy, MED systems become a viable and environmentally friendly alternative to fossil-based processes, helping to reduce greenhouse gas emissions and operating expenses.

Thermal desalination techniques, such as MED, are crucial not only for freshwater production but also for brine concentration in zero liquid discharge processes. However, fouling on heat transfer surfaces remains a significant operational obstacle. Accumulated fouling increases thermal resistance, reduces heat transfer efficiency, and adversely affects distillate productivity. This deterioration leads to increased energy consumption and maintenance expenses, which reduces the overall performance and economic viability of MED systems. Therefore, understanding and mitigating the consequences of fouling is crucial to improve the system reliability and durability.

A dynamic model was developed using the Engineering Equation Solver (EES) in this study to evaluate the effect of fouling accumulation on the performance of a solar-powered MED system. Operational data from an existing MED plant in Almeria, Spain, confirmed the validity of the model. Results highlight important links between fouling accumulation and system performance decline, highlighting the critical importance of implementing effective fouling management strategies. We predicted the consequences of fouling growth over time through two time dependent models for fouling accumulation and its impact on key performance parameters such as heat transfer coefficients, distillate production, and energy efficiency.

The findings of this study highlight the importance of reducing fouling to maintain MED system performance over a long operating period. Results also highlight the importance of continuing studies on innovative antifouling technologies and materials to improve the sustainability and economic efficiency of MED systems.

Keywords: Multi-effect desalination (MED); Fouling; Solar energy; Thermal desalination; Brine concentration; Freshwater production

PT 189

The 100% RES Islands Initiative - the Energy Water nexus

Gianni Chianetta

Greening the Islands Foundation, Via Sciuti 112, Palermo 90100, Italy
Tel. +39 3483614500, gianni.chianetta@greeningtheislands.org

The 100% RES Islands Initiative, launched by GTI Foundation at New York Climate Week 2023, in partnership with UN DESA and Global Renewables Alliance, aims at developing case studies to demonstrate the technical and economic feasibility of achieving 100% RES in a relative short timeframe. It builds on a vision of small islands as ideal testbeds of fully renewable energy systems. For small islands worldwide, which suffer existential threats from the rapidly accelerating impacts of climate change, developing ambitious renewable energy strategies stands as a vital priority. As reinforced by the major outcome of the SIDS4 Conference, the Antigua and Barbuda Agenda for SIDS (ABAS), switching to renewable energy has a key role to play for small islands' energy security as well as economy-wide decarbonisation and revitalisation through job creation, empowerment of local value chains and communities, and circularity. Switching to a 100% RES scenario has direct impact on the reduction of emissions and costs of the water desalination which play a key role in the energy consumption and demand fluctuation in an island energy system. The speech will include the presentation of the case study of Curacao, a Caribbean island of the Kingdom of Netherland, and Lipari, a minor island of Sicily which is hosting a RES+Desalination project.

Keywords: 100% RES; Islands; Energy-Water nexus; Full decarbonisation

PT 190

Lithium recovery from LIB wastewater using monovalent selective capacitive deionization and bipolar membrane electrodialysis

Minji Je*, Seoyeon Lee, Yongjun Choi, Jae-Wuk Koo, **Sangho Lee***

**Kookmin Unive rsity, Seoul 02707, Korea*
Tel. +82 10-3182-2019, jeminji123@kookmin.ac.kr, sanghlee@kookmin.ac.kr

The rapid growth of lithium-ion batteries (LIBs) in electric vehicles and electronic devices has resulted in a surge of battery waste rich in valuable metals. Among these, lithium (Li+) stands out for its high recycling value, making efficient recovery essential for both resource sustainability and economic feasibility. However, conventional recovery methods often generate acidic wastewater, resulting in higher costs and environmental risks.

To address these challenges, a novel wastewater treatment approach that combines monovalent selective capacitive deionization (MSCDI) with bipolar membrane electrodialysis (BPED) was investigated as an innovative technique for lithium recovery and sulfuric acid regeneration. A laboratory-scale MSCDI-BPED system was used to evaluate the selec-

tive recovery of lithium ions under various operating conditions. Synthetic LIB wastewater was pretreated using the lab-scale MSCDI system. During this process, the MSCDI system operated in semi-batch mode, where feedwater lines were alternated during adsorption and desorption phases to enhance lithium selectivity and recovery efficiency. The subsequent BPED process converted lithium sulfate (Li_2SO_4) into high-purity lithium hydroxide (LiOH) while simultaneously regenerating sulfuric acid (H_2SO_4).

Results demonstrated that MSCDI process achieved high lithium selectivity, with a recovery rate exceeding 90%, by effectively separating monovalent ions from competing multivalent ions such as cobalt, manganese, and nickel. The BPED process further enhanced the system by producing high-purity lithium hydroxide (LiOH) with a purity exceeding 97% while simultaneously regenerating sulfuric acid (H_2SO_4), aligning with the goals of economic and environmental sustainability. To optimize the integrated system, Response Surface Methodology (RSM) was applied to develop regression models for both the MSCDI and BPED systems. Multivariate optimization was conducted to identify conditions that satisfy multiple objectives, including lithium recovery, LiOH purity, and sulfuric acid regeneration efficiency.

This study highlights the potential of the MSCDI-BPED integrated system for sustainable and efficient lithium recovery from LIB wastewater, offering a novel approach for resource valorization in lithium battery recycling.

Keywords: Secondary battery wastewater; Lithium recovery; Capacitive deionization; Electrodialysis; Sustainability

PT 191

Optimization of a hybrid PV/T-driven desalination system for sustainable freshwater production

Ahmed Abdelhalim*, Shehab Mansour, Omar Khalil

**KFUPM, Academic Road - Building 818 - Room 230,
Dhahran 31261, Saudi Arabia
Tel. +966 500241464, g202114750@kfupm.edu.sa*

This research evaluates the potential of a hybrid desalination system that combines membrane distillation (MD) and reverse osmosis (RO) to achieve higher energy efficiency and freshwater production. The system is optimized using a photovoltaic-thermal (PV/T) collector, which simultaneously generates electricity and heat from PV/T panels to meet the energy needs of both RO and MD. Advanced optimization techniques such as particle swarm optimization (PSO), genetic algorithms (GA), and differential evolution (DE) are employed to analyze system performance under varying conditions, such as water salinity, solar irradiation, and operational parameters. This ensures the system operates with superior efficiency, minimal waste, and optimal consistency.

The study highlights the integration of PV/T technology with RO and direct contact membrane distillation (DCMD), achieving freshwater production at less than $\$1/m^3$. Operating without energy storage, the system harnesses solar energy during daylight, providing a cost-effective and eco-friendly solution for water production in arid regions.

By addressing water scarcity while promoting sustainable energy use, this hybrid system reduces environmental impacts and offers a reliable, renewable method for desalination. Overall, this research contributes to sustainable water resource management and offers a viable solution to climate change-induced water scarcity.

Keywords: Hybrid desalination system; Membrane distillation (MD); Reverse osmosis (RO); Photovoltaic-thermal (PV/T); Freshwater production; Optimization techniques

PT 192

Front-end and back-end nanofiltration for brine mining

Salman Arab*, Nikolay Voutchkov, Noura Chehab

**NEOM Community 1, NEOM 49643, Saudi Arabia*
salman.arab@neom.com

Brine generated from desalination plants and industrial production processes is highly saline and its discharge into aquatic or terrestrial habitats can have negative environmental impacts. To overcome this challenge, the water industry has developed technologies to recover additional water from the brine and harvest minerals in solid crystal form. Despite their positive environmental impact, current brine mining technologies are rarely adopted in practice. In addition, current brine mining technologies generate mixed salt products that have limited or no commercial value.

Recently, an international research team of the Water Innovation Center (WIC) of NEOM, Saudi Arabia, has developed an innovative brine valorization system for production of potable water from seawater with imbedded synergistic multistage brine mining technologies. Its purpose is to recover commercially viable minerals (i.e., sodium chloride, potassium chloride, rubidium chloride, calcium carbonate, magnesium hydroxide) and elemental metals (i.e., lithium and magnesium) from desalination brine or other high salinity sources such as high salinity groundwater, mineral water from springs, produced water from wells, and other natural or human-made streams with a total dissolved solids (TDS) concentration of 2000 mg/L, or more.

Both front-end and back-end NF systems are tested at the WIC Brine Mining Demonstration Facility in Duba, Saudi Arabia. Initial results show that backend NF systems are more cost-effective when the latest generation NF membrane elements on the market are applied.

This paper analyzes the differences between applying back-end NF and front-end NF for various scenarios in desalination plants and focusing on comparing the capital expenditure (CAPEX), operational expenditure (OPEX), product water quality, brine concentration, water volumes, and brine volumes.

Keywords: Seawater; Brine recovery; Brine mining; Nanofiltration; Desalination

PT 193

Carbon footprint of desalination and mitigation strategies

Salman Arab*, Nikolay Voutchkov, Noura Chehab

**NEOM Community 1, NEOM 49643, Saudi Arabia*
salman.arab@neom.com

Seawater desalination plants have been contributing to meeting the growing demand for freshwater. The growth in water demand is not only associated with the growth of population, the development of many industries that are heavily reliant on water plays a huge role in the increase of water demand. Although desalination plants heavily contribute to freshwater production, they have been negatively contributing to the increase of greenhouse gases (GHG) emissions in the atmosphere, and this leads to significant impacts on climate change. The increase in GHG emissions including Carbon Dioxide (CO_2) and the issues associated with water scarcity are considered to be critical and related. Unfortunately, meeting the growing demand for water through desalination plants contributes to the growth of carbon emissions through the intensification of energy use in desalination processes. Desalination systems can contribute to the increase of GHG emissions, primarily through the energy sources used to power the system. This includes CO_2, which is generated from the combustion of fossil fuels to produce electricity for desalination. Globally, carbon emissions have been increasing throughout the years. The International Energy Agency (IEA) has reported that the global carbon emissions related to energy combustion and industrial processes have increased by 1740% between the years (1990-2022), rising from 2.0 Gt in 1990 to 36.8 Gt in 2022.

GHG emissions associated with electricity generation for desalination are different depending on the implemented carbon mitigation strategies. In the Middle East, the adoption of desalination processes was focused on thermal desalination which involves the heavy use of fossil fuels due to their availability in the region. Thermal desalination is reliant on fossil fuels, this makes it an interesting option for countries with high fossil fuels resources. However, thermal desalination can heavily contribute to the increase of GHG emission. This leads thermal desalination adopters to consider other processes that have a lower impact on the increase of carbon emissions. The implementation of membrane technologies through RO desalination processes is growing in the Middle East and it is starting to align with other regions around the world that depend on RO technologies to produce freshwater. Analyzing the carbon emissions from diverse technologies like RO, MED, and MSF gives an idea on the sources of emissions within desalination and leads to generating effective solutions.

Keywords: Carbon footprint; Desalination; Emissions; Sustainability; Decarbonization

PT 196

Lowering OPEX and feed pressure requirements for municipal water production and reuse using Aquaporin Inside BWRO

Jan Benecke*, Xuan Tung Nguyen, Xin Hui Lim, Wanting Wang, Weng Hong Ho, Guofei Sun, Khung Hanh Le, Joerg Vogel, Liyun Tai, Na Peng, Victor Monsalvo Garcia, Juan Arévalo Vilches

**Aquaporin, Kongens Lyngby 2800, Denmark*
Tel. Tel. +45 53555522, jbe@quaporin.com

The Aquaporin Inside® CLEAR series of low-energy BWRO membranes, fabricated using a proprietary Aquaporin Inside® formulation, offers exceptional water permeability for energy-efficient desalination applications. This presentation will highlight successful case studies demonstrating substantial energy savings in various brackish water desalination scenarios, including municipal wastewater reuse and municipal drinking water production from well water. Municipal wastewater reuse: In collaboration with PUB Singapore, CLEAR Plus elements were benchmarked against two industry-leading competitor membranes and achieved over 20% energy reduction during a 3-months operation in a 2-stage pilot system (2x7 + 1x7 array, 4" elements) treating MBR effluent at 75% recovery and 3 m^3/h permeation. This significant energy saving was attributed to the membranes' enhanced water permeability, which allowed for lower operating pressures while maintaining high permeate flux and permeate quality. To ensure long-term performance and reliability, the CLEAR Plus elements underwent subsequent rigorous testing, including 15+ months of continuous operation and multiple CIP stress tests. These tests demonstrated the membranes' resilience to chemical cleaning agents and their ability to maintain consistent performance over extended periods. Eventually, operation was scaled up to a full-scale two-stage treatment train (2x168 + 1x168 array, 8" elements) operated alongside an identical treatment train equipped with industry-leading competitor membranes for benchmarking. During the first 4 months of operation at 80% recovery and 395 m^3/h permeation, the CLEAR Plus elements demonstrated a 22% reduction in feed pressure while achieving strict permeate quality standards, outperforming the competitor membrane. Municipal drinking water production from well water: Together with aqualia, we have demonstrated significant energy reductions in BWRO pilot- and full-scale benchmark studies treating well water for municipal drinking water production. Select cases and results will be presented. New product developments: An overview of recent advancements and relevant in-house test results will be presented, highlighting the ongoing commitment to innovation and optimization within the Aquaporin Inside® RO membrane product portfolio.

Keywords: BWRO; Novel membranes; Energy efficiency; Municipal wastewater reuse

PT 197

Performance of a containerized multistage variable power electrodialysis desalination system

Jonathan Bessette*, Shane Pratt, Benjamin Judge, Amos Winter

**MIT, 77 Massachusetts Ave., Cambridge, MA 02139, USA*
Tel. +1 6072354839, jbessett@mit.edu

There is a growing demand for adaptive desalination in decentralized applications – from drinking water in remote communities to waste management in mining industries. One such technology that has high potential for these applications is electrodialysis. Electrodialysis can be used at a variety of input salinities – from brackish [1] to high salinity brine concentration [2], and recirculation-based systems can allow for the targeting of various output salinities. Its flexible, electrically driven operation also lends itself well to handling variable power, such as with renewable energy sources. Recent work has explored and piloted optimal direct-drive electrodialysis using flow-commanded current control [3], but this work was limited to a single stack at relatively low flow rates (~10 m^3/d). Variable-power, adaptive electrodialysis has yet to be tested at commercial scale using multi-stage stacks. We apply novel, adaptive control and energy management mechanisms to a multistage electrodialysis system and examine its performance amidst a variety of feedwater, output water, and recovery ratio scenarios. Such scenarios encompass a range of applications, from brackish water desalination for drinking water, to brine concentration for produced water volume reduction. The system was constructed using three Veolia V20 electrodialysis stacks in a 20-foot shipping container and tested in both a controlled environment in Cambridge, and on real groundwater conditions in New Mexico.

Keywords: Electrodialysis; Containerized; Decentralized; Energy management; Renewables; Control

References

[1] Strathmann. (2010) Electrodialysis, a mature technology with a multitude of new applications. Desalination.
[2] McGovern et al. (2014) On the cost of electrodialysis for the desalination of high salinity feeds. Applied Energy.
[3] Bessette et al. (2024) Direct-drive photovoltaic electrodialysis via flow-commanded current control. Nature Water.

PT 198

"Alma de Mar", a pioneer initiative to extract the real value from brine SWRO plants to table

Naiara Hernández Ibáñez*, Juan Arévalo, Javier Hernández, Víctor Monsalvo, Frank Rogalla

**Aqualia, EDAS Racons (Denia) Crta. Nacional 332, km 204, Denia, 03700, Spain, naiara.hernandez@fcc.es*

Brine mining have been a hot topic in desalination in the last 5 years. The search of valuable raw materials in the sea it is an interesting topic, and in the latest years an intense effort on the extraction of raw materials, including critical raw materials (CRM) from brine have been studied worldwide, including several European Union research programs and awarded projects (Horizon H2020, Horizon Europe, LIFE…). Several minerals and metals have been studied, based on the European industry and European society needs. Many components have been identified, and several research lines have been developed in this way. However, sometimes it seems that many efforts have been done in the extraction of minority ions extraction in seawater and seawater brine, like Lithium, and little attention have been paid to majority ions with high markets, like sodium chloride.

Following this approach, and taking into consideration the huge market and potential growth in salt market, the extraction of high purity sodium chloride from reverse osmosis seawater brines it is a fast approach to reach the market in brine valorization.

The use of seawater brines in the production of high purity salt brings present clear advantages compared with seawater. The higher concentration of salts in brine, and the higher purity due to the cleaning process of seawater in pre-treatment can produce more sodium chloride than seawater and without impurities present in seawater like particles and microplastics.

For the production of salt, and intensified system based on traditional salines production have been implemented in Tenerife (Canary Islands, Spain) as a pilot experience in the production of high quality sodium chloride. With this pilot saline production, up to 100 tons per year can be produced.

Different markets can be reached in the use of the salt, but the fastest early adopters in the market can be the use of those salts to produce gourmet products as high purity table salt. Salt for food it is the 21% of the market in the salt production, but higher quality added products can be implemented, with fastest reach into the market.

Considering this, and as a part of its vision for circular economy, byproduct valorization and specifically brine valorization research line, Aqualia have created its own salt trademark, called Alma de Mar (sea soul in Spanish) to commercialize the salt produced in the brine valorization research center in Tenerife. This product, with high purity it is commercialized flavored in 8 different flavors, looking for one of the fastest growing markets, the gourmet table salts. This product, protected in 38 countries, it is the first and fast approach of Aqualia to reach the market in brine valorization, complementing the research lines to produce other compounds like industrial grade sodium chloride, Calcium and magnesium salts, and minority ions extraction (Li, V, B, Co, Sc, Ga, In, Rb…).

Keywords: Brine valorization; Salt; Desalination; Circular economy

PT 199

Membranes for water reclamation in industrial application: a feasible and proven opportunity

Naiara Hernández Ibáñez*, Juan Arévalo Vilches, Antonio Giménez Lorang, Irene Fernández Fernández, Marc Sauchelli, Víctor Monsalvo, Frank Rogalla

**Aqualia, EDAS Racons (Denia) Crta. Nacional 332, km 204, Denia 03700, Spain, naiara.hernandez@fcc.es*

Water reuse is a safe and often the least energy-intensive method of providing water from non conventional sources in water stressed regions. Recent advances in membrane technology allow for reclamation of wastewater through the production of high-quality treated water, including potable reuse.

This paper compiles results from up to three experiences under different pilot- and demo-scale conditions around membrane-based water reclamation solutions for secondary-treated wastewater in a brewery and the description of the multipurpose treatment train for water reuse in an urban wastewater treatment plant.

In the brewery wastewater tests, microfiltration, ultrafiltration and nanofiltration membranes produced effluents that fulfil the limits of the national regulatory framework for reuse in industrial services (RD 1620/2007), either for cooling water uses or for industrial uses. Coupling to the reverse osmosis units in tertiary trains led to further water polishing and an improved treated water quality. Blending after reverse osmosis ensured adequate electrical conductivity and corrosivity for the intended use.

The three tests validated the solution and allowed to define optimum operational settings of individual processes, like coagulation, ozonation, filtration flux, recovery, blending, etc.

The experience of the municipal WWTP aims to help the election of the best treatment train for the requirements of the final use. Different membrane technologies and a combination of them will be tested (ultrafiltration, nanofiltration, reverse osmosis and also electrodeionization), optimizing the operation to obtain an effluent with the required quality with the minimum energy consumption.

Keywords: Water reclamation; Nanofiltration; Ultrafiltration; Reverse osmosis; Industrial reuse

PT 201

Enhanced CO_2/CH_4 separation using amine-modified ZIF-8 mixed matrix membranes

Imran Ullah Khan*, Mohd Hafiz Dzarfan Othman, Mukhlis A. Raman, Musawira Iftikhar

Universiti Teknologi Malaysia, Faculty of Chemical and Energy Engineering, Johor Bahru 81300, Malaysia
Tel. +60 1116057580, imranullahkhan@utm.my

Amine-modified mixed matrix membranes (A-Ms) have been developed with improved anti-plasticization behavior at high pressure for natural gas purification. Neat polysulfone (PSf) hollow fiber membranes and amine-modified zeolitic imidazole framework-8 (A-ZIF-8) blended PSf membranes have been prepared with the aim of purifying natural gas. The fabricated membranes have been evaluated using gas performance tests, thermogravimetric analysis (TGA), atomic force microscopy (AFM), Fourier transform infrared spectroscopy (FTIR), differential scanning calorimetry (DSC), and field emission scanning electron microscopy (FESEM). When tested using pure gases, the membrane with 0.25 weight percent A-ZIF-8 demonstrated a substantial enhancement in CO2/CH4 selectivity of 50%, 72%, and 69% when compared to the neat membrane, and an increase of 33%, 78%, and 77% in CO_2/CH_4 selectivity compared to the virgin ZIF-8-based membrane at feed pressures of 6, 8, and 10 bar (g), respectively. Subsequently, the separation performance has decreased due to the increased A-ZIF-8 loading. Improved anti-plasticization behavior at high feed pressure is further demonstrated by the exceptional gas separation performance at low loading of A-ZIF-8 nanoparticles. The promising results showed the potential use of A-ZIF-8 for natural gas purification.

Keywords: Amine modification; Selectivity; Plasticization; Pure gases

PT 202

Brine valorization system with internal reuse of brine minerals

Christopher East*, Noura Chehab, Ahmed Al-Amoudi, Nikolay Voutchkov

ENOWA – NEOM, 206C2, Neom 49643, Saudi Arabia
Tel. +966 534538181, christopher.east@neom.com

The provision of water for human activity is essential. In the areas with significant water stress one viable option is desalination of either seawater of brackish water. However, the effects of desalination brine on the environment have been a point of discussion for several years. One year's worth of brine from a 100 megaliter a day desalination plant contains between two and three million tons of salts which are returned to the ocean at approximately twice the concentration of which they were taken. Although the water cycle is short, with most of the water returning to the ocean within 2 weeks, questions remain about the local effects of brine on marine life. Consequently, zero liquid discharge (ZLD) has been researched by many groups around the globe in an effort to mitigate the effects for desalination brine of the ocean. Despite the ongoing research there are still many technical challenges remaining, chief of which is preparing minerals of acceptable quality for sale into global markets. If the proceeding minerals cannot be sold, then the accumulation of salts on land will create a far larger environmental problem than discharge of brine back to the ocean.

In regions where ZLD is mandated for seawater desalination, the development of a viable ZLD scheme for the economical extraction of salable salts from the desalination brine is critical. Others have looked at this problem in a modular way before, proposing different seawater desalination brine mining schemes for: sodium chloride, bromine, magnesium sulfate, magnesium [1–7] but a viable system for complete treatment of the brine is yet to emerge. This paper proposes a scheme for desalination brine valorization with zero liquid discharge in view. The scheme takes approximately 13% of the sodium chloride in the seawater and uses it for the production of other minerals and chemicals in the process including recycling where possible.

Keywords: Brine valorization; Ocean brine mining; Zero liquid discharge

References

[1] Athanasoulia, I.G., Kyriazi, M., Katsiolis, S., Novakovic, J., Malamis, D. (2023). Technical Annals, 1(4).
[2] Bi, J., Chen, T., Xie, Y., Shen, R., Li, B., Sun, M., Guo, X. and Zhao, Y. (2024). J. Environ. Sci., 142, pp.21-32.
[3] Rivero-Falcón, Á., Peñate Suárez, B., Melián-Martel, N. (2023). Water, 15(8), 1600.
[4] Al-Amoudi, A. S., Ihm, S., Farooque, A. M., Al-Waznani, E. S., & Voutchkov, N. (2023). Desalination, 116789.
[5] Ihm, S., Al-Amoudi, A.S., Yoo, Y., Fellows, C.M., Farooque, A.M., Al-Waznani, E.S., Al-Jehani, Y., Al-Shaikh, K., Al-Biladi, A.O., Al-Senani, A.N. and Voutchkov, N. (2024). Desalination, p.117414.
[6] Molinari, R., Avci, A. H., Argurio, P., Curcio, E., Meca, S., Plà-Castellana, M., & Cortina, J. L. (2021). Journal of Cleaner Production, 328, 129645.
[7] Figueira, M., Reig, M., de Labastida, M. F., Cortina, J. L., & Valderrama, C. (2022). Journal of environmental management, 314, 114984.

PT 203

Identifying membrane foulants and the role diagnosis plays in optimized performance to reduce chemicals and maximize membrane life

Doug Eisberg*, Ken Robinson, Stuart Leak

**Kurita, 140 Bosstick Blvd., San Marcos, CA 92069, USA*
Tel. +1 7602143862, deisberg@avistatech.com

The application of membrane technology including membrane separations and membrane filtration have expanded over the years to treat a wide range of waters in many different industry segments around the globe. As technology evolves, the application of membranes is now common in more challenging applications. These challenging waters result in a wide range of foulants that must be properly addressed to ensure reliable system performance and many times, problems occur that were not originally anticipated.

Luckily, the latest generation of membrane evaluation tools can help the industry identify these foulants with more certainty than ever before. While proper chemical selection is key to system optimization, many times the core problem is identified as a process design problem. This presentation will cover some of the latest membrane evaluation tools and the diagnostic process to resolve system challenges resulting in minimized chemical usage and extending membrane life.

Keywords: Membrane optimization; Membrane; Autopsy; Diagnostic; Chemical

PT 205

Kick back with multi-stage SWRO systems, less hassles and more output — a membrane manufacturer's experience

Alvaro Lagartos*, Jose Luis Nuno#

**Senior Technical Marketing Manager, LG Chem, LG NanoH2O, LLC, Barcelona, Spain*
Tel. +34 647 674 355, alagartos@lgchem.com
#Vice-president of Business Development, TSG Water Resources

Reverse osmosis for seawater desalination (SWRO) is becoming the leading technology to produce potable water for mass populations in coastal areas or where the region is highly arid without rainfall. However, the relatively high energy consumption and membrane fouling of SWRO systems during operation continue to challenge the RO industry, especially in light of climate change and emphasizing sustainable water production. RO plant operators, designers, and technology suppliers continue to search for solutions that minimize cost factors impacted by feed pressure requirements and maintenance costs driven by fouling.

Multi-stage SWRO system designs have shown several advantages over single-stage SWRO systems, especially related to the abovementioned cost factors. Since a multi- stage

SWRO configuration improves the balancing of the system flux and reduces the concentration polarization, the system recovery can be increased by distributing the "workload" of each of the membranes in a pressure vessel without compromising the membrane's lifespan. These advantages improve the operational costs of desalination by reducing costs associated with membrane cleaning, chemical use, membrane replacements, labor, and overall plant downtime. Furthermore, capital investments (CAPEX) can also be reduced as less equipment is required with a higher recovery system.

In September 2023, LG NanoH2O™ SWRO membranes, based on the breakthrough Thin-Film Nanocomposite (TFN) RO technology, were installed in a high recovery multi-stage SWRO system producing potable water for the hospitality industry in Cabo San Lucas, in the Baja California region of Mexico. The membranes were installed in two racks with a configuration of 24:12 pressure vessels each equipped with 7 and 6 TFN membranes respectively for first and second stage. Both arrays are equipped with a Bi-Turbo two-stage turbocharger capable of treating 1.4 MGD (5,300 m^3/d). This paper will review the pros and cons of TFN SWRO membranes in a multi-stage SWRO design, highlighting energy, flux, polarization, cross-flow, and advantages observed during the operation compared to a hypothetical single-stage system with the same feed conditions and standard recovery.

Keywords: SWRO; Multistage; Energy consumption; Fouling

PT 206

OPEX optimization in RO systems for challenging water: a new revolutionary 36 mil membrane feed spacer design

Alvaro Lagartos

Senior Technical Marketing Manager, LG Chem, LG Chem, Ltd., Barcelona, Spain, Tel. +34 647 674 355, alagartos@lgchem.com

Climate change and water scarcity are leading countries to search for alternative climate- independent water sources. Reusing and recycling water through reverse osmosis (RO) are becoming priorities for industrial and municipal water treatment plants. Consequently, RO membranes are treating more challenging water which requires more robust and optimized membrane performance.

Due to the above, two main focuses of research in RO technology are energy consumption and membrane fouling. A spiral-wound RO module is composed of several so-called envelopes, each connected to a permeate collection tube, feed spacer, and permeate spacer. The primary function of a feed spacer is to separate two membrane envelopes allowing the feed stream to freely flow between membrane leaves while creating turbulent flow to minimize concentration polarization on the membrane surface. This particular feature of a membrane module construction has a key role also in fouling resistance and energy consumption since it directly affects the hydrodynamics of feed cross-flow through an element.

The differential pressure (dP) in a RO membrane system is a key performance indicator. Higher dP increases the energy cost of operation and requires frequent chemical cleanings. Therefore, reducing it and preventing its rapid increase during operation has a beneficial effect on both, CAPEX and OPEX. At constant operating conditions, dP depends on the geometry of the feed spacer: mesh size, thickness, strand diameter, and angle. Understanding and optimizing these parameters are necessary to improve its design and membrane performance.

Versus more standard spacers of 28 or 34 mil thickness, a new revolutionary development of a 36-mil ultra-low dP feed spacer with 3 layers that minimizes flow disturbance and pressure losses without increasing concentration polarization has been developed. Moreover, the new spacer delays the onset of fouling during system operation, reducing its rate and improving the efficiency of chemical cleaning.

This paper will provide an overview of feed spacers and their effect on both, feed pressure and fouling growth, and it will show the test results for this new membrane innovation to battle challenging water in the desalination industry.

Keywords: Reverse osmosis; Energy consumption; Fouling; Feed spacer; CFD modeling; Differential pressure

PT 208

Dakhla desalination plant using renewable energy

Lahcen Hasnaoui*, Mohamed Ouhssain

**DIAEA Consultant, Apt 5 Bat 4 Res Zaitoun Hay Nahda 1,
Rabat AA 10210, Morocco
Tel. +212 661479424, lahcen1hasnaoui@gmail.com*

This paper concerns the project of desalination in Dakhla region in the south of Morocco, the project involves the construction of a Sea Water Desalination Complex that comprises four categories of components:

- An industrial seawater desalination unit with a production capacity of 113,376 m^3/d of desalinated water intended for irrigation and potable water, located on the southern slope of the Skiymate estuarine guelta, above the upper submergence level of this guelta in the north at 130 km of Dakhla.
- A wind farm (PE) to supply energy to the plant and its annexes, as well as to the irrigation facilities
- Water distribution networks (irrigation and drinking water) and electrical power.
- An irrigated perimeter of 5000 ha.

The Dakhla Seawater Desalination Complex project comprises several components:

(1) a desalination plant comprising:
  - a seawater collection and pumping basin,
  - a seawater desalination plant (building with internal equipment),
  - 2 desalinated water storage tanks for agricultural use (2 x 87,000 m^3),
  - 2 desalinated water storage tanks for drinking water requirements (2 x 2,500 m^3).

(2) 2 underwater and underground pipelines: one to convey oceanic water from the open sea intake to the plant, and the other to transport brine from desalination operations.

(3) an underground land pipeline between the seawater collection and pumping basin and the desalination plant.
(4) a small-scale wind farm (12 wind turbines, 60 MW), which will serve as a source of energy for the project,
(5) a transformer station to supply power to a local grid.
(6) a network of underground power cables between the turbines and the substation.
(7) two overhead power cables, one between the substation and the plant, and the other between the substation and the ONEE network
(8) a network of access tracks (and roads) to the various project components.

This project is supported by an agreement called the Public Private Partnership (PPP) between the ministry of agriculture and a Nareva- Engie group. The project is under construction.

Keywords: Desalination; Irrigation; Renewable energy; Potable water supply.

PT 209

Addressing water scarcity in the Canary Islands: SWRO membranes with TFN technology as a proven solution for irrigation

Beatriz Calderon*, Alvaro Lagartos, Silvia Gallego

LG Chem, Sevilla 41003, Spain
Tel. +34 628885052, beatrizc@lgchem.com

Spain is one of the leading countries in Europe with 12% of the agriculture production, climbing up to the second position for vegetable. With annual revenues above 63,000 million euros, agriculture production represents 2–3% of the Gross National Product (GNP). Specifically in the Canary Islands, this percentage is 1–2% of the regional GNP. Due to their unique weather conditions with long sun hours, seasonal rain, and rich soil, the archipelago constitutes a suitable environment for the cultivation of a great variety of crops, including bananas, tomatoes, cucumbers, or avocados.

Water scarcity pushes society to find alternative climate-independent water sources to secure the existing demand. Reverse osmosis is the leading technology for desalted water production globally. Spain, including the Canary Islands, is one of the regions with the highest desalination installed capacity. Europe's first desalination facility was established in the archipelago back in 1964, making the region a global benchmark in the industry. Today, there are over 300 plants within its seven islands.

Irrigation for agriculture represents up to 70% of the water consumption worldwide. However, only 2–3% is coming from desalination processes. Spain represents a unique case, as up to 21% of the desalinated water production is dedicated to agriculture and irrigation purposes. In the Canary Islands, where 32% of the total water production is coming from seawater desalination, this rate is also significant, between 10–11%.

The successful usage of seawater desalination for irrigation requires optimizing energy consumption and its final cost per cubic meter, but also membrane rejection for TDS and boron due to the sensitivities of the different crops. SWRO TFN membranes, with the industry's highest salt rejection and very strong boron removal performance, are widely used in the Canary Islands, helping to optimize water production with strict quality requirements for agriculture.

In this paper, different examples of design and operation in the Canary Islands with SWRO systems using TFN membranes will be included to show their potential benefits of water production for irrigation.

Keywords: Agriculture; SWRO; TFN; Canary Islands

PT 210

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

Yiman Liu[a,b]*, Abrar Adem[a], Afrasiab Yameen[a], Nirajan Dhakal[a], Peter Vollaard[c], Rinnert Schurer[c], Begüm Tanis[b], Jan C. Schippers[a], Maria D. Kennedy[a,b]

[a] *IHE Delft, Institute for Water Education, PO Box 3015, 2601 DA Delft, The Netherlands, *Tel. +31 0633813768, yi.liu@un-ihe.org*
[b] *Delft University of Technology, Faculty of Civil Engineering, Stevinweg 1, 2628 CN Delft, the Netherlands*
[c] *Evides Water Company, PO Box 4472, 3006 AL Rotterdam, the Netherlands*

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 to 8, coagulant dose (Fe^{3+}) from 0 to 20 mg/L and rapid mixing intensity (G) from 300 to 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 (R2 > 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 particulate and colloidal fouling removal during coagulation.

Keywords: Particulate fouling; Coagulation; Rapid mixing; pH; Coagulant dose; MFI-UF; Biopolymer fraction; Fouling prediction

PT 211

Sustainable carbonaceous materials-based catalytic membranes for organic wastewater treatment: Progress and prospects

Yongtao Xue*, Jia Wei Chew

Chalmers University of Technology, Gothenburg 41258, Sweden
Tel. +46 762280237, yongtao@chalmers.se

Catalytic membrane, as a cutting-edge hybrid technology, is promising for organic wastewater treatment not only because of the excellent removal efficiency for various organic pollutants, but also because of the mitigation of membrane fouling. However, some challenges persist, including the relatively high fabrication costs of membranes, the high possibility of metal ions leaching from membrane structures, and the poor renewability of synthetic materials, which significantly restrict more widespread application. To address these issues, carbonaceous materials (e.g., biochar, activated carbon, carbon nanotubes, graphene, graphene oxide) are renewable and environmentally friendly materials that inherently have large surface areas, high porosity, and tuneable surface functional groups that can be employed as excellent alternatives in catalytic membranes. In this review, various methods (e.g., blending, in-situ growth, interfacial polymerization, and layer-by-layer assembly) for the fabrication of carbonaceous materials-based membranes are comprehensively summarized and discussed. Subsequently, the integration of catalytic membranes in different processes, whether individually (e.g., photocatalytic process, advanced oxidization process, and electrocatalytic process) or hybridized (e.g., photoelectrochemical process, photo-assisted advanced oxidization process), is assessed. In addition, various carbonaceous materials-based catalytic membranes implemented for the remediation of

wastewater are critically discussed. Furthermore, the existing challenges are described, and further research recommendations are proposed. This review is expected to be beneficial for advancing the development of carbonaceous materials-based catalytic membranes for practical decontamination of organic wastewater.

Keywords: Catalytic membrane; Carbonaceous materials; Wastewater remediation; Performance

PT 212

Computational chemistry methods for unveiling high recovery reverse osmosis scaling

Victor Yangali Quintanilla*, Loren Ramsay, Torben Lund Skovhus, Ditte Andreasen Søborg

**Grundfos Holding A/S, Poul Due Jensens Vej 7, Bjerringbro 8850, Denmark*
vyangali@grundfos.com

Introduction

Water treatment with conventional reverse osmosis (RO) remains ahead of high recovery RO (HRRO). With over 600 installations of HRRO by 2021 [1], the adoption of HRRO is limited due to many reasons. One of the reasons is that there are few players in the market with tracked verifiable records. Another reason is that promised high recoveries of at least 90% are not practically achieved, and many times the high recoveries are limited to around 85%. Thus, the competitive advantage of HRRO can be deselected by users finding conventional RO multistage alternatives. The best-in-class multistage RO may guarantee recoveries of around 85%, which may also be the case for HRRO at similar water feed conditions.

HRRO needs better scaling predictions to achieve simulated recoveries. By determining appropriate scaling limits based on saturation index (SI) and calcium carbonate precipitation potential (CCPP) the systems can be better designed. In this study 4 types of water were selected aiming to reach recoveries of 90%. Moreover, the study investigated the automation options of computational chemistry methods into real-time water treatment systems.

Methodology

Water samples were collected from 4 different sources (river, seawater, wastewater effluent and tap water) and analysed for chemical parameters by a certified laboratory (Eurofins) and in the laboratory of Via University College in Horsens.

The model for estimation of scaling limits (SI and CCPP) was adapted from proven PHREEQC simulations applied to field RO data and validated by sensor measurements [2]. For the automation part, one alternative was evaluated, by using a Python version adaptation of PHREEQC [3] developed by Vitens engineers, VIPHREEQC [4].

Results

A sensitivity analyses of SI and CCPP revealed that pH and temperature have a significant effect on both scaling indexes, with pH having a larger effect than temperature. At 90% recovery, the river water presented the highest calcite SI, followed by wastewater effluent, groundwater and seawater.

In a semi-batch operation of a HRRO pilot system, calculations of pH and SI in the retentate offered an early detection possibility for determining maximum recoveries before the onset of scaling.

Conclusions

By utilizing computation methods for chemistry analysis, it could be demonstrated that scaling indexes can be used to select water types that may not limit the application of HRRO for water desalination and water reuse.

Keywords: Reverse osmosis; High recovery; Simulations; Scaling

References

[1] Bluetech Horizon Scan. High Recovery Reverse Osmosis, 2021.
[2] S. Hager, M. Meinardus, T. Hoffmann and K. Glas. CaCO3 deposits in reverse osmosis: Part II – Simulation model for hydrochemical predictions of reverse osmosis retentates and scaling propensity. Brewing Sci., 75 (2022) 54–68.
[3] United States Geological Survey (USGS) Science for a changing World. PHEREEQC Version 3. https://www.usgs.gov/software/phreeqc-version-3/
[4] Vitens Copyright, Licensed under the Apache License, Version 2.0

PT 215

Contribution to improving the performance of pretreatment in seawater desalination: Case of BWC

Hassiba Ben Ottmane*, Mourad Berrabah

**Ecole Nationale Polytechnique d'Oran- ENPO, BP 1523 Oran EL Mnaouer, Oran 31000, Algeria*
Tel. +213 540 86 17 14, hasenporan@gmail.com

The seawater desalination plant in BENI SAF, Ain Temouchent, Algeria, operated by BENI SAF WATER COMPANY (BWC), employs conventional physico-chemical pretreatment before undergoing reverse osmosis for desalination. However, the efficacy of the primary sand filters at the BWC plant has declined over time. To enhance their efficiency, a new filtration medium, Filtralite MC 0.8–1.6, was introduced. Our study was conducted on-site to evaluate the impact of substituting sand with Filtralite for seawater pretreatment before reverse osmosis at BWC. This substitution aimed to mitigate the risk of osmosis membrane fouling due to water impurities. The assessment spanned from October 2020 to February 2021, involving testing of filtration cycles and effluent quality, particularly in challenging scenarios with elevated suspended solids and moderate turbidity.

Results indicate notable improvements. Production losses were slashed by 45%, plummeting from 673,000 m^3 to 380,000 m^3. Furthermore, the quality of filtered water displayed enhancement, with a 0.3–0.5 SDI point decrease compared to the previous year's corresponding timeframe. This advancement led to a remarkable 60% reduction in the need for cartridge filter replacements. By incorporating Filtralite, the BWC plant achieved superior pretreatment efficiency, safeguarding the reverse osmosis process from potential fouling and bolstering overall operational performance.

Keywords: RO desalination; Sand filter; Filtralite filter; fouling membrane; Improvement of pretreatment performance

PT 216

Dynamic control of the back-pressure in a photovoltaic-powered desalination system for enhanced system performance

Emmanuel Ogunniyi*, Bryce S. Richards

**Karlsruhe Institute of Technology, Pfinztalstraße 71a, Karlsruhe Durlach 76227, Germany*
emmanuel.ogunniyi@kit.edu

In photovoltaic (PV)-powered membrane desalination (PV-membrane) systems, solar irradiance (SI) fluctuations often result in continuous variations of PV power supply to the system. These lead to reduced or unstable feed water pressure and flow rate, which often result in suboptimal permeate that falls below permissible drinkable quality (e.g. with electrical conductivity, EC below 1.0 mS/cm). Additionally, when the PV power "ramp-down" deviation exceeds a certain threshold, there is electrical shutdown of the pump, which causes operational intermittencies and reduction in the total daily production of clean drinkable water. Energy buffering methods – whether via mechanical (e.g. pressure accumulator) or electrical means (e.g. battery, supercapacitor) is commonly used to address this, however, this is often associated with energy conversion losses and reduced efficiency.

In this study, an alternative method of dynamic control of PV-membrane back-pressure via an integrated actuator valve control is investigated. This can be an effective method for minimising the number of pump shutdowns, thus enhancing system performance during the SI fluctuations, without additional energy buffering solution. The experiments evaluated the performance of two common desalination membranes: BW30 and NF90 (DuPont Filmtec 4040) with synthetic brackish water (EC ~ 1.2 mS/cm), and compared the proposed dynamic back-pressure control system with a directly-coupled (uncontrolled) configuration. The results show that, the dynamic back-pressure control with BW30 reduced the number of pump shutdowns by 86% with a corresponding daily production gain of 7.5%. For the NF90 membrane, pump shutdowns were reduced by 57%, accompanied by a 14.6% gain in daily production respectively. For both membranes, the quality of permeate produced is drinkable at EC < 0.68 mS/cm.

This study highlights that the direct regulation of membrane hydrodynamics (via the back-pressure control) during SI fluctuations, is an effective and alternative method of enhancing the system performance without energy buffering during the SI fluctuations. This approach is also an advancement towards more sustainable and reliable PV-membrane desalination processes.

Keywords: Desalination; Fluctuation; Membrane; Photovoltaic; Power control; Shutdown; Solar irradiance.

PT 217

Desalination brine matters: Impacts of antiscalants on seagrass and its corresponding bacterial epiphytes

Ryan Sirota*, Gidon Winters, Gilad Antler, Eyal Rahav, Edo Bar-Zeev

Ben-Gurion University of the Negev, Mishol Dafduf 14/7, Eilat 8801173, Israel, Tel. +972 53 7258696, rsirota43@gmail.com

Alongside freshwater production, seawater reverse osmosis (SWRO) desalination facilities disseminate hypersaline brine and chemical additives, including antiscalants, into the adjacent coastal environment. This chronic discharge, particularly into oligotrophic waters, raises significant ecological concerns. Surprisingly, most studies investigating the effects of SWRO brine discharge did not directly test if and how antiscalants affect sessile coastal communities. Here, using a 4-week long (subacute) mesocosm approach, we investigated the effects of brine (5% above ambient salinity) combined with either polymer-based or polyphosphonate-based antiscalants on the ecophysiology of the ecosystem engineer seagrass Halophila stipulacea and its bacterial epiphytes. Results show that elevated salinity and antiscalants altered bacterial communities, increasing epiphytic bacterial abundance on leaves (<263%) and in the top sediment layer (<24%), while reducing their abundances among roots (<47%). Moreover, the optimal quantum yields of the seagrasses exposed to polyphosphonate-antiscalant improved (Fv/Fm; +9%) along with the aboveground biomass (+12%). Conversely, the polymer treatment decreased shoot numbers (<28%), reduced the effective quantum yield of photosystem II (?Fv\/Fm'; <20%), and increased chlorophyll a + b concentrations by 31% compared to the phosphonate treatment which decreased chlorophyll concentrations up to 20%. These results and corresponding insights highlight that polyphosphonate-antiscalant and polymer-antiscalants significantly alter the ecophysiology of keystone species in the mixing area after one month of exposure. Specifically, these changes in microbial communities and seagrass health suggest that these disruptions in nutrient cycling are critical for ecosystem stability. Altogether, this study underscores the need for sustainable management and improved selection of antiscalants to reduce the ecological footprint of SWRO facilities and support ecosystem resilience.

Keywords: SWRO desalination brine; Antiscalants; Halophila stipulacea; Benthic bacteria; Epiphytic bacteria

PT 218

Synergistic effects of 3D-printed spacers and modular vibration towards membrane fouling mitigation

Aws Al-Tayawi*, Imre Vajk Fazekas, Szabolcs Kertész

University of Szeged, Szeged 6722, Hungary
awsaltayawi@uomosul.edu.iq

In recent decades, unprecedented growth and expansion have been experienced by industries worldwide. While many positive changes and significant improvements in the quality of life have been brought about, new challenges and problems have also been presented to human society. One of the most significant challenges faced is the issue of managing the large volumes of polluted water and wastewater generated. Today, membrane filtration techniques are recognized as a crucial component of wastewater treatment technologies. In membrane-based systems, semipermeable membranes are utilized for filtration, allowing water molecules to pass through while retaining some or all solid particles present in the water. Despite advancements, membrane filtration is still hindered by the inevitable fouling of membranes during operation. As operation progresses, retained particles on the membrane surface and within the pores impede fluid flow, significantly reducing process efficiency. In constant pressure systems, flux decreases, whereas in constant flux systems, pressure demands increase. Numerous methods have been researched to address fouling, such as backflushing (where permeate flows through the membrane in the opposite direction for a few seconds), the use of detergents, enzymatic additives, module vibration, and the integration of flow-diverting units into the module. During measurements, the latter two methods and their combinations were tested and compared.

In this study, proprietary 3D-printed spacers with varied geometries, modular vibration, and their combinations were examined for membrane fouling mitigation. Permeate flux, membrane retention, resistance, and specific energy consumption were analyzed as key parameters. Spacers were fabricated from materials ranked by tensile strength, including PCTG, PETG, PLA, and resin. The results demonstrated that performance significantly improved when modular vibration was combined with spacers. Flux values increased by over 300%, and total membrane resistance was reduced by more than 85% when high vibration was paired with the Sp.2 (or Sp.4) spacer made of PETG. Specific energy consumption was also reduced by nearly 85%, with stable performance maintained throughout the process. Filtration quality, evaluated via chemical oxygen demand and the retention of proteins, lactose, and solids, showed minimal variation. Spacers alone often outperformed low vibration, offering a more energy-efficient alternative.

Keywords: Ultrafiltration; 3D printed spacers; Membrane fouling; Dairy wastewater

Acknowledgments

This study was supported by the project 142414 FK and 2022-1.2.6-TÉT-IPARI-TR-2022-00011 project from the National Research, Development, and Innovation Office (NKFI), Hungary. Aws N. Al-Tayawi acknowledge the financial backing provided through the University Research Fellowship Programme of the Ministry of Culture and Innovation, funded by the National Fund for Research, Development and Innovation (grant number EKÖP-24-3-SZTE-476).

PT 219

Novel 4-channel membrane distillation spiral wound module with heat integration

Bart Nelemans*, Kirtiraj Chavan

**Aquastill b.v., Nusterweg 69, Sittard 6136KT, The Netherlands*
b.nelemans@Aquastill.nl

Membrane distillation (MD) is a promising technology, with various configurations which have been extensively investigated for numerous applications. Amongst these, air gap membrane distillation (AGMD) has generally been the most effective when considering key performance indicators such as flux, energy recovery, and electricity consumption for brine treatment. Certain applications need alternative solutions because of high energy intensity, stricter government regulations, and the high cost associated with wastewater treatment and resource recovery. One such application is metal pickling in the steel industry, which produces hazardous wastewater that requires energy-intensive treatment.

A common disadvantage of the common MD configurations is their one-pass recovery limitation. This limitation arises due to the restricted amount of heat that the fluid can retain before entering the module. However, the treatment and recovery of said wastewater with MD provides an opportunity through a direct integration of low-grade waste heat reducing carbon footprint massively. This option also reduces the total processing volume of hazardous wastewater and eliminates the need for an expensive, chemical-resistant heat exchanger due to strong acids like hydrochloric acid.

Several challenges are associated with this process:

- Purification of the acid from wastewater with high vapour pressure reduction and increasing membrane wetting probability
- Material chemical resistance necessitating the selection of high-quality polymers and bonding methods
- The constructional challenge in the integrating an additional flowing channel in an MD module requiring extra entry and exit points
- Scaling up of MD modules poses challenges to the production methods

In 2024, a plate and frame lab module (0.2 m^2) successfully demonstrated heat integration for acid purification without wetting issues.

The cylindrical module's development introduced new condenser materials, potting resins, and welding methods to solve chemical resistance issues, all successfully tested individually.

The construction of a cylindrical lab module with a 0.26 m^2 membrane surface and 1.7 m envelope length demonstrated the feasibility of integrating an additional channel. This module achieved a flux of approximately 8 lmh for tap water at a high ?T of 20K. Testing with HCl pickling wastewater confirmed its chemical resistance.

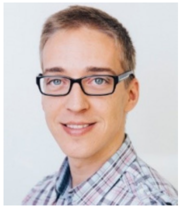
Scaling up presents challenges because multiple flags must be integrated and connected, which lead to a pilot scale module (5 m^2) with short channel length (ca. 1.3 m). This acts as a stepping stone to an approximately 15 m^2 industrial module. The initial tests of the 5 m^2 module resulted in a leak tight module with a flux of 3.15 lmh with a GOR of 1.2 at a ?T =16K. This demonstrates the scaling up capabilities.

Before scaling to an industrial module, the next step is to build a module with longer channels for improved heat recovery and higher GOR values.

Keywords: Novel membrane distillation module; Heat integration; High recovery; Metal pickling; Acid concentration

PT 220

Improvement of ultrafiltration by module integrated 3D printed turbulence promoters



Szabolcs Kertész*, Aws N. Al-Tayawi, Hadid Sukmana, Cecilia Hodúr, Imre Ábrahám, Nóra Garabné Ábrahám, Andrea Süveges-Gruber, Zsuzsanna László

**University of Szeged, Szeged 6720, Hungary, kertesz@mk.u-szeged.hu*

Membrane fouling still remains a significant challenge in various applications, particularly in wastewater treatment or in liquid dairy by-product concentration, where high concentrations of organic matter can lead to decreased permeate flux and increased operational costs. The use of 3D printed turbulence promoters/spacers (3DPTP) has been shown to improve the hydrodynamic conditions within the filtration module, thereby enhancing mass transfer and reducing the deposition of foulants on the membrane surface. The integration of 3DPTP into ultrafiltration systems/modules has emerged as a promising approach to enhance filtration performance and mitigate membrane fouling, so represents a significant advancement in membrane technology.

Our research group have demonstrated that the incorporation of 3DPTP can significantly increase permeate flux into different ultrafiltration configurations, such as dead-end and cross-flow ultrafiltration modules. This enhancement is attributed to the improved turbulence and mixing induced by the 3DPTP, which disrupt the boundary layer near the membrane surface and facilitate the removal of foulants. Moreover, the design flexibility offered by 3D printing technology allows for the customization of 3DPTP tailored to specific applications and operational conditions. For example, the geometry and arrangement of the 3DPTP can be optimized to maximize their effectiveness in different types of ultrafiltration systems. This adaptability is particularly beneficial in addressing the unique challenges posed by various feed streams, such as those encountered in dairy wastewater treatment or dairy by-product concentration, where the composition can vary significantly. These innovations not only improve the operational efficiency of filtration processes but also contribute to the sustainability of water treatment practices. However, continued research and development in this area are essential to fully realize the potential of 3D printing in optimizing ultrafiltration performance. In addition to enhancing permeate flux, the integration of 3DPTP has been linked to prolonged membrane lifespan. In this conference, we plan to present the current scientific results of one national and one international project.

Keywords: Membrane separation intensification; Ultrafiltration; Dairy by-product utilization; Dairy wastewater treatment; 3D printed turbulence promoters/spacers

Acknowledgment

This study was supported by the project NKFI-FK-142414 and 2022-1.2.6-TÉT-IPARI-TR-2022-00011 project from the National Research, Development, and Innovation Office (NKFI), Hungary.

PT 221

Environmentally friendly biofouling control in seawater intakes using UVC-LED: a new non-chemical approach

Harry Polman*, **Menko Remmelts**, Kaveh Samimi-Namin

H2O Biofouling Solutions BV, Nijverheidsweg 14A, Elst 6662 NG, The Netherlands, hpolman@h2obfs.com

This paper presents the results of trials conducted using a promising new technology for controlling marine biofouling in seawater intakes of sea water reverse osmosis (SWRO) plants. These plants often face challenges with marine biofouling and the use of oxidative biocides, which can have adverse effects on reverse osmosis (RO) membranes when over-applied. Seawater intake structures create ideal conditions for the settlement and growth of marine organisms, leading to significant operational issues, such as increased wall roughness, reduced pipe diameters, and overall head loss. These factors can disrupt operations, increasing the risk of unplanned shutdowns, which can lead to costly production losses and penalties due to maintenance interruptions. This paper shares the results of recent pilot tests of an innovative UVC-LED technology. Previous studies have demonstrated that surface-integrated UVC-LEDs on marine vessels prevent biofouling. This patented technology is now being scaled up by Philips, AkzoNobel and Damen Shipyards. Exclusive trials have been conducted to explore the application of UVC-LEDs in seawater intakes, and the initial results have been highly promising. The technology completely prevents biofouling on treated surfaces while consuming minimal power, making it an energy-efficient, biocide free solution. Pilot tests were conducted at a seawater intake facility in the Netherlands, using three identical pipe setups: Untreated seawater (control), Seawater treated with Ecodosing™, Seawater treated with UVC-LED integrated surfaces. Results show that the UVC-LED technology is at least as effective as Chlorination. This paper details these findings, along with an analysis of power consumption, future opportunities, and challenges.

Keywords: Desalination; Biofouling; Chlorine; Membrane fouling; Operational reliability; UVC-LED

PT 223

Europe leading the way to reduce energy use in water reuse and brackish desalination projects: a tale of two plants

Angel Abajas, Rolando Bosleman*, Erik Desormeaux

**Energy Recovery Inc, 1717 Doolittle Drive, San Leandro, CA 94577, USA*
rbosleman@energyrecovery.com

Energy costs in Europe have risen to record high prices in the last few years and electricity rates have stabilized at some of the most expensive prices in the world. Utilities in the EU are leading the way in using new technologies to reduce the energy of wastewater reuse and brackish desalination plants via the largest load at the plant, the low pressure reverse osmosis (LPRO) system. This abstract covers two cases of utilities in Europe incorporating new isobaric energy recovery devices launched last year to address the pain point of LPRO energy use.

The first plant is the "Deeper Blue" reuse project at the Farys wastewater treatment plant in Aalst, Belgium. It is scheduled to be commissioned in 2025 and will be one of the first multi-barrier municipal reuse facilities designed for aquifer recovery and recharge, also known as indirect potable reuse. Energy saving technologies such as the new low pressure PX (LPPX) from Energy recovery will reduce the energy use of the LPRO system by approximately 20% and will be the first municipal reuse plant in Europe to use this new technology.

The second plant is a LPRO facility located on Lake Biel in Switzerland that underwent a complete redesign to provide clean water for 70,000 individuals in Biel and Nidau. The utility provider, Energie Service Biel/Bienne (ESB), sought a modern, energy-efficient solution for water treatment to remove trace contaminants. The goal was to reduce energy consumption and lower trace substances by approximately 50% to combat highly variable raw water quality and prepare for the effects of climate change. This end user also selected the LPPX and estimates that the facility will save an 740 MWh/y, roughly equivalent to 36% of the energy consumption of the new system, and save an estimated $118,500 USD in operating costs annually.* The plant's new energy-efficient system design utilizes the PX and combines it with innovative features to lower electricity usage and align with Switzerland's net zero goals.

Keywords: Energy recovery; LPRO; Desalination; Reuse; Brackish; Contaminants

PT 224

Energy recovery device retrofit of an existing BWRO plant in Spain

Rolando Bosleman*, **Juan Cifuentes**

**Energy Recovery Inc, 1717 Doolittle Drive, San Leandro, CA 94577, USA*

rbosleman@energyrecovery.com

Rising in energy costs, water scarcity and environmental indicators are triggering the necessity of using the most efficient energy recovery devices (ERD) in reverse osmosis desalination system, both in seawater and in brackish water systems.

Brackish water reverse osmosis (BWRO) systems were typically not using ERD as the combination of high recovery and low operating pressures produce a small amount of energy to be saved. This approach is not correct anymore. As example, some BWRO are going under retrofit to install the most efficient ERD, even when they had already installed other type of ERD operating at less efficiency.

The installation to be discussed is placed in the Southeast of Spain, and produces water for agriculture irrigation. It is composed of 4 trains producing 5,000 m^3/d of permeate; comprising two stage RO and turbocharger as inter-stage boosting ERD, to treat brackish water from ground wells which suffers a high variability in terms of salinity due to seawater intrusion to the reservoir. Total RO recovery is 65%.

The retrofit project has studied two possible options: installing a double stage-double isobaric ERD and inter-stage booster pump for flow balance; and the other option a double stage with single isobaric ERD and an inter-stage booster pump for flow balance. On both solutions, the selected ERD is the Energy Recovery's PX Pressure Exchanger®.

First retrofitting option ensures the largest energy savings, as almost all the brine energy is recovered with an efficiency over 93% in each of the energy recovery stages, reducing the specific energy consumption (SEC) 21 % in average for all the operating conditions, compared to the SEC of the system using turbocharger as ERD.

Second retrofitting option is slightly less efficient, but was the selected one manly because of footprint requirements and CAPEX impact, having up to 21% of SEC reduction compared to the original plant design, depending on the operating conditions.

Considering that the retrofit is applied to a system with an existing ERD, the return of investment (ROI) of less than 5 years is a clear signal of the benefits of using an isobaric ERD in brackish water reverse osmosis facilities. The retrofit will also allow improved operations for all the feed-water salinities and pressures, providing additional flexibility to the system.

This paper will present the detailed technical evaluation of this BWRO retrofit, considering the impacts on capital cost, operational cost and operational changes required when integrating the isobaric ERD into the current configuration.

Keywords: Energy recovery device; ERD; Brackish water reverse osmosis; BWRO; Specific energy consumption; SEC; Return of investment; ROI

PT 225

PX Q400 impact in demonstration plant achieving less than 2 kWh/m³ in energy consumption

Rolando Bosleman*, Juan Cifuentes

**Energy Recovery Inc, 1717 Doolittle Drive, San Leandro, CA 94577, USA*
rbosleman@energyrecovery.com

The Instituto Tecnológico de Canarias (ITC) has developed a demonstration Seawater Reverse osmosis desalination plant with the goal of achieving an specific energy consumption of less than 2 kWh/m^3, with a nominal capacity of 2,500 m^3/d.

This goal can only be achieved by using the most efficient commercial equipment available, and most importantly, the most efficient energy recovery devices. Using the PX Q400 Pressure Exchanger® has been one of the main foundations to achieve Specific Energy Consumption values of 1.86 kWh/m^3 during the test plant operation.

PX Q400 has demonstrated that is the best in class energy recovery device, operating consistently at efficiencies over 97%, produced by the low pressure losses in both high pressure side and low pressure side.

In combination with the highest efficiency, the salinity increase produced by the volumetric mixing at the PX has been as low as 1%, which allows to operate the reverse osmosis at almost the same feed pressure as if there was no isobaric ERD installed.

The achievement of the low Specific Energy Consumption has also been attained with a flawlessly operation of the PX Q400, which has contributed to the high reliability during the commissioning and demonstration of the testing plant.

Keywords: Energy recovery device (ERD); Seawater reverse osmosis (SWRO); Specific energy consumption (SEC); Volumetric mixing

PT 226

Optimization of membrane filtration processes using the design of experiments in different whey solutions

Hadid Sukmana*, József Csanádi, Cecilia Hodúr, Zsuzsanna László, Gábor Veréb, Sándor Beszédes, Imre Ábrahám, Nóra Garabné Ábrahám, Andrea Süveges-Gruber, Szabolcs Kertész

Faculty of Engineering, University of Szeged, Moszkvai krt. 9, Szeged 6725, Hungary, Tel. +36 703592886, sukmana@mk.u-szeged.hu

Dairy effluents are distinct from other industrial wastewaters due to their elevated chemical oxygen demand (COD), which can severely disrupt aquatic ecosystems if untreated. Membrane filtration technology has emerged as a promising advanced method for water purification, particularly in reducing COD to acceptable levels. Key parameters for evaluating membrane performance include flux and rejection. Flux represents the permeate

volume and production rate, while rejection quantifies the membrane's efficacy in COD removal, collectively determining its ability to reduce COD.

This study investigates the optimal conditions for microfiltration (MF) and ultrafiltration (UF) membranes, followed by the application of diafiltration (DF) techniques (MF/DF and UF/DF) on various whey solutions. Statistical optimization using the Design of Experiments (DOE) was employed to identify the most favorable operating conditions. Synthetic whey solutions with a COD concentration of approximately 72,000 mg/L were used. MF was performed using membranes with pore sizes of 0.1, 0.22, and 0.45 μm at a pressure of 1 bar, under varying temperatures (15, 20, and 25°C) and stirring speeds (300, 400, and 500 rpm). UF was conducted using membranes with molecular weight cut-offs of 50, 100, and 150 kDa under varying pressures (2, 2.5, and 3 bar) and stirring speeds (300, 400, and 500 rpm) at 25°C. The optimal conditions identified for MF and UF membranes were subsequently applied to MF/DF and UF/DF processes using synthetic and fresh whey. Membrane performance was evaluated in terms of flux, COD rejection, and membrane resistance to determine efficiency. The findings provide insights into optimizing membrane-based separation techniques to treat whey solutions effectively.

Keywords: Design of experiments; Diafiltration; Membrane filtration; Microfiltration; Ultrafiltration; Whey solutions

PT 227

Protein-incorporated filtration membrane for urea removal in portable peritoneal dialysis applications

Mei Qun Seah*, Elin Posch, Mehdi Pejman, Florian Schmitz, Martin Andersson

**Chalmers University of Technology, Chalmers Tekniska Högskola AB, Gothenburg 41296, Sweden, meiq@chalmers.se*

Dialysis treatments for patients with kidney failure severely disrupt the patient's quality of life due to their high frequency and long treatment sessions. To date, commercial dialyzers typically remove urea from the dialysate via urease conversion, direct urea adsorption, or oxidation mechanism. However, these methodologies could not achieve complete urea removal, making it unsuitable for portability purposes. In this work, a filtration membrane is developed with a support and an active layer. The active layer responsible for urea rejection is incorporated with aquaporin proteins. The proteins were stabilized using an encapsulation method developed previously. The aquaporins within the filtration membrane act as a passive and highly selective water transport channel, allowing enhanced flux permeation while maintaining high urea rejection. The membrane performance was then benchmarked against commercial dialyzers in terms of flux permeability and urea rejection using synthetic peritoneal dialysate. Structural analysis of the stabilized aquaporins and the aquaporin-incorporated membranes were conducted using TEM and FESEM, respectively. The biomimetic membranes recorded at least 40% increase in terms of flux and improved NaCl rejection to 97%. The findings of this work provided insight into the application of filtration membranes to dialysis applications.

Keywords: Aquaporin; Membrane; Polymer; Flux; Rejection; Urea

PT 228

Biomimetic membranes with gramicidin A for separation of mono- and divalent ions

Elin Posch*, Mei Qun Seah, Florian Schmitz, Simon Isaksson, Martin Andersson

**Chalmers University of Technology, Kemivägen 4, Gothenburg 41258, Sweden, Tel. +46 761415912, elinpo@chalmers.se*

This work is leveraging the finest filtration systems in nature, utilizing proteins. Biomimetic membranes with incorporated gramicidin A (gA) stabilized by silica have been developed for high precision and energy efficient separation of mono- and divalent ions in salt mixtures.

The gA liposomes were produced by extrusion with filters ranging from 400–100 nm. Silicification of the gA liposomes was done by adding pre-hydrolyzed tetraethyl orthosilicate to the solution and left stirring for 1.5 h. The biomimetic membranes were fabricated with 2 wt% 2-methyl-2,4-pentanediol and 0.2 wt% 1,3,5-benzenetricarbonyl trichloride on polyether sulfone substrate with 100 %v/v and 50 %v/v coverage of gA liposils deposited over the substrate surface. The gA membranes were examined in a high pressure stirred cell with 1 h of compaction at 13 bar and tested at 12 bar for 5000 ppm NaCl and $CaCl_2$, respectively. Volume and conductivity of the permeate was measured.

Dynamic light scattering (DLS) showed that gA liposomes were synthesized with a size of 93.71 ± 3.83 nm, and gA liposils 207.91 ± 28.41 nm. Atomic force microscopy imaging also showed uniform sizes of the silicified gA liposils. Initial membrane testing showed that depending on the volume coverage of gA, the gA membranes alter the permeability but pass $Na^+ > Ca^{2+}$ in both cases. The permeability increased with 100% v/v coverage of gA compared to the blank, whilst the salt selectivity ratio was higher for 50% v/v coverage compared to the blank. However, further testing and optimization of the composition of the membrane needs to be performed for optimized separation of mono- and divalent ions.

Moving forward, in silico simulation and mutations of proteins will be performed for creation of a biomimetic membrane for Li^+ recycling. Utilizing the lithium transporter in the same platform for membrane fabrication as mentioned in this work, a membrane for recovery of lithium from spent lithium-ion batteries could be achieved.

Keywords: Membrane; Gramicidin A; Salt rejection; Separation ions

PT 229

Pilot-scale advanced wastewater treatment for direct potable reuse: achieving safe water for the beverage industry

Rui M.C. Viegas*, David Figueiredo, Elsa Mesquita, Sofia Charrua, Carla Costa, Rita Lourinho, Maria João Rosa

**National Laboratory for Civil Engineering (LNEC), Avenida do Brasil, 101, Lisboa 1700-066, Portugal, Tel. +351 218443841, rviegas@lnec.pt*

Potable reuse can provide a realistic and practical source of drinking water under severe water scarcity, uncertain/unreliable supply or emergency situations and pilot demonstration projects are essential for developing future guidelines and best practices. To demonstrate the safety and feasibility of direct potable reuse (DPR) in the beverage industry, a pilot-scale study was conducted at the Beirolas Water Resource Recovery Facility (WRRF) in Lisbon, Portugal, with tertiary treatment and sand filtration.

The study tested four advanced treatment schemes, comprising different combinations of ultrafiltration (UF), ozonation (O_3), biologically active granular activated carbon (BAC), and reverse osmosis (RO), evaluated in continuous operation (24/7):

1. UF+RO,
2. UF+O_3+RO,
3. UF+O_3+BAC+RO,
4. O_3+BAC+RO.

The containerised automated pilot unit, with photovoltaic energy production, produced water complying with EU and Portuguese drinking water standards. The water quality monitoring included parameters such as total organic carbon (TOC), nutrients, trace compounds (pharmaceuticals, PFAS, disinfection by-products), and pathogen indicators (bacteria, viruses, and protozoa). Regular operational monitoring assessed normalised permeate fluxes, pressures, and permeate quality to compare the performance of the four configurations.

Key results indicated that all treatment schemes achieved water quality suitable for the beverage industry. Contaminants of emerging concern, including PFAS, pharmaceuticals, and disinfection by-products, were consistently below detection limits. PFAS (<2 ng/L), THMs (<2 µg/L), 5 HAAs (<1 µg/L), bromate (<3 ng/L), NDMA (<8 ng/L), and pharmaceuticals (<0.3 µg/L). Pathogen indicators were below quantifiable levels, ensuring microbiological safety.

Operational monitoring results indicated lower normalized net driving pressure, i.e. lower energy demand, for the UF (+ low-dose Cl_2, whenever needed for RO biofouling control) + RO scheme.

Considering the results obtained and since downstream safety barriers are provided by the beverage production steps for controlling pathogens and volatile dissolved chemicals, this scheme proves adequate for this specific application. In cases where additional safety barriers should be accounted for, BAC/O_3 could be considered.

These findings validate the capability of advanced treatment systems to meet stringent potable water standards, ensuring the safety and reliability of DPR for industrial applications. By demonstrating the production of safe, high-quality water in a real-world context, the study builds trust in water reuse practices and highlights their role in addressing water scarcity challenges while advancing sustainable industrial processes.

Notably, 1,000 litres of craft beer were brewed using the treated water, showcasing its potential for real-world applications.

Keywords: Direct potable reuse; Beverage industry; Reverse osmosis; Contaminants of emerging concern

Acknowledgements

This research was funded by the European Union's programme Horizon 2020 (B-WaterSmart, GA No. 869171).

PT 230

Fighting water scarcity through the urban reuse of wastewater – Porto case study

Mónica Read*, Cecilia Santos, Ruben Fernandes

**Águas e Energia do Porto, E.M., Rua do Barão de Nova Sintra 285, Porto 4300-367, Portugal*
Tel. +351 966120982, monica.read@aguasdoporto.pt

Amid the growing challenge of water scarcity, Water Reuse (WR) has emerged as a key strategy in combating climate change and promoting sustainable water resource management. As part of a contingency plan to enhance efficiency in water use, the city of Porto has implemented a strategic initiative focused on water reuse, producing high-quality water as a reliable alternative to potable water consumption in various applications.

In this context, Águas e Energia do Porto (AEdP) installed a modular Membrane Bioreactor (MBR) unit at the Freixo Wastewater Treatment Plant. This unit, equipped with ultrafiltration (UF) flat membrane technology, has the capacity to produce up to 1,000 m^3/d of water for reuse. Integrated into the existing conventional activated sludge (CAS) system, the MBR serves as a complementary treatment stage.

The system was tested in 2023 to optimize its performance and ensure that the permeate consistently meets legal quality requirements. Throughout 2024, the plant's operating conditions were closely monitored to ensure process stability, permeate quality, and cost efficiency. Key process parameters – including membrane flux ($L/m^2{\cdot}h$), backwash pressure (bar), transmembrane pressure (TMP, mbar), and membrane permeability ($L/m^2{\cdot}h{\cdot}bar$) – were optimized, while energy usage was monitored as electrical consumption per cubic meter of reused wastewater (kWh/m^3).

Analytical results confirmed the production of high-quality permeate, with low levels of Biochemical Oxygen Demand (BOD5), Total Suspended Solids (TSS), Turbidity, and Escherichia coli, alongside non-detectable Legionella spp. The permeate consistently met Class A WR standards as defined by EU regulations and Portuguese legislation, making it suitable for a variety of non-potable uses such as agricultural irrigation, urban applications, and ecosystem support.

This success enabled the licensing of WR production for multiple uses and led to its implementation in public space cleaning in Porto. The city began by utilizing WR for street cleaning, followed by its application in vehicle and container washing. Currently, municipal cleaning vehicles are supplied with WR, significantly reducing potable water consumption and presenting an innovative approach to addressing water scarcity. Daily monitoring ensures the consistent quality of the water.

The project is now expanding, as it sets an example for other municipalities. With its Class A grade, WR is expected to be adopted for additional uses, such as irrigating green spaces. Furthermore, recognizing its potential for industrial applications, AEdP is actively pursuing partnerships to foster city-industry synergies, advancing circular economy principles and pushing the boundaries of sustainability.

Keywords: Water reuse; Urban reuse; MBR

PT 231

Spatio-temporal analysis of water samples from 18 stations in Kota, Rajasthan, India for 2022-23: based on CCME guidelines

Himanchal Bhardwaj, Deeptha Giridharan, Sunil Duhan, Anugya Shukla, Aswathy Puthukkulam, Deepika Bhattu, Venkata Ravibabu Mandla, **Anand Plappall**y*

**IIT Jodhpur, 222 ME Building IIT Jodhpur Karwar, Jodhpur 342037, India*
anandk@iitj.ac.in

Testing of water collected from eighteen stations in the city of Kota, Rajasthan India was performed in 2022–23. Six parameters including pH, turbidity, total dissolved solids, total hardness, total alkalinity and iron content were studied. Acceptable limits from the Indian standard IS 10500 : 2012 (drinking water specification) was set as control. Following CCME guidelines, none of the eighteen stations randomly selected from a total of 46 stations surveyed were found to have excellent water quality. Geo-spatial maps delineate the parametric variability across the survey location in the city for summer, winter and rainy seasons. Irrespective of seasons and sources, the north-east boundary of the survey tile showcased high pH in the water.

Surface water samples were collected from 6 stations which included pond, lake and canal. Canal based water sources were found to have water quality index (WQI) values more than 75. During summer, all six water bodies showcased high turbidity far beyond the acceptable limits of 1 NTU. Land use change of water bodies prompted these investigations. Most of municipal water samples collected from six locations exhibited high pH beyond the average of the pH range 6.5–8.5, irrespective of seasons. All six hand pump sourced water samples showcased total alkalinity beyond the acceptable limit of 200mg/l as $CaCO_3$. More than half of these samples exhibited a WQI of less than 37. Estimated average water quality indices reflect that municipal water comes under the occasionally threatened category and hand pump samples from the proposed smart city limits are categorized as impaired.

Keywords: WQI; Geo-spatial; pH; Turbidity; Fe; Rajasthan

PT 232

Closed-loop reverse osmosis with VUV photolysis for the removal of pharmaceuticals and PFAS from water systems

Domenico Santoro*, Ehsan Nazloo, Andrew Safulko, Erin Mackey

**Western University, 67 Orkney Cres, London Ontario, ON N5X3R7, Canada*
dsantor@uwo.ca

This study addresses the challenge of removing persistent organic contaminants, such as pharmaceuticals and PFAS, which are difficult to degrade with conventional water treatment methods. As freshwater resources become scarcer, water reuse has emerged as a crucial strategy, but persistent pollutants often hinder the success of traditional treatment systems. The research proposes a novel integrated approach combining vacuum ultraviolet (VUV) treatment with reverse osmosis (RO) membrane filtration to enhance contaminant removal.

The system works by using VUV-based advanced oxidation and reduction processes (AOP/ARP) to target larger molecules in the reject water fraction. These molecules are repeatedly exposed to VUV radiation until they are sufficiently fragmented to pass through the membrane with the permeate. This approach improves energy efficiency by recirculating the reject water for repeated exposure to VUV, maximizing degradation while maintaining compact reactor design.

Pilot-scale testing on a pharmaceutical mixture demonstrated that the integrated RO-VUV system produced cleaner permeate water and achieved a 90% recovery rate. The brine quality was comparable to the initial feedwater, reducing the need for post-treatment and lowering costs. Additionally, the system significantly reduced the time required for contaminant degradation, particularly for persistent compounds, and showed improved energy efficiency. The electrical energy per order (EEO) for the RO-VUV system was 3.3 kWh per order, compared to 8.5 kWh per order for the standalone VUV system.

This integrated system provides a scalable and cost-effective solution for removing persistent organic contaminants, offering improved performance in desalination and water reuse. By combining high-pressure membrane filtration with VUV treatment, the approach addresses limitations of conventional systems and presents a promising framework for sustainable water management.

Keywords: Reverse osmosis; Vacuum ultraviolet; Pharmaceuticals; Water reuse; Advanced oxidation processes

PT 233

"Mar Menor"— a combined technical solution proposal based on desal techniques and other water treatment methods

Rafael Buendia Candel*, Domingo Zarzo, Alberto Morales, Elena Campos

**Sacyr Agua, C/ Juan Esplandiú 11, Planta 14, Madrid 28007, Spain
rbuendia@sacyr.com*

Located in the SE of Spain, with its 135 km^2, the coastal lagoon of the Mar Menor is one of the largest coastal lagoons in Europe and the largest in the Iberian Peninsula. It´s basin is separated from the Mediterranean Sea by a narrow sandy cord (La manga) 22 km long, which is turn in crossed by several channels and gullies that determine the hypersaline but purely marine waters. Multiple uses converge on the space, mainly tourist, recreational and fishing, without forgetting the important agricultural use of its surrounding areas. All of them pace the lagoon as a key factor in the regional development plans as well as having an important emblematic significance for the Region of Murcia. Despite the enormous environmental, strategic and economic value, the lagoon has undergone an evident process of transformation and deterioration. Historically, there are numerous aspects that, directly or indirectly, have influenced the environmental problems of the Mar Menor. One of the most evident consequences of all these impacts is the notable deterioration of water quality. Along the last 10 years high nitrate levels, above 1 mg/l were found along the western shore of the lagooncreating a drastic change in eutrophication levels has been experienced and the lagoon is now considered to be in a state that can be called a "severe eutrophic crisis" that has led to "environmental collapse". The aim of this paper is to expose the problem and possible actions to solve it in a satisfactory manner.

Keywords: Seawater; Nitrates; Reverse osmosis; Irrigation; Zero discharge; Water balance

PT 234

Going forward with RO for PFAS removal: experience with TFN RO membranes from lab to pilot and to a full-scale plant

Eugene Rozenbaoum*, Young Ju Lee, Wansuk Choi, Jung Soo Kim, Roy Daly

**LG Chem, 21250 Hawthorne Blvd, Torrance, CA 90503, USA
Tel. +1 626 3531302, eugener@lgchem.com*

Per- and polyfluoroalkyl substances (PFAS) are a group of man-made chemicals that have been manufactured and used in a variety of industries around the world since the 1940s. Sometimes known as "forever chemicals", these substances are very persistent in the environment and human body – they don't break down because of their C-F backbone

and can accumulate over time. There is strong evidence that exposure to PFAS can lead to adverse human health effects including cancer and reproductive and immune system harm.

PFAS is a water treatment challenge since conventional treatment processes currently employed in the drinking water facilities do not effectively remove them. Advanced treatment methods are required for the removal of PFAS. While accepted treatment methods for PFAS include activated carbon (GAC) and ion exchange (IX), they are less effective than reverse osmosis (RO) in the removal of short-chain PFAS and no more effective than RO in the removal of long-chain PFAS. As a result, RO becomes the most effective choice for removal of these constituents.

On April 10, 2024, the U.S. Environmental Protection Agency (EPA) announced the final National Drinking Water Standards for six PFAS species. The new limits require public water systems to monitor PFAS at some of the lowest levels ever regulated. Transition to the full compliance with the new regulations should be completed by April 2029. In Europe, the European Union Drinking Water Directive (DWD), which took effect on 12 January 2021, limits the total amount of PFAS in drinking water to 0.5 ug/L and the amount of 20 individual PFAS to less than 0.1 ug/L each. The DWD requires member states to comply with these limits by 2026.

In this paper, we present results of the benchtop study that evaluates the rejection of PFAS of different carbon chain length by TFN BWRO and NF membranes. Six PFAS species that are currently regulated by EPA, including PFOA, PFOS, PFHxS, PFNA, GenX, and PFBS were tested with three TFN RO membranes under various operating conditions (pressure 70–125 psi (4.8–8.6 bar) and concentration 10–100 ppb). Results were compared with other commercial BWRO membranes tested in parallel at the same conditions and confirmed superior rejection of TFN RO membranes. We further present pilot case studies performed at various locations across the U.S. that demonstrate several scenarios of using TFN RO membranes to treat water sources of various origins including well water, surface water and conventional water treatment plant effluent as a polishing step. Finally, we will summarize the results of the first months of operation of newly installed TFN RO membranes at the Northwest Water Treatment Plant (NWTP) in Brunswick County, North Carolina, the first surface water treatment facility in the country to use RO for post-filtration advanced treatment to remove PFAS.

Keywords: CEC; PFAS; Reverse osmosis; TFN membranes

PT 236

Revolutionizing 3D printing with brine valorization

Mohammed Alsindi*, Noura Chehab, Salman Arab, Nikolay Voutchkov

**Neom, Neom Community 1, Sharma 47311, Saudi Arabia*
Tel. +966 500055308, mohammed.alsindi@neom.com

NEOM, a new development in Saudi Arabia, will rely on desalination to provide potable water to its inhabitants. However, desalination produces brine, which can harm the environment if not properly managed. Discharging brine directly into oceans or other bodies of water can harm marine life and ecosystems, while improper disposal on land can contaminate groundwater. To address these concerns and support NEOM's zero-liquid discharge requirements, this project proposes reusing brine in 3D-printable concrete.

The innovative approach uses NEOM brine as a concrete accelerator, mixed with water to create a printing system involving two pumpable composites: one with Portland cement and the other with brine. The resulting product has compressive strength suitable for use as a construction material and can be used to build structures and art installations. Additionally, this approach provides an environmentally sustainable solution for managing brine while producing a valuable structural material.

3D printable concrete with reused brine has the potential to revolutionize the desalination and construction industries. It can eliminate the use of cement, reduce waste, lower CO_2 emissions, and promote sustainability. Overall, this project offers an innovative solution for managing brine and contributing to a more sustainable future.

Keywords: Seawater; Brine recovery; Concrete 3D printing; Sustainability development goals; Circular economy

PT 237

Magnesium remineralization: Impact on microbial water quality of reverse osmosis produced drinking water during distribution

Nadia Farhat*, Ratna Putri, Alejandra Ibarra Felix, Johannes Vrouwenvelder

**KAUST, Thuwal 23955, Rabigh, Saudi Arabia*
Tel. +966 562604415, nadia.farhat@kaust.edu.sa

Membrane desalination produces soft, corrosive water with a bland taste, requiring post-treatment for safe consumption. In countries like Saudi Arabia, where desalinated water is common, reverse osmosis (RO) tap water is typically remineralized only with calcium. Several recommendations advise for magnesium addition as well. The WHO suggests at least 10 mg/L of magnesium, while Saudi guidelines recommend 5 mg/L. This study assessed the impact of magnesium remineralization on the biological stability and microbial community of RO water through hydrostatic and hydrodynamic experiments.

In the hydrostatic experiments, RO water was supplemented with various magnesium salts at different concentrations and several magnesium-to-calcium ratios to evaluate bacterial growth and biofilm formation. No significant effect was found with magnesium concentrations up to 50 mg/L. Nutrient addition experiments showed that biological stability was limited by assimilable organic carbon, and not impacted by magnesium.

In the hydrodynamic setup (simulative distribution network), magnesium chloride was added to one network to reach 50 mg/L of magnesium, while the control network received no magnesium. Magnesium addition did not significantly alter biological abundance in bulk water or biofilm but resulted in a distinct biofilm community with higher bacterial diversity and a dominant Piscinibacter genus, while Legionella was absent.

These results suggest that magnesium remineralization has no negative impact on microbial abundance and can improve RO water quality by enhancing microbial diversity and possibly reducing potentially harmful bacteria.

Keywords: Desalination; Remineralization

PT 241

Near zero liquid discharge with seeded membrane distillation crystallization

Stefanie Flatscher*, Mark Hlawitschka

Johannes Kepler Universität, Institut für Verfahre, Altenbergerstraße 69, Linz 4040, Austria
Tel. +43 73224689747, stefanie.flatscher@jku.at

Membrane distillation (MD) combined with crystallization offers a sustainable solution for treating saline wastewater while recovering valuable salts and water. Seeded Membrane Distillation Crystallization (MDC) improves conventional methods with seeded crystallization and in situ crystal removal, achieving water recovery rates over 95% and producing high-purity salts with near-zero liquid discharge (ZLD).

Seeded MDC utilizes heterogeneous seed crystals to promote controlled nucleation and prevent scaling on the membrane surface. By incorporating seed crystals and sedimentation within a classifier, the system eliminates the need for a separate crystallizer, reducing costs. Silica seed crystals enhance crystallization efficiency in highly concentrated salt solutions, with key factors including supersaturation, temperature, and seed size influencing the process additionally. Experiments with NaCl solutions exceeding 20wt% achieve salt precipitation within a metastable supersaturation range (S = 1.03±0.02) at moderate temperatures (45–55°C). A temperature increase of 5°C ± 1°C within the chosen operating range resulted in a 15% ± 2% increase in crystal size, suggesting a great potential for temperature control to influence crystal growth. Additionally, silica seed crystals reduced membrane wetting and minimized concentration polarization by decreasing the boundary layer near the membrane surface. The permeate flux increases due to the decrease of the concentration polarization by 41%.

Seeded MDC also proves effective for multi-salt solutions, such as NaCl, $CaCl_2$, and KCl mixtures with a total salinity exceeding 22wt%. High-purity salts (92%) were recovered due to the differing solubility limits of each salt. Continuous sedimentation in the classifier allowed for sequential recovery, achieving water and salt recovery rates exceeding 90%. Additionally, the study highlights the potential for optimizing salt separation based on solubility products by adjusting key parameters like temperature, seed concentration, and crystal growth. These findings pave the way for developing efficient fractional crystallization techniques for diverse salt mixtures utilizing MDC.

Keywords: Membrane distillation crystallisation; (Near) zero liquid discharge; Resource recovery

PT 243

ZIF-8 and A-ZIF-8 for efficient p-Cresol adsorption

Musawira Iftikhar*, Imran Ullah Khan, Mohd Hafiz Dzarfan Othman

**University Technology Malysia (UTM), Unit 625 Cinta Ayu Suites Apartment, Johor Bahru 81300, Malaysia*
iftikharmusawira@gmail.com

To effectively remove p-Cresol from blood, adsorbents with high adsorption efficiency needs to be designed and developed. Due to their unique textual properties, wide surface area, and chemical stability, metal-organic frameworks (MOFs), have attracted attention as promising materials for a variety of applications. However, their potential in adsorption processes, especially for removing uremic toxins like p-cresol, remains underexplored. Zeolitic imidazolate frameworks-8 (ZIF-8) and its amine-functionalized derivative (A-ZIF-8) were synthesized in this study with the aim to evaluate its performance as p-Cresol adsorbents in aqueous solutions. To confirm the structural properties and successful amine modification of A-ZIF-8, various characterization techniques were used, such as Fourier Transform Infrared Spectroscopy (FTIR), X-ray Diffraction (XRD), Field Emission Scanning Electron Microscopy (FESEM), and Brunauer-Emmett-Teller (BET) analysis. The results revealed that A-ZIF-8 exhibited enhanced crystallinity, surface area, and pore volume compared to pristine ZIF-8. Zeta potential measurements showed a shift from -3.47 mV for ZIF-8 to +35 mV for A-ZIF-8, significantly improving its adsorption capacity of the negatively charged p-cresol. Adsorption studies demonstrated that A-ZIF-8 achieved a maximum p-cresol uptake of 432 mg/g, substantially outperforming ZIF-8's 289 mg/g. Thermogravimetric analysis and adsorption-desorption isotherms further indicated enhanced thermal stability and microporosity in A-ZIF-8. These findings underscore the effectiveness of amine modification in boosting the adsorption capabilities of ZIF-8, positioning A-ZIF-8 as a superior candidate for uremic toxin removal in protein adsorption.

Keywords: ZIF-8; p-Cresol adsorption; Dialysis; Biocompatibility; Characterization

PT 244

Evaluation of reverse osmosis membrane performance for the treatment of oil sands process-affected water (OSPW)

Seoyeon Lee*, Sanghlee Lee, Song Lee, Yusik Kim, Hyeongrak Cho, Yongjun Choi

Kookmin University, Seoul 02707, Korea
Tel. +82 10 4907 8375, yeon623@kookmin.ac.kr

The oil sands deposits in northern Alberta, Canada, which is a home to the world's third largest oil reserves, contain approximately 2.5 trillion barrels of recoverable bitumen. The extraction of bitumen from the oil sands in this region generates a significant volume of oil sands process-affected water (OSPW), totaling approximately 10? m^3. The objective of this study is to apply the reverse osmosis (RO) process to effectively treat OSPW, which contains potentially problematic organic and inorganic constituents. In addition, to meet

stringent Canadian discharge regulations and achieve zero liquid discharge, the study evaluated the removal efficiency and fouling behavior of seawater reverse osmosis (SWRO) and high-temperature reverse osmosis (HTRO) membranes.

Synthetic feed waters were prepared for various conditions, including low and high bitumen concentrations, TDS levels, and temperature. Oil removal efficiency, salt rejection, and water flux were analyzed to compare membrane performance. Oil analysis was performed using excitation-emission matrix fluorescence spectroscopy (EEM). The results showed that SWRO had higher water flux, TDS removal, and oil removal efficiency than HTRO under room temperature conditions. However, as the feedwater temperature increased, the removal efficiency and water flux of HTRO improved over those of SWRO. This study aims to provide a feasible strategy for the treatment and reuse of high-temperature OSPW by evaluating various parameters and applying integrated water treatment processes suitable for oil sands regions, such as SWRO with waste heat recovery and HTRO hybrid processes.

Keywords: Oil sands process-affected water (OSPW); Seawater reverse osmosis (SWRO); High-temperature reverse osmosis (HTRO)

PT 245

Functionalized Li^+/H^+ separation membranes for pH sensing

João Teixeira*, Ricardo Campos, Magda Barros, Ana Moreira, Daniela Campanhã, José Gonçalves

Centre for Nanotechnology and Advanced Materials, Vila Nova de Famalicão 4760-034, Portugal
Tel. +351 933835111, jlteixeira@centi.pt

Water quality monitoring through pH sensing is crucial for human health and environmental protection. In desalination processes, pH control guarantees the efficient removal of salts and contaminants while upholding water safety standards. Industries such as batteries and textiles rely on this kind of monitoring to respond promptly and effectively to changes in acidity or alkalinity which directly impact final production. Flexible pH sensors are easy to use and offer quick and accurate data, but they face challenges from temperature fluctuations, pressure variation, and chemical interference. Lithium poses significant issues, as it can interact with the sensitive layer of the sensor, altering its electrochemical properties and potentially competing with hydrogen ions for active sites. This competition hinders selectivity, leading to inaccurate pH readings. Due to the similar hydrated ionic radius for Li^+ and H^+, it can easily infiltrate or modify the chemical structure of the sensitive layer, diminishing performance and stability.

The work proposed by the NGS – New Generation Storage project aims to address a pH sensor in a specific stage of the lithium refining process. The issues related to the performance of pH sensor at higher lithium concentrations will be mitigated by the development of functionalized polymeric separation membranes. These membranes act as a barrier, allowing hydrogen ions to pass through and block or significantly reduce lithium permeation. Different polymers were employed, namely polyvinyl chloride, (PVC) or poly(vinylidene fluoride-trifluoroethylene), (P(VDF-TrFE). To achieve a better separation, different additives were studied (lithium trifluoromethanesulfonateimide, LiOTF, or Crown-4-ether). This work presents a cost-effective, thermal, and chemically stable solution. Electrochemical, structural, and mechanical (diffusion) tests were performed to evaluate the performance of the separation membranes. The results demonstrated the membrane's ability to block lithium ions, revealing interesting potential for future applications. This work was developed within the scope of the project "NGS – New Generation Storage" [C644936001-00000045], financed by PRR – Plano de Recuperação e Resiliência under the Next Generation EU from the European Union.

Keywords: Electrochemistry; Membranes; pH sensing; Water quality

PT 249

Reducing non-revenue water: the first step toward addressing water scarcity and enhancing efficiency

Flávio Oliveira*, Sara Cunha

**Águas e Energia do Porto, Rua Barão de Nova Sintra, 285,
Porto 4300-367, Portugal
Tel. +351 220100220, flavio.oliveira@aguasdoporto.pt*

Águas e Energia do Porto (AEdP) manages the urban water cycle in Porto, the second-largest city in Portugal. Renowned nationally and internationally for reducing water losses and non-revenue water (NRW), AEdP serves nearly 170,000 consumers and impacts 500,000 people daily. The utility operates an 820 km pipeline network and six water tanks with a total capacity of 125,450 cubic meters.

Water efficiency is vital for sustainable resource management, addressing water scarcity, and environmental sustainability. AEdP is at the forefront of NRW reduction initiatives, ensuring responsible and sustainable water use. This technical paper highlights water efficiency's role in sustainability, AEdP's strategies, and the results achieved, focusing on Porto's example.

Water efficiency: a pillar of responsible and sustainable use

Efficient water use is both a technical and environmental imperative. By optimizing networks and minimizing losses, we ensure that every drop counts, aligning with global efforts to combat water scarcity and climate change while preserving resources for future generations. Efficient use balances growing demands with conservation.

Porto and AEdP: a case study in water efficiency excellence

Porto, through AEdP, showcases the transformative impact of water efficiency. By using advanced technologies and data-driven strategies, AEdP achieved significant NRW reductions. Created in 2006, AEdP initially faced NRW levels of about 54%, stemming from inefficient operational management that hindered service quality and fault repairs.

From 2006, AEdP implemented strategic projects to address water losses. Its NRW Management and Reduction Strategic Program aimed to lower NRW to 20% by 2024. Remarkably, NRW was reduced to below 12% by the end of 2024, underscoring AEdP's operational excellence and commitment to sustainability.

Porto's results highlight a significant decrease in water losses, leading to enhanced efficiency and reduced environmental impact. Furthermore, these efforts have strengthened community trust and set a global benchmark. AEdP's success story underscores the importance of aligning technical excellence with a vision of long-term sustainability.

Financial savings generated from water losses reduction were reinvested into advanced technologies, infrastructure upgrades, and customer engagement programs.

Conclusion

Reducing NRW is a crucial first step in combating water scarcity and improving efficiency. AEdP's journey from 54% NRW in 2006 to below 12% in 2024 exemplifies the potential of focused efforts. This progress ensures sustainable resource use and serves as a model for utilities worldwide.

By aligning these efforts with broader sustainability initiatives, we can protect water resources, enhance resilience, and inspire innovation. Porto's example demonstrates the power of dedication, innovation, and strategic planning to address water scarcity and build a sustainable future for generations to come.

Keywords: Non-revenue water; Water efficiency; Resource optimization; Technical and operational excellence

PT 250

Backwash wastewater treatment with advanced ceramic membranes: maximizing water reuse and ZLD solutions

Patrick Buchta*, Julis Gloeckner

**CERAFILTEC, Saarbruecken 66121, Germany*
Tel. +49 1752942961, patrick.buchta@cerafiltec.com

Ceramic membranes are becoming the mainstream technology in the global filtration market, steadily replacing polymeric UF membranes due to their robust performance, sustainability, and ability to handle challenging feed waters. This includes the treatment of backwash wastewater. Advanced ceramic membranes operate reliably with long lifetime independent of chemical cleaning frequency or feed water contaminants like abrasive PAC and without fiber breakages, making it ideal for achieving water reuse and ZLD goals. Additionally, submerged ceramic membrane can concentrate the sludge further than any other membrane system to minimize the requirements for further sludge treatment like filter presses and centrifuges. Their adoption aligns with global sustainability goals, including clean water and sanitation (SDG 6), responsible consumption (SDG 12), and industry innovation and infrastructure (SDG 9).

At a macros level, the industry is migrating toward ceramic membranes, as demonstrated by PUB's investment in large-scale wastewater treatment plants and focus on desalination projects using this technology and Scottish Water's recently commitment of £800 million for ceramic membrane plants over the next years. Leading companies, including several blue-chip firms and hyperscalers, are selecting ceramic membranes for their superior performance and total cost of ownership benefits. CERAFILTEC's projects alone contribute over 1,000,000 m³/d of capacity across applications such as seawater pretreatment, potable water production, and wastewater reuse.

With maximizing water reuse and optimizing ZLD solutions, ceramic membranes are an essential technology to advance these goals. We will highlight the value of treating backwash wastewater to potable standards or as RO feedwater for ZLD. Ceramic membrane enabled solutions reduce sludge volumes, lowers operational costs, and ensures every drop of water is maximized. We will report on the outcomes of a three-year German government-funded FITWAS project, and showcasing successful pilots in North Africa and Europe that demonstrate the scalability and adaptability of ceramic membranes. Additionally, we will present findings from two fixed installations in Europe that enable maximum water reuse for a utility and a private-sector client utilizing ceramic membranes for backwash wastewater treatment to optimize water reuse.

Treating backwash waste is the most cost-effective and sustainable strategy for reducing energy consumption per m^3, managing sludge, and making optimal use of every drop of water. CERAFILTEC's technology advances these goals while providing reliable, energy-efficient solutions for modern water treatment challenges.

Keywords: Ceramic membranes; Filtration; Water reuse; ZLD; Sustainability; Circular economy; Backwash wastewater; Sludge reduction; CERAFILTEC

PT 251

Smart monitoring of contaminants of emerging concern in wastewater treatment

Rui M.C. Viegas*, Catarina Silva, Célia M. Manaia, Gabriela Faria, Cláudio Costa, Maria João Rosa

National Laboratory for Civil Engineering (LNEC), Avenida do Brasil, 101, Lisboa 1700-066, Portugal
Tel. +351 218443841, rviegas@lnec.pt

The current analytical and monitoring systems for detecting trace contaminants of emerging concern (CECs), such as pharmaceutical compounds (PhCs) and antimicrobial resistance (AMR), are expensive and time-consuming, posing challenges for routine application in wastewater treatment plants (WWTPs) and water quality monitoring. These limitations hinder real-time decision-making and operational efficiency. Smart monitoring solutions, such as soft sensors, offer a transformative approach by enabling continuous, cost-effective, near-real-time estimation of contaminant levels through advanced algorithms and data integration. This reduces reliance on labour-intensive laboratory analyses, supporting proactive management and enhancing treatment process efficiency while addressing the growing demand for sustainable water management.

In this context, the EU-funded LIFE Fitting project (lifefitting.lnec.pt/) aims to develop and demonstrate, at full scale in three large WWTPs, an innovative set of tools (PLAN-DO toolbox, TRL 7, ready for professional software production) for strategic planning, monitoring, and intelligent operation of WWTPs. This includes the "MonitorTool," designed to produce simplified protocols for routine use by water utilities to monitor WWTPs for emerging contaminants (e.g., PhCs, AMR) based on online bulk parameters and AMR biomarkers.

Field water quality data from 27 monitoring campaigns conducted at the WWTPs and their receiving waters were used as inputs for MonitorTool. These data included analyses of over 54 PhCs, microbial indicators, AMR biomarkers, and regular (e.g., BOD5, COD, nitrogen, phosphorus, colour) and non-regular (e.g., T254, alkalinity) bulk indicator parameters.

Correlations between CEC concentrations/removals and other water quality parameters are being explored using Projection to Latent Structures regression (PLSR), a versatile multivariate data analysis method increasingly applied in fields such as bioinformatics, machine learning, and chemometrics, including water and wastewater treatment.

Results confirm that water spectroscopic data are key surrogates for CEC concentrations and removals. Specifically, absorbance at 254 nm, an indicator of organic matter aromaticity and C=C bonds characteristic of several PhCs, emerges as the most prominent surrogate. Other key surrogates include nitrogen species and parameters, such as ammonia nitrogen and total nitrogen, related to nitrification/denitrification conditions in WWTPs, as expected. Furthermore, fluorescence spectroscopy through excitation-emission matrices with parallel factor analysis (EEM-PARAFAC) is being explored as a high-resolution proxy for CECs.

The correlations underway constitute a practical and cost-effective way of supporting on a continuous basis the routine monitoring of the WWTP effectiveness towards CECs.

Acknowledgements

This research was funded by the European Union under the LIFE Programme, Grant Agreement 101114188-LIFE22-ENV-PT-LIFE Fitting.

Keywords: Smart monitoring; Contaminants of emerging concern; Projection to latent structures regression

PT 252

Brine concentration – design and operation of two ultra-high-pressure RO plants with over 10 years of operation

Christoph Ruisinger, Ralf Krüger*, Jürgen Müller

OSMO Membrane Systems GmbH, Am Längenbühl 5,
Leonberg 71229, Germany
Tel. +49 151193937, r.krueger@osmo-membrane.de

In many industries, brine concentration plays a vital role in production chains. Alongside established methods such as evaporators and crystallizers, membrane technology—especially ultra-high-pressure reverse osmosis (UHP-RO)—is increasingly being employed. This shift is driven by significant energy savings in the overall process, especially when thin brines are pre-concentrated using UHP-RO before entering thermal evaporators. Additionally, the highly purified permeate stream of membrane processes can often be reused in production.

This presentation highlights key findings from the design and long-term operation of two industrial brine concentration plants, both of which have been in operation for over 10 years

The first plant treats wastewater containing high amounts of sodium nitrate from different sources with varying concentrations. Sodium nitrate is concentrated using a cascade of RO systems operating at different pressure levels, including UHP-RO, before being crystallized. The resulting high-purity sodium sulfate is marketed, while the permeate is reused as process water, creating a completely closed-loop water cycle (Zero Liquid Discharge, ZLD).

The second plant concentrates lithium brine used in battery production. In this facility, two streams with different lithium sulfate concentrations are processed using a sophisticated configuration of RO system, also employing UHP-RO. The concentrate is then fed to spray dryers, and the permeate is once again reused as process water.

The discussion will address critical aspects of plant design and operation, including process development, evaluation of conceptual designs, equipment specification criteria, operational experience, and assessment of energy-saving potential. Key topics will include:

- Brine Assessment: Analysis of key parameters and challenges such as scaling, fouling, and mechanical membrane damage.
- Design Calculations: Process configurations, membrane selection, and the application of advanced design tools.
- Laboratory Testing: Pilot plant testing using OSMO systems and proof-of-concept validation.
- Process Adaptation: Adjustments to process concepts based on test results.
- Equipment Specification and Design: Selection of membranes (compaction), pressure vessels (pressure resistance and corrosion), and pumps.
- Operation and Maintenance: Monitoring strategies, membrane lifespans, and maintenance best practices.
- Operational Data and Energy Savings: Real-world performance data and insights into energy efficiency improvements.

These examples demonstrate that, despite the challenges associated with brine concentration, membrane processes—when designed, selected, and operated with expertise—can significantly enhance energy efficiency, reduce environmental impact, and support sustainable industrial practices.

Keywords: Brine concentration; UHPRO; Ultra-high pressure; ZLD; Lithium; Wastewater; Reuse

PT 253

Regeneration of haemodialysis spent dialysate by mixed matrix membranes of cellulose acetate /silica/metal organic framework (MOF)

Maria Norberta de Pinho*, José Francisco Guerreiro, Miguel Pereira da Silva, Marta Bordonhos, Miguel Minhalma, Moisés Luzia Pinto

Instituto Superior Técnico, Avenida Rovisco Pais,1, Lisbon 1049-001, Portugal
Tel. +351 962472280, marianpinho@tecnico.ulisboa.pt

The development in 1960 of the Loeb-Sourirajan cellulose acetate (CA) asymmetric membranes not only made possible to envisage the technical economic viability of the industrial scale-up of reverse osmosis for sea water desalination but also allowed the establishment of Pressure -Driven Membrane Processes in several industrial sectors and with special relevance in water, food, pharmaceutical, environmental and health areas. In this last area, the haemodialysis requires large volumes of water to clean and reprocess the equipment and membranes as well as to prepare the dialysis fluid (500–600L/week/patient).Despite the tentative of regeneration, in the 1970–1990s, of the large volumes of spent dialysis by the REDY system, which was a sorbent system with several layers, including: activated carbon, this complex system was abandoned due mainly to the difficulty in removing uremic toxins(UT).The present work addresses a new concept of regeneration through Mixed Matrix Membranes (MMM) incorporating MOFs as adsorbents with the ability to capture UTs.

The UiO_2-66(Zr) is synthesized and characterized and a novel approach of its incorporation in CA and hybrid CA/SiO_2 membranes is presented to assess the removal efficiency of the UTs - urea and p-cresyl sulphate (p-CS) from spent dialysis fluid The CA membranes are casted by the phase inversion technique with two different porous structures and the CA/SiO_2 membranes are casted by coupling the phase inversion technique with the sol-gel method in conditions that assure the covalent bounding of the silica to the cellulose acetate matrix. The MOF UiO_2-66(Zr) is dispersed into the casting solutions to yield CA/MOF membranes and CA/SiO_2 /MOF membranes [1]. The membranes are characterized by the hydraulic permeability, Lp, at 25°C. and the molecular weight cut-off, MWCO.

The cellulose acetate and cellulose acetate – silica hybrid membranes incorporating the MOF - UiO_2-66 (Zr) proved to be very efficient in ultrafiltration removal of urea and p-cresil sulfate from a spent dialysis fluid. The potential integration of ultrafiltration with nanofiltration/reverse osmosis envisages the development of a process for the spent dialysis fluid regeneration.

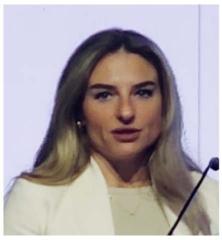
Keywords: Mixed matrix membranes; CA/silica/MOF membranes; UiO_2-66(Zr) dispersion in casting solutions; Uremic toxins removal; Regeneration of spent dialysate in haemodialysis (500–600L/week/patient)

The authors F,Guerreiro,M.P.Silva,M.Bordonhos,M.Minhalma,M.L.Pinto,M.N.de Pinho acknowledge FCT support through UIDB/04540/2020(CeFEMA&LaPMET) and UIDB/04028/2020(CERENA)

[1] Guerreiro, J.F. et al., Desalination 2023,565,116860

PT 254

Advancing industrial brine concentration: pilot demonstration and evaluation of a novel high pressure process with energy recovery



Christine Kleffner*, Yuliya Schiesser, Jochen Henkel, Eric Kadaj, Angel Abajas, Gerd Braun

TH Köln, Betzdorfer Str. 2, Cologne 50679, Germany
Tel. +49 1638771857, christine.kleffner@mail.de

The urgent need to minimize industrial wastewater emissions into surface waters necessitates the optimization and advancement of energy-efficient processes for the concentration of high-osmotic-pressure solutions. This study introduces a novel brine concentration process that synergistically combines ultra-high pressure reverse osmosis (UHPRO) with ultra-high pressure low-salt rejection reverse osmosis (UHP-LSRRO), leveraging state-of-the-art membrane technologies and energy recovery systems.

Key findings include performance data from 4-inch spiral-wound membrane element prototypes, which demonstrated operational robustness under pressures up to 120 bar. The membranes achieved sodium chloride concentrations near saturation in the brine and produced permeates with concentrations as well as volumes that allow for an overall efficient process operation, confirming the feasibility of the application.

The integration of an advanced energy recovery device (ERD) into the pilot system was pivotal, achieving energy savings of up to 60%, depending on the process configuration. This significantly enhances the economic viability of high-pressure membrane processes by reducing operational energy costs.

Despite some performance losses due to irreversible membrane deformation, the combined use of UHPRO and UHP-LSRRO, supported by energy recovery technologies, represents a critical step towards large-scale industrial brine management. This approach aligns with goals of resource recovery, water reuse, and minimal liquid discharge (MLD) implementation.

Future research should address practical challenges, such as fouling and scaling from contaminants in real brine streams, to further optimize operational efficiency. Additionally, advances in ultra-high pressure membrane products and widespread adoption of the technology are expected to lower capital costs and improve performance compared to current industrial standards.

Overall, this study underscores the transformative potential of integrating advanced membrane processes with innovative energy recovery systems to achieve sustainable and efficient brine concentration solutions.

Keywords: Brine concentration; Ultra-high pressure processes; Energy recovery; Industrial brine concentration

PT 255

Innovative monitoring solutions for reverse osmosis plants by Pyxis Lab®

Diana Cruz*, Dario Alonso

Pyxis Europe SL, Castelldefels 08860, Spain
Tel. +34 603478222, diana.cruz@pyxis-lab.com

Pyxis Lab® is a North American engineering company specializing in advanced sensor technology for the water treatment industry. As a leader in fluorescence-based monitoring solutions, Pyxis Lab® provides innovative tools to optimize chemical dosing and membrane protection in reverse osmosis (RO) plants.

One of Pyxis Lab®'s key innovations is the use of PTSA (1,3,6,8-pyrenetetrasulfonic acid) as a fluorescence tracer for real-time monitoring of antiscalant dosing in RO systems. The ST-500RO in-line fluorometer and the SP-350RO portable fluorometer measure PTSA concentrations with high accuracy, allowing for continuous optimization of antiscalant feed rates. These sensors integrate contaminant compensation algorithms to correct for color and turbidity interference and communicate directly with control systems via 4–20 mA and RS-485 Modbus RTU outputs. This technology enables service companies to comply with bid specifications requiring in-line antiscalant monitoring, enhancing operational efficiency and cost-effectiveness.

Additionally, Pyxis Lab® has introduced a breakthrough solution for real-time monitoring of free chlorine and sodium bisulfite in membrane dechlorination processes. The ST-765SS-DCL sensor provides direct measurement of free chlorine (0.00–5.00 ppm) and bisulfite (0.0–100 ppm), eliminating the need to rely on oxidation-reduction potential (ORP) as an indirect indicator. This ensures complete chlorine removal while preventing bisulfite overdosing, a crucial factor in extending membrane lifespan and reducing chemical waste. The sensor features a gold electrode design without membranes, automated self-cleaning, and compatibility with seawater applications (CPVC construction).

For plug-and-play integration, Pyxis Lab® offers the IK-765P-DCL panel, which combines free chlorine and bisulfite monitoring with pH and temperature measurement, a local display, and data logging capabilities. With a replaceable sensor head lasting up to two years, this system minimizes maintenance and eliminates the need for traditional reagents or electrolyte solutions.

By combining cost-effective fluorescence monitoring with highly accurate chlorine and bisulfite detection, Pyxis Lab® is revolutionizing chemical control strategies in RO plants. These cutting-edge technologies empower industries to achieve superior water treatment efficiency, reduced membrane replacements, lower downtime, and enhanced cost savings.

Keywords: Monitoring; Reverse osmosis; Chemicals; Florescence; Chlorine; Optimization

PT 256

Innovative marine work on the first desalination plant in Portugal

Ana Fernandez, Jose Maria Colubi*

GS Inima, Madrid 28023, Spain
Tel. +34 675061236, josemaria.colubi@inima.com

In recent years, the Algarve region has suffered a prolonged drought associated with a situation of water scarcity that is now considered structural. Thus, despite the fact that water availability in Portugal is higher than the European average, water supply in Portugal, in particular in the Algarve region, is under stress, and the problem is expected to increase with climate change. For these reasons, the Regional Water Efficiency Plan for the Algarve Region, developed in 2020 by the APA and the Directorate General for Agriculture and Rural Development (DGADR), identified as a possible structural measure to reinforce water production capacity, the creation of a desalination system in the Algarve region, with the objective of ensuring an alternative and reliable source for the supply of drinking water to the Algarve region. The desalination system to be implemented in phase 1 (year 0) will produce 500 L/s = 1800 m^3/h = 43 200 m^3/d = 16 hm^3/y of drinking water. The system will be ready to be expanded in the future (Phase 2 - Horizon Year) by installing the necessary equipment in EE1 and EDAM, which will produce 750 L/s = 2700 m^3/h = 64 800 m^3/d = 24 hm^3/y of drinking water.

The dimensioning of the EDAM takes into account that, in Phase 1, the flow rate of drinking water production can vary between the nominal flow rate of Year 0 and a minimum flow rate of 25% of this value. It is also taken into account that, after expansion, the variation of the treated water flow rate will be between 25% of the Year 0 flow rate and the nominal flow rate of the year HP.

Difficulties encountered and environmental requirements:

- Profile with cliff on the discharge route
- Maintain minimum cover to avoid impact on the cliffs
- Avoid visual impact
- Avoid environmental impact on the coastline
- Marine resources
- Intake and discharge pipes must be made of HDPE material.

It should be stressed that this project therefore forms part of an investment which provides a significant response to the shortages affecting the Algarve region, which are likely to worsen in the face of the effects of climate change, and which are essential for the continuity and development of economic activity and its diversification in the Algarve and for the well-being of the local population.

Tourist activities predominate in the study area, in particular the presence of a large number of tourist accommodation establishments, beach resorts and their car parks and the Açoteias runway, as well as the Pinhal do Concelho sewage treatment plant, in addition to part of the beaches of Falésia and Rocha Baixinha, where it is envisaged that the circuits will enter the sea.

The evolution of the landscape will not be affected by the presence of the construction of the maritime works and is expected to evolve, as it has done so far, in response to the tourist and agricultural values that predominate in the region.

Keywords: Desalination; Innovations; Pionnering; Sustainable; Microtunneling; Reverse osmosis

PT 257

Development of PVDF distillation membranes for brine treatment using triethyl phosphate as green solvent

Matilde Traverso, Marcello Pagliero*, Camilla Costa, Ilaria Rizzardi, Antonio Comite

Università degli Studi di Genova, via Dodecaneso 31, Genova 16146, Italy
Tel. +39 0103358731, marcello.pagliero@unige.it

Membrane distillation (MD) has a great potential to become one of the best technologies for treating concentrated brines thanks to the relatively small influence of salt concentration on the distillation flux. Developing sustainable membranes that grant large distillation flux is still one of the key aspects needed to unlock the upscaling of MD at an industrial level.

PVDF (polyvinylidene fluoride) is a common polymer used to prepare membranes thanks to its great thermal and chemical resistance. Moreover, PVDF can be easily dissolved in many organic solvents. Therefore, membrane preparation can be carried out using several techniques such as electrospinning, sintering, and phase inversion.

Non-solvent induced phase separation (NIPS) is one of the main technique commonly used for porous membrane separation. However, non sustainable solvents and pore forming agents are commonly used

In this work, porous hydrophobic PVDF membranes were prepared via NIPS, using triethylphosphate as a green solvent. The effect of the main preparation parameters on the membrane characteristics were investigated.

Using a weak non-solvent it was possible to delay the PVDF precipitation, avoiding the formation of a dense skin layer and increasing the surface porosity and pore size. Moreover, this process increased the surface roughness enhancing the water contact angle up to 145°.

The dope solution concentration had a great impact on the pore size of the membranes that decreased from almost 0.8 µm to 0.1 µm as the PVDF concentration was increased from 14wt% to 18wt%. In the meanwhile, the pore size distribution curve was also narrowed and the liquid entry pressure increased dramatically. This effect is related to the reduction of defects in the membrane structure.

The membranes were then tested in a vacuum membrane distillation setup reaching a distillation flux up to 22.5 L/m²h treating a 90 g/L NaCl brine at 60°C.

The membranes showed a constant flux throughout the tests and complete salt rejection.

Keywords: PVDF; NIPS; Green solvent; Brine treatment

PT 258

Multi-stage optimisation of electrodialysis with bipolar membranes for chemicals production

Giovanni Virruso*, Andrea Culcasi, Alessandro Tamburini, Andrea Cipollina, Giorgio Domenico Maria Micale

Università di Palermo, Viale delle Scienze Ed. 6, Palermo 90128, Italy
giovanni.virruso01@unipa.it

ElectroDialysis with Bipolar Membranes (EDBM) is an electrically driven membrane process, which uses a brine and some water to produce acid and alkaline solutions. Specifically, this process uses monopolar ion exchange membranes, i.e., cationic and anionic membranes, along with bipolar membranes. When an electric field is applied to the membranes, the selective movement of ions is accomplished and water dissociation, into protons and hydroxide ions, is promoted inside the bipolar membranes. The production of acid and base solutions is achieved in different compartments and the desalination of the salt stream is carried out in the salt compartments. Previous studies have shown that starting from sodium chloride brines and producing sodium hydroxide with concentrations between 0.5 and 1 mol l^{-1}, lead to a levelized cost of sodium hydroxide (LCoNaOH), for a standard single-stage EDBM unit, in the range of 280–370 € ton^{-1} [1]. This cost results lower compared to the current market price of sodium hydroxide, about 700 € ton^{-1} [2]. The LCoNaOH could be further reduced through the development of optimised multi-stage approaches, as well as the chemicals concentration reached by EDBM can be further increased.

The aim of the present work is to study and optimise multi-stage EDBM systems as a way to further reduce the LCoNaOH and increase EDBM's attractiveness for chemicals production. Specifically, stacks with equal features were connected in serial arrangement and operated at different operative conditions to improve the current utilisation. A fully validated model with distributed parameters and a multi-scale structure was employed to simulate the multi-stage EDBM system, employing the continuous feed and bleed process configuration. The model is capable of predicting also non-ideal phenomena, such as concentration polarization, undesired fluxes (i.e., osmotic, diffusive and electroosmotic) and current leakages via manifolds. A total number of stacks between 2 and 10 in the multi-stage EDBM system were simulated to produce target concentrations of 0.5, 1 and 1.5 mol l^{-1}. The operative conditions of each stack were optimized by acting on the current density. In this way, each stack operates properly for the specific concentration variation, maximising its performance and leading to an overall reduction in the production cost.

Results revealed that the multi-stage EDBM system can reduce the LCoNaOH by 10–30%. For the target concentration of 0.5 mol l^{-1}, the best number of stages was three, while five and seven stages were obtained for the 1 and 1.5 mol l^{-1} targets, respectively.

This analysis proved that the adoption of multi-stage EDBM systems can significantly reduce the production cost, guiding the selection of the most appropriate number of stages depending on the desired chemical concentration.

Keywords: EDBM; BMED; Ion-exchange membrane; Model; Process intensification.

Acknowledgments

This project has received funding from the European Union's LIFE 2021-2027 programme under Grant Agreement 1

PT 259

Exploring the circularity of brine valorisation through neural network modelling of an electrodialysis with bipolar membranes pilo

Giovanni Virruso*, Andrea Cipollina, Alessandro Tamburini,
Giorgio Domenico Maria Micale

Università di Palermo, Viale delle Scienze Ed. 6, Palermo 90128, Italy
giovanni.virruso01@unipa.it

Electrodialysis with bipolar membranes (EDBM) is an innovative electro-membrane-based technology, capable of simultaneously producing acid and base streams. The versatility of the produced chemicals in a wide application field and the modular nature of the EDBM technology have recently increased the attention toward this process.

EDBM can be employed for in situ production of chemicals, reducing transportation, handling and storage costs and burdens, but also integrated with other technologies into circular approaches for the valorisation of residual brines, recovering high-value materials, such as magnesium, lithium, calcium and chromium, and minimising discharged volumes. Innovative schemes, which foresee feeding the chemicals compartment with a brine instead of water, can be adopted in those cases in which an acidified brine and/or an alkaline brine can be reused. In this way, the brine treatment capacity of the process is increased and, at the same time, the water consumption is reduced.

The aim of the present work is to model EDBM's behaviour when these innovative saline feed schemes are employed and to characterise them in a wide range of operating conditions. Due to the challenge of describing the process with a conventional mechanistic approach, caused by non-ideal behaviour of membranes and ion interactions in multi-ionic systems, a data-driven model based on neural networks was developed.

A set of data obtained from a semi-industrial scale EDBM unit was utilised to train and validate the neural network. A feedforward network with six inputs (i.e., flowrates, current density and salt presence) and three outputs (i.e., voltage and acid and base concentration) was adopted.

Results demonstrated that feeding one chemical compartment at a time leads to similar results in terms of base performance indicators, while feeding both chemical compartments leads to a reduction in performance. The network is capable of describing the different behaviours due to the salt presence in the compartments, enabling to simulate a larger range of operating conditions in terms of current densities and solution flowrates. The model was utilised to conduct an economic analysis which proved that, in addition to environmental benefits, there could also be an economic improvement in selecting these innovative schemes, due to the reduction in water consumption.

Keywords: EDBM; BMED; ANN; Model; Process configuration

Acknowledgments

This project has received funding from the European Union's LIFE 2021-2027 programme under Grant Agreement 101147407-LIFE23-ENV-IT-MAREMAG LIFE

PT 260

Online analysis of brines for valorization using a solution cathode glow discharge analyzer

Christopher East*, Connor Fogal, Anders Palmgren, Anthea Sargeaunt, Nikolay Voutchkov

**ENOWA – NEOM, 206C2 Neom 49643, Saudi Arabia*
Tel. +966 534538181, christopher.east@neom.com

Desalination brine valorization is a field currently generating a lot of interest in the desalination industry and amongst other potential downstream industries, like the chloralkali and magnesium production industries. While the operation of a brine valorization plant will not be as sensitive to impurities as the other downstream industries, process control will be a key factor in reducing operational expenditure of industrial scale plants. For process control to be effective online analyzers need to feed data back to the control room. As process stream compositions increase in complexity or concentration the ability to analyze some parameters becomes increasingly difficult. In the case of metal ions in solution, the lower the concentration of the analyte the more difficult accurate analysis becomes. Furthermore, online analytical systems are not available currently for many metal ions in solution or concentrations are too low, forcing plants to rely on laboratory data or inferences from other parameters for process control rather than control the process directly. For metal ions, the gold standard for laboratory analysis is Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) or Mass Spectroscopy (ICP-MS) providing with detection limits into the micrograms or nanograms for most elements or even picograms per liter in some cases. Integrating ICP-OES or ICP-MS as an online analyzer could be technically possible but the operational complexities of gas supplies and cooling remain as prohibitive barriers to implementation.

Solution Cathode Glow Discharge (SCGD) analyzers utilize an atmospheric plasma for the excitation of atoms analyzable by an optical emission spectrometer, similar to ICP-OES. Because the SCGD plasma is generated between the solution, acting as a cathode, and an anode above situated above the plasma the solution is also drawn into the plasma at the same time. Both phenomena eliminate the need for argon or nitrogen gas to run the system but because the plasma is atmospheric spectral interferences generated by the elements in the air at some wavelengths occur. Nevertheless, significant interference free spectral range remains for the analysis of metal ions in solution with similar or better detection limits to the ICP-OES for most elements. With modern automation and autodilution a system can be left for up to a month before more dilution water and calibration standards are required.

In this paper we compare SCGD analyzer results from a prototype system with laboratory based ICP-OES results for the same streams, collected from the NEOM ENOWA Brine Mining Demonstration Plant in Duba, Saudi Arabia.

Keywords: Online monitoring; Brine mining; Solution cathode glow discharge

PT 262

Utilizing desalination brine to simultaneously produce high-purity magnesium carbonate and vaterite-type calcium carbonate

Abdallatif Abdalrhman*, Seungwon Ihm, Eslam Alwaznani, Mohammad Talibi, Myoung-Jin Kim

**Saline Water Conversion Corporation (SWCC), Saudi Arabia*
Tel. +966 562092936, AAbdalrhman@swcc.gov.sa

The rapid growth in global population has necessitated the identification of novel and sustainable raw material sources. Although resource utilization is essential to the economy, over 99% of the most widely used resources are unsustainable; moreover, resource consumption and environmental impacts are increasing at an alarming rate across industries. Therefore, circular economy strategies such as reusing industrial wastewater should be adopted, as they can effectively conserve energy and materials while reducing the dependence on natural resources.

Seawater is a precious natural resource increasingly utilized in various industrial and scientific settings. Reject brine, a byproduct of desalination is a valuable source of minerals and a complex mixture of highly concentrated electrolytes such as Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, Li+, Cl^{-}, SO_4^{2-}, and Br^{-}.

Desalination brine is a valuable resource that is widely utilized in various industrial and scientific fields. Many of the previous studies on the utilization of brine have focused on either recovering Mg from brine using alkalis or extracting Ca from industrial by-products using desalination brine as a solvent. Our current study presents a sustainable and cost-effective approach for resource recovery by facilitating the simultaneous production of $MgCO_3$ and vaterite-type $CaCO_3$ from desalination brine using industrial by-products (Alkali waste dust from the cement industry) and Captured CO_2.

In our study, desalination brine will be used as a source for Mg recovery and as a solvent for Ca extraction from industrial by-products (Cement Kiln Dust). This industrial by-product (CKD) will act as an alkali to precipitate Mg, as well as a source of Ca. An integrated $MgCO_3$ and $CaCO_3$ production scheme based on the utilization of desalination brine, an industrial by-product from the cement industry, and captured CO_2 was developed and tested. This study aims to use the desalination brine and the Cement Kiln Dust (CKD) to recover $MgCO_3$ with high yield and purity simultaneously and produce high-purity vaterite-type CaCO3. To achieve this, the effects of the ionic strength of the different components in the brine on the Mg recovery and vaterite-type $CaCO_3$ formation efficiency were investigated. A pilot system has been designed and will be evaluated in terms of the recovery efficiency and purity of the powders produced.

Keywords: Brine valorization and mining; CO_2 capturing and utilization; Circular economy

PT 263

Machine learning frameworks for intelligent decision-making and enhanced desalination efficiency

Najat A. Amin*, Adnan Qamar, Henry Tanudjaja, Ratul Das, Thomas Altmann, Noreddine Ghaffour

King Abdullah University of Science and Technology, Thuwal 23955-69, Saudi Arabia
Tel. +966 534534449, najat.amin@kaust.edu.sa

Integrating data-driven and machine learning (ML) approaches into reverse osmosis (RO) desalination processes offers significant potential for optimizing plant efficiency and enhancing operational control. RO membrane systems are widely used for water purification and desalination. However, membrane biofouling is a significant challenge in RO systems, leading to increased pressure drops, elevated operational costs, and greater energy consumption. Additionally, biofouling requires more frequent chemical cleanings, resulting in shortening the membrane lifespan. Therefore, developing advanced strategies for monitoring and early detection of biofilm formation on membrane systems is critically required.

Herein, a Deep Neural Network (DNN) was utilized to measure biofilm thickness and correlate it with feed water quality and operational parameters to develop an AI framework for real-time performance evaluation and early decision-making in membrane filtration systems. The database of biofilm images generated from an in-situ Optical Coherence Tomography (OCT) scan of growing biofouling on RO filtration cells was used to train a Convolutional Neural Network (CNN) to predict the thickness of biofilm in RO systems instantly. In addition, Non-Linear Regression-Deep Neural Network (NLR-DNN) was trained to accurately predict the non-linear relationship between various parameters and growing biofouling inside the filtration channel. This dual-model approach not only provides accurate real-time data but also predicts potential issues before they escalate.

The findings demonstrated that, with proper training, the proposed machine learning model can effectively evaluate how variations in input parameters over time influence the performance of RO membranes through a large-scale, data-driven approach. This developed framework will be migrated to pilot facilities and ultimately to desalination plants for better decision-making and preventive controls that would reduce the water production cost in an artificial governance environment.

Keywords: Machine learning; Desalination; Artificial intelligence; Membrane (bio)fouling; Early detection

PT 264

Membrane distillation-proton exchange membrane electrolysis integrated system for hydrogen production

Aamer Ali*, Wenyu Zhao, Vincenzo Liso, Cejna Anna Quist-Jensen

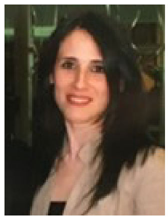
Aalborg University, Pontoppidanstræde 111, Aalborg 9220, Denmark
aal@energy.aau.dk

To achieve the EU's future hydrogen production goals, a substantial supply of ultrapure water will be required. At present, ultra-pure water, typically sourced from municipal drinking supplies, is utilized by proton exchange membrane (PEM) electrolysis for hydrogen production. However, to sustainably and harmoniously meet the future demand for ultrapure water in hydrogen production, it is essential to explore alternative water sources. In this study, we evaluated the technical feasibility of direct contact membrane distillation (DCMD) for treatment of water from various sources, including synthetic and real water samples from river, lake, groundwater, seawater, tap water as well as industrial wastewater for hydrogen production through PEM electrolyzer. The permeate quality measured in terms of its conductivity, pH, total organic carbon, and ionic concentration and the average flux of the permeate were monitored as the performance parameters. Potential of using heat released by the electrolyser for water treatment was also analysed. It was observed that the conductivity of the permeate from synthetic water samples did not exceed 1.34 μS/cm, while that from real water samples varied between 0.98 and 3.19 μS/cm. A systematic investigation about the cause of conductivity of the permeate indicated that some components of the setup were contributing to the increased in conductivity. It was concluded that in addition to a dedicated and well-clean system, a post-treatment of the permeate might be necessary to meet the water quality requirements for hydrogen production through PEM electrolyser. Integrated MD-PEM electrolyser system was also modelled to determine the optimal working conditions for the integrated system. It was concluded that MD offers a simple, technically viable and energetically attractive solution for treatment of water from various natural sources.

Keywords: Membrane distillation; Ultra pure water; PEM electrolyser; Process integration

PT 265

Identification and quantification of contaminants of emerging concern and microplastics in different aquatic compartments



Maria Augusta Dionísio de Sousa*,
Romeu Ventura Martinho de Avó, Maria Adelaide Ferreira da Silva Rocha

**Águas e Energia do Porto, E.M., Rua Barão de Nova Sintra, 285, Porto, 4300-367, Portugal*
augusta.sousa@aguasdoporto.pt

Nowadays, water stress is high, mainly due to increased consumption and poor water management, and further exacerbated by climate changes. From a consumption perspective, there is the need to decrease the waste of water and adapt the uses given to this resource. On the other hand, it is mandatory to pursue a more circular and resilient economy, by identifying and mitigating the sources of contamination, reusing and recycling wastewaters, and using desalination in appropriate contexts.

Micropollutants, such as pharmaceutical compounds and other contaminants of emerging concern (CECs), as well as microplastics (MPs), are recognized and characterized due to their presence in trace amounts, among different environmental compartments and living organisms. To date, it is mostly consensual amongst scientists that wastewater treatment plants (WWTPs) are the main sources of micropollutants in water bodies.

The marine environment can receive inputs of these hazardous substances through riverine sources, direct discharges, as well as atmospheric deposition. Therefore, a large number of micropollutants can be present in these ecosystems, which may cause severe adverse effects to the organisms living there, not to mention the impact on human health.

To characterize different aquatic compartments in terms of micropollutants' content, a list of 12 CECs and 12 MPs was established, and two independent analytical methods were developed, optimized, and validated.

In the case of CECs, target compounds included: amisulprid, carbamazepine, citalopram, clarithromycin, diclofenac, hydrochlorothiazide, metoprolol, venlafaxine, benzotriazole, candesartan, irbesartan, and the mixture of 4-methylbenzotriazole and 6-methylbenzotriazole. Freshwater, marine water, and wastewater samples were analyzed by solid-phase extraction followed by ultra high-performance liquid chromatography coupled to tandem mass spectrometry (SPE-UHPLC-MS/MS).

Regarding MPs, a new method was developed for the determination of: polyethylene, polypropylene, polystyrene, polyvinyl chloride, polycarbonate, poly(methyl methacrylate), polyethylene terephthalate, polyurethane, acrylonitrile-butadiene-styrene resin, styrene-butadiene rubber, nylon 6, and nylon 66. Samples were analyzed for these synthetic polymers by pyrolysis-gas chromatography/mass spectrometry (Py-GC/MS), which provides both qualitative and quantitative data on microplastic mixtures. The method was further automated with the use of F-Search MPs software.

Altogether, the data and results obtained from this study may support the choice of more adequate treatment processes, and eventually propel the development of new ones, to break or slow down the cycle of CECs and MPs in the aquatic environment.

Keywords: Contaminants of emerging concern; Microplastics; LC-MS/MS; (Py)-GC/MS

PT 266

Engineered carbonates for enhanced remineralization processes

Vega Bierwolf*, Heidrun Vedder, Victor Wasmuth,
Assiyeh Tabatabai, Christopher Pust

Lhoist, Wulfrath 42489, Germany, Tel. +49 2058 17 3941, vega.bierwolf@lhoist.com

Remineralization is crucial for restoring essential minerals in desalinated water, ensuring its quality and safety for both human consumption and industrial use. Desalinated water, while free from salinity and contaminants, lacks vital minerals such as calcium and magnesium and buffer capacity, essential for human health and asset protection in municipal and industrial processes. Current methods for remineralization include lime and CO_2 injection or limestone bed filtration. The primary challenge in limestone-based remineralization is the slow dissolution rate of carbonates, requiring long contact times and large footprints to meet desired remineralization levels. This increases operational costs and limits the application of carbonate-based remineralization to large-scale desalination facilities where space availability is not a concern.

A simple approach to improving the dissolution kinetics of calcium carbonate is to decrease the particle size to the lower micron range. However, studies have shown that the available mass-to-volume ratio of calcium carbonate in a limestone filter is much higher than that of fine calcium carbonate particles in a dosed slurry, thereby diminishing the expected gain from lower particle size. Moreover, dosing a slurry of fine carbonates adds to the cost and complexity of the remineralization process.

To address these challenges, our work focuses on developing innovative carbonate products engineered for fast dissolution and easy implementation in existing limestone bed filtration equipment. The innovative media is produced by granulating highly reactive carbonates (Ca and Mg-based) to create ultra-porous engineered carbonates with a spherical form. The granules are designed for the neutralization of water to achieve the calco-carbonic equilibrium through pH adjustment. Their high reactivity allows for increased performance in units previously filled with dense carbonate without requiring expansion. The granular shape provides advantages in terms of pneumatic conveying and silo feeding.

Our research demonstrates that the innovative product design significantly enhances the dissolution speed of carbonates. The increased surface area and high reactivity of these products allow for more efficient remineralization, reducing the required contact times by up to three times compared to dense carbonates. This improvement is particularly relevant for desalination plants with space constraints, as it enables the use of smaller treatment facilities without compromising performance.

Keywords: Remineralization; Calcium carbonate; Dissolution kinetics; Corrosion

PT 267

Novel technology for lithium extraction from seawater using carbon-based nanoporous membranes

Sergio Sanchez*, Miguel Duarte, Adélio Mendes

**LEPABE, Porto University, Porto 4200-041, Portugal*
sergion.buitrago@gmail.com

The accelerating production of electric vehicles, coupled with the strategic shift away from combustion engines, has led to an increase in demand for lithium, a critical component in battery production. Seawater has been identified as the source with the highest concentrations of lithium, ranging from 0.17 mg L^{-1} on the surface and 11.7 mg L^{-1} in deep sea water. However, conventional extraction techniques are encumbered by significant drawbacks, including high operational costs and extended extraction times. Consequently, there is an imperative to explore novel desalination technologies for lithium extraction, including adsorption, membrane, and electrochemical processes. However, these novel technologies continue to grapple with challenges, including the high cost of adsorbents, their limited selectivity for lithium, and substantial investment requirements. To address these challenges, this study proposes a novel electrochemical cell design, featuring two graphite current collectors and a porous carbon-based membrane derived from cellulose as lithium selective membrane. The potential difference results in the accumulation of Li^+ ions on the catholyte, attributable to the disparity in the hydrated ionic radius between Li^+ and other cations. The efficacy of this technique was assessed using ICP (inductively coupled plasma) spectroscopy. The simplicity of this design compared to previously reported electrochemical reactors is a promising prospect, allowing its scalability for large-scale applications.

Keywords: Lithium; Desalination; Seawater; Carbon membranes

PT 268

Membrane distillation for the treatment of industrial wastewaters

Aamer Ali*, Hussein Fairousha Sulaiman, Cejna Anna Quist-Jensen

Aalborg University, Pontoppidanstræde 111, Aalborg 9220, Denmark
aal@energy.aau.dk

Water scarcity, coupled with stringent environmental regulations, has significantly enhances the focus on industrial water treatment. Effective treatment solutions support the EU's circular economy and sustainability goals by enabling water reuse and reducing industrial environmental footprints. This study, conducted as part of the European projects Melodizer and CORNERSTONE, investigates the application of direct contact membrane distillation (MD) for treating wastewater from the brewery and steel industries. Steel industry wastewater was treated using a polypropylene (PP) hollow fiber membrane (0.2 µm pore size, 73% porosity), while brewery wastewater was treated with a polyvinylidene difluoride

(PVDF) flat sheet membrane (0.2 μm pore size, 70% porosity). Feed inlet temperatures ranged from 40°C to 65°C, with other operating conditions held constant. Performance metrics included permeate flux and conductivity, with permeate weight converted to flux measurements. A hollow fiber module was also modelled to analyze the impact of module size on flux and specific thermal energy consumption (STEC).

Key experimental results for brewery and steel wastewater treatment showed that MD exhibited stable flux throughout the testing period, indicating no significant membrane fouling or wetting. Higher feed inlet temperatures increased flux due to a greater driving force, as MD is a thermally driven process. Permeate conductivity ranged from 1 to 5 μS/cm, with conductivity-based rejection consistently reaching 99.9%. The modelling results revealed that the appropriate packing density of the hollow fiber membrane modules holds the key for heat recovery from MD permeate. It was noted that only the module with higher (>35%) packing density offer substantial heat recovery from the permeate of direct contact MD.

Keywords: Membrane distillation; Industrial wastewater; Brewery; Steel industry; Packing density

PT 269

Trends in RO/NF membrane biofouling control

Markus Busch

LANXESS Deutschland GmbH, Kennedyplatz 1, Koeln 50569, Germany
Tel. +49-162-4633709, markus.busch@lanxess.com

Reverse osmosis (RO) and nanofiltration (NF) membranes are of essential importance for resilient water supply, since they allow the use of marginal water sources such as river, sea and waste water. However, biofouling is considered the Achilles heel of RO/NF membrane processes. The microbial control challenge arises from the incompatibility of RO/NF membranes with all oxidizing biocides. Yet, if biofouling is not properly controlled, this results in increased energy consumption, productivity losses, increased cleaning frequency, and also induces membrane damage; effective microbial control is therefore vitally important. The key need is to control biofouling during operation; in addition, membranes must also be properly preserved during storage and shut-downs.

Beyond intense pre-treatment, one of the most efficient methods to control the biofilm on membranes relies on non-oxidizing biocidal products relying on the active substances such as Dibromo-nitrilopropionamide (DBNPA), the 3:1 mixture of chloro-methylisothiazolinone and -methylisothiazolinone (CMIT/MIT), as well as glutaraldehyde (GA). Dosing protocols are very flexible, based on the high efficiency and versality of these non-oxidizing biocides, and may include “online” and “offline” configurations.

In this publication, typical “online” and “offline” operation and dosage protocols are described, including innovative approaches for more efficient “clean-in-place” (CIP) protocols. The above mentioned non-oxidizing biocides differentiate technically by active substance, mode of action, dosage protocol and membrane compatibility. This results in tailored recommendations for different application needs.

There is also a need for extended membrane preservation, which applies to new membranes as well as to membranes in systems that are shut-down for extended periods, i.e. many months and sometimes even years, when consumption underlies strong variations or during times when lower cost water resources are available. The need for this long-term membrane preservation application is different and results in different biocide and dosage recommendations.

Biocides are strictly regulated by the European Union's Biocidal Products Regulation (BPR) and the relevant approvals need to be obtained and sustained. In addition, specific industry approvals are required. Therefore, the complex and demanding regulatory framework is also explained and current status and regulatory trends are illustrated in this publication. The investment in regulatory support is significant, in order to enable broad, effective and sustainable microbial control solutions for membranes. Through the unique regulatory support and broad solutions offering, the crucial need for water resource resiliency is enabled.

Keywords: Biofouling; Microbial control; Biocide; Regulation; BPR

PT 270

Natural adsorbents for sustainable recovery of key components from mining wastewater and seawater: preliminary experimental result

Lourdes García-Rodríguez*, Hugo Sánchez-Moreno, Celso Recalde-Moreno

**Universidad de Sevilla, ETSI, Camino de Los Descubrimientos, s/n, Seville 41092, Spain*
Tel. +34 626986292, mgarcia17@us.es

The recovery of valuable components existing in water reservoirs and wastewater represents a non-conventional strategy to obtain valuable raw materials. Besides, water reuse from industrial wastewater requires the removal of specific components. With the main aim to develop sustainable processes, the use of renewable energies, minimising energy consumption and along with adopting circular economy concepts become essential. Within this frame, natural adsorbents have been considered to recover mercury, chromium, cobalt, nickel, copper, arsenic, cadmium and lead and metals in general. This work relies on outstanding results published by the authors [1,2] dealing with natural adsorbents based on natural cabuya fibers (Agave Americana L. ASPARAGACEAE)). Such natural cellulose fibers, after being functionalised exhibited good adsorption performance of mercury. Main objective of this paper is the assessment of such adsorbents for metal recovery. This work presents preliminary experimental results obtained by using real samples of seawater and mining wastewater are reported. Specifically, Atlantic seawater, Persian Gulf seawater and wastewater from artisanal gold mining at the Virgen de las Nieves Beneficiation Plant in Zaruma, Ecuador.

Keywords: Mining wastewater; Natural adsorbents; Natural cellulose fibers; Seawater mining; Metal recovery

[1] H. Sánchez-Moreno, L.García-Rodríguez, C. Recalde-Moreno. Natural cellulose fibers (Agave Americana L. ASPARAGACEAE) impregnated with magnetite nanoparticles as a novel adsorbent of mercury (Hg) in aqueous solutions. Adsorption (2025) 31:16. https://doi.org/10.1007/s10450-024-00577-1.

2. H. Sánchez-Moreno, L. García-Rodríguez, C. Recalde-Moreno. Natural cellulose fibers from Agave Americana L. ASPARAGACEAE as an effective adsorbent for mercury in aqueous solution. Adsorption (2025). In press.

PT 271

VMEMD and related separation processes from lab-scale to industrial size by module technology of EvCon

Markus Wenzel

EvCon GmbH, Gewerbestraße 7, Pliening-Landsham 85652, Germany
Tel. +49 1702136290, mwe@evcon-water.com

Seawater desalination was one of the first target applications for companies that are or were active in the field of membrane distillation (MD). The use of MD is advantageous at locations with free waste heat, for example from industrial plants or power generators, but these are rare. Statistics clearly show that most desalination projects now use the more efficient reverse osmosis instead of thermal processes. In this application, the technology cannot sufficiently exploit its potential. The situation is different when particularly pure water or a very high salt content is to be achieved in the concentrate. Examples include the concentration of industrial wastewater, the enrichment of dissolved materials (battery recycling) in aqueous liquids, the recovery of process water or the production of pure water for hydrogen production by electrolysis. In the latter case, waste heat is even available.

Vacuum multi-effect membrane distillation (VMEMD) is a powerful variant of MD with very high separation sharpness. The distillate obtained corresponds to high-purity water with a conductivity in the range of 1µS/cm, whereby salt ions from the feed are completely retained. Only dissolved gases or volatile substances can cause a slight increase in the distillate conductivity. If necessary, feed solutions can be concentrated until just before the dissolved salts crystallise.

EvCon GmbH uses plate and frame module technology to implement a particularly strong and reliable form of VMEMD and other related separation processes in its plants. The technology is based on the use of equal parts to produce cost-effective distillation stages. These stages work as "effects" in multi-effect distillation. Combining single or multiple effects with mechanical vapour recompression is also possible and has been tested.

The hydrophobic membrane is used like an ideal demister. Should the membrane become wetted after a long period of operation in high salinity range, the module design used effectively keeps leakage liquid away from the distillate and detects the unwanted flow. At the next maintenance interval, it is then possible to regenerate this wetting and continue operation without the need to replace the module or to compromise on distillate quality.

In the module, the condensation surfaces are equipped with polymer film and the evaporation surface with hydrophobic membrane. The arrangement of the surfaces in the module enables a very good heat transfer, although the module is made of polymers. This property gives the modules durability and resistance even to very corrosive liquids. Special modules contain frames that are designed without a membrane or even without a polymer film. This also effectively prevents liquids with wetting properties, for example with a high TOC, being concentrated or droplet entrainment after flash evaporation. Various module generations and sizes are available. Plants ranging from laboratory to large industrial scale can be implemented.

Keywords: Membrane distillation; VMEMD; Brine concentration; Purified water; Hydrogen; Electrolysis; Battery recycling; Wetting and membrane recovery

PT 273

Maximizing water production with minimal footprint for containerized systems

Eli Oklejas

FEDCO, 800 Ternes Dr., Monroe, Michigan, USA
Tel. +1 (734) 241-3935, eoklejas@fedco-usa.com

The ever-increasing worldwide scarcity of freshwater sources, coupled with the increased expense and decreased availability of brine disposal options due to environmental regulations, there is an increasing demand for high recovery, high efficiency, containerized reverse osmosis (RO) systems. Considering these market trends, and the inherent physical limitation of containerized systems, the optimization of system efficiency and footprint are critical to ensuring minimization of brine feed streams, and maximum utilization of feed streams and energy, which often rely on renewable resources in remote or mobile locations.

This technical paper outlines advancements in equipment technologies and system design philosophy to meet these design goals, including the utilization of optimal-speed high efficiency pumps, ultra-compact vessels configurations, and brine-staged designs for increased permeate recovery utilizing compact energy recovery devices.

Keywords: Water production; Energy recovery devices

PT 274

Novel thin-film nanocomposite (TFN) membranes by incorporation of halloysite nanoclay for pressure retarded osmosis applications

Akif Nihal, **Syed Javaid Zaidi***

UNESCO Chair on Desalination and Water Treatment, Center for Advanced Materials, Qatar University, Doha 2713, Qatar
**Email: szaidi@qu.edu.qa, smjavaidzaidi@gmail.com. Tel. +974 44037723.*

Recently, pressure retarded osmosis (PRO) process has been proposed for the brine management of reject before discharge to sea as well as a source of renewable energy generation. PRO process requires a salinity gradient resource for power generation with the potential of using a concentrated SW brine from the desalination plant as a draw solution. The aim of this study is the fabrication of nanocomposite membrane by incorporation of halloysite nanoclay into the polysulfone (PSf) support layer for the precise utilization in the PRO process. Until now, there is no specific membrane for the PRO process and all the commercial membranes utilized either are forward osmosis membranes or modified RO membranes.

Incorporating halloysite nanoclay into the polysulfone (PSf) support layer of thin-film nanocomposite (TFN) membranes has demonstrated significant potential in enhancing the performance of pressure-retarded osmosis (PRO) systems. Halloysite nanoclay, a naturally occurring aluminosilicate material, features a layered structure that offers high surface area, mechanical stability, and excellent dispersibility in solvents such as N,N-dimethylformamide (DMF). When integrated into the PSf support layer, halloysite nanoclay not only improves the mechanical properties and hydrophilicity of the membrane but also optimizes its porosity and pore size distribution, essential for efficient water transport and reduced internal concentration polarization (ICP). The fabrication process involves dispersing halloysite nanoclay in DMF, followed by casting the modified polysulfone solution to create a robust and hydrophilic support layer. This modified support structure effectively enhances the water flux by improving the wettability and maintaining structural integrity under hydraulic pressures typical in PRO applications. These membranes have been characterized by FTIR, SEM, AFM, contact angle and XRD. The performance of these membranes in a PRO setup have shown that TFN membranes with halloysite-enhanced support layers achieve higher water flux and power density compared to conventional thin-film composite membranes, making them well-suited for osmotic power generation applications. These findings underscore the significant advantages of utilizing halloysite nanoclay in TFN membrane design, providing a pathway for sustainable and efficient energy generation through salinity gradient power. The incorporation of halloysite nanoclay into the polysulfone (PSf) support layer of thin-film nanocomposite (TFN) membranes marks a significant advancement in pressure-retarded osmosis (PRO) applications. The unique properties of halloysite nanoclay—such as its layered structure, high surface area, and excellent dispersibility enhance the mechanical strength, hydrophilicity, and porosity of the support layer.

Keywords: Pressure retarded osmosis; Nanocomposite membranes; Halloysite nanoclay; Brine management

Acknowledgments

This Publication was supported by Qatar University project number QUT2RP-CAM-24/25-354. The findings achieved herein are solely the responsibility of the authors.

PT 278

Current situation of physical pretreatment systems used in seawater reverse osmosis desalination plants in the Canary Islands

Sigrid Arenas Urrea[1]*, Baltasar Peñate Suarez[1], Noemi Melián Martel[2]

[1] *Water Department – Canary Islands Institute of Technology (ITC), Playa de Pozo Izquierdo, s/n, Las Palmas, Spain, sigarenas@itccanarias.org*
[2] *Department of Process Engineering, Industrial and Civil Engineering School, Universidad de Las Palmas de Gran Canaria, Spain*

The Canary Islands are characterized by an arid climate and limited water resources making them significantly depend on seawater desalination to meet supply public water needs. Currently, desalination provides more than 50% of total water consumption on some islands, being the reverse osmosis the unique technology for seawater due to its efficiency and reliability. This study analyzed the current state of physical pretreatment systems used in desalination plants in the Canary Islands.

To get this information, the 28 seawater desalination plants for human consumption, both public and private management were analyzed. These facilities are located on the islands of Gran Canaria, Lanzarote, Fuerteventura, Tenerife and El Hierro. Of the total desalination plants analyzed, it was identified that only five operate with an open intake, while the rest use beach wells as intake. In addition, this study also explores the operational challenges of facilities with an open intake, particularly regarding to membrane fouling in reverse osmosis compared to those using seawater well intakes.

This work has been supported by INTERREG MAC 2021–2027 program through the IDIWATER project (1/MAC/1/1.1/0022).

Keywords: Seawater desalination plants; Canary Islands; Membrane fouling; Reverse osmosis; Physical pretreatment

PT 279

Seawater desalination plant in the Algarve: enhancing water resilience and security

Adriana Espanha, Claudia Dimas, Marisa Viriato, Pedro Ramos, Ricardo Estigarribia, **Rui Sancho***

Águas do Algarve, SA, Rua do Repouso, 10, 8000-100, Faro, Portugal
r.sancho@adp.pt, Drinking Water Operations Coordinator

Ensuring a reliable and resilient water supply is a critical challenge for the Algarve region, given its dependency on variable surface and groundwater resources. The Seawater Desalination Plant (SWRO – seawater reverse osmosis), developed by Águas do Algarve, SA, represents a key infrastructure project to strengthen water security through diversification of sources and redundancy mechanisms. This project, backed by the RRP (Recovery and Resilience Plan) funded by the European Commission, follows a structured implementation roadmap from design (2024-2025) to commissioning (2026-2027) and full operation (2027-2030).

Águas do Algarve SWRO integrates state-of-the-art reverse osmosis technology, optimized pre-treatment, and energy-efficient solutions, including Energy Recovery Devices (ERD) and high-efficiency motors, to minimize operational costs and environmental impact. Additionally, an on-site renewable energy production unit (3.86 MWp) will significantly reduce dependence on the public electricity grid and lower greenhouse gas emissions.

This abstract presents the strategic role of SWRO in the region's water supply system, its technical specifications, sustainability measures, and the challenges of balancing energy efficiency with desalination needs. The project exemplifies an integrated approach to climate resilience and sustainable water management in Portugal.

Keywords: Seawater desalination; Water security; Resilience; Reverse osmosis; Energy efficiency

PT 280

Seawater desalination circular schemes for green hydrogen production

Simona M. Asaro, Giovanni Campisi, Alessandro Tamburini, Andrea Culcasi, Giorgio Micale, **Andrea Cipollina**

Dipartimento di Ingegneria, Università di Palermo, Viale delle Scienze Ed. 6, 90128 Palermo, Italy, andrea.cipollina@unipa.it

As the industrial sector of energy production moves its attention to renewable sources, hydrogen becomes one of the most promising energy carriers. Currently, the main industrial origin of hydrogen is the steam reforming of natural gas, though research is driving the rapid development of advanced water electrolysers which, coupled with renewable energy sources, allow the production of green hydrogen (Chen et al., 2023). However, one of the main limitation to the scale-up of water electrolysis is the necessity of very large amount of ultra-pure water: 9 kg of water per each kg of produced hydrogen. Moreover, the water target specs are very strict, as an electrical conductivity lower than 0.05 μS cm^{-1} is required in order to maintain efficient and reliable process and high purity of the produced hydrogen (Zhao et al., 2025).

The aim of this work is to demonstrate, via a complex simulation platform, that ultra-pure water can be produced in an economically viable and environmentally sustainable way from the sea, thus boosting the potential for the scale up of water electrolysis technologies. An innovative treatment chain has been designed and simulated to analyse the integration effectiveness of a series of well-proven membrane technologies. The feed saline solution, with an initial TDS concentration of 35 g L^{-1} undergoes a pretreatment step of Microfiltration/Ultrafiltration (MF/UF), then passing through a multi-stage Reverse Osmosis (RO) unit, eventually being further demineralized with an Electro-Deionization unit (EDI), a new generation technology that combines the principles of electrodialysis and ion exchange to produce ultra-pure water with high current efficiency. On the other side, a brine valorisation strategy is implemented aiming at the maximization of water recovery and minimization of waste volumes via the recovery of valuable minerals. To guarantee maximum flexibility, the simulation tool was developed in modules, allowing to study different possible configurations of the treatment chain, changing the order of the various steps and adding recycle loops. The optimal configuration and operating conditions for the production of ultra-pure water are evaluated in terms of electrical conductivity of the produced water, Water Recovery (WR) and Specific Energy Consumption (SEC). The results obtained in the present work are precious for their contribute to the economical feasibility of water electrolysis scale-up and grants the chance of using green hydrogen a valid energy storage.

Keywords: Electromembrane; Electro-deionisation; Ultra-pure water; Water recovery; Process optimization

References

Chen, Y., Liu, C., Xu, J., Xia, C., Wang, P., Xia, B. Y., Yan, Y., Wang, X. (2023). Key components and design strategy for a proton exchange membrane water electrolyzer. *Small Structures*, *4*(6), 2200130. https://doi.org/10.1002/sstr.20220013

Zhao, W., Quist-Jensen, C. A., Zhong, Z., Li, N., Araya, S. S., Ali, A., Liso, V. (2025). Membrane distillation for producing ultra-pure water for PEM electrolysis. *Int. J.Hydrogen Energy*, *99*, 232–240. https://doi.org/10.1016/j.ijhydene.2024.12.219

PT 281

Energy recovery from waste(water) streams in the chemical industry by anerobic treatment and adapted pre-/post-treatment

Yuliya Schiesser*, Meenakshi Prasad, Li Chen, Christoph Blöcher

Covestro Deutschland AG, 51373 Leverkusen, Germany, yuliya.schiesser@covestro.com

Chemical industries often discharge highly energetic, nutrient-rich and salt-loaded wastewater into advanced aerobic biological treatment systems or incineration facilities. These methods consume significant energy to reduce carbon and other nutrients without aiming to recover them, thus contributing to greenhouse gas emissions and climate change.

Within the Cornerstone project, funded by the European Union (grant number: 101138504), in a case study for the chemical industry the anaerobic treatment of highly organically polluted wastewater streams is investigated. Direct application of anaerobic processes to chemical industrial wastewater is challenging due to high salt content, high levels of nutrients (esp. nitrogen), or other persistent substances. Therefore, a pre-treatment via membranes (such as Nanofiltration) is considered to separate these recalcitrant components, enhancing the anaerobic potential of the wastewater.

Additionally, membrane technologies such as reverse osmosis (RO) and electrodialysis with bipolar membranes (EDBM) are being explored for post-treatment of wastewater following anaerobic digestion. These methods aim to remove salt, enabling the recovery of water and nitrogen.

Finally, integrating membrane technologies with anaerobic processes is expected to achieve at least 40% water and nutrients (NH3) recovery for relevant streams in the chemical industry.

Keywords: Anaerobic treatment; Chemical industry; Membrane technologies; Nutrient recovery; Water recovery; Salt rejection

PT 282

Semi-closed reverse osmosis (SCRO) for low-energy, high-resilience desalination

Qianhong She [a b]

[a] *Singapore Membrane Technology Centre, Nanyang Environment and Water Research Institute, Nanyang Technological University, Singapore 637141*
[b] *School of Civil and Environmental Engineering, Nanyang Technological University, Singapore 639798*
QHSHE@ntu.edu.sg

Desalination via membrane-based reverse osmosis (RO) is one of the most promising solutions to address the issues of water scarcity and has attracted unprecedented interest in recent decades. However, the prevailing process, single-stage RO (SSRO), consumes much higher than thermodynamic minimum energy as its operation requires over-pressurization (OP) of the feed. Although alternative RO processes, such as batch RO (BRO), closed-circuit RO (CCRO), and multi-stage RO (MSRO), mitigate osmotic pressure (OP), they each have drawbacks. In BRO and CCRO, the mixing of recirculated concentrate with the feed increases entropy and energy consumption. Meanwhile, MSRO cannot utilize high-efficiency isobaric pressure exchangers, preventing it from achieving high energy efficiency in practice. Additionally, MSRO requires extra boosting systems, leading to higher capital expenditures. In this talk, I will introduce a new RO process, namely, semi-closed reverse osmosis (SCRO), which is patented from our recent research and features a concise design and flexible operation. In SCRO, multiple-cycle operation with varied applied pressures is performed to mitigate OP without additional staging, while the intermediate feed and corresponding concentrate in each cycle are stored in separate tanks to circumvent mixing. Analytic results reveal that SCRO integrating energy recovery devices consumes less energy than all the other RO processes that have been tested at the bench- or pilot scale for desalination within typical water recovery regions. Such superiority of SCRO is more significant at higher recoveries. Experimental testing further demonstrates that SCRO has lower fouling than conventional RO, which further saves energy and chemical use in practice. This study suggests that SCRO can be a promising alternative to state-of-the-art RO processes in low-energy desalination.

Keywords: Reverse osmosis; Energy saving; Low-energy desalination

PT 283

Eco-friendly deep-sea desalination combining reverse osmosis and oil and gas solutions

Antoine Vuillermet

Waterise, Portugal
Tel. +33 6 08 65 78 10 / +1 310 910 8628, antoine.vuillermet@waterise.com

As coastal communities struggle to adjust to climate change and secure resilient water supply, more and more desalination projects are being launched, including in Portugal. Conventional desalination (reverse osmosis done on land, with shallow water intake and brine discharge) has known pitfalls: high impact of shallow water intake on fauna and flora, high energy utilization, release of concentrated brine back to sea, need for large coastal areas to set-up the facilities, exposure to algae blooms.

Waterise is a Norwegian company with offices in Oslo and Madrid, that has developed a game changing deep sea desalination solution combining two very well proven technology: deep-sea design, installation and operations from the Oil and Gas world, and the traditional reverse osmosis process. Waterise installs and operates reverse osmosis membranes on the deep sea bed, eliminating the impact on fauna and flora, reducing by 40% the energy consumption and the need of coastal land by 90% compared to conventional desalination, without any chemicals, while benefiting from Oil & Gas high reliability standards, remaining a very economical solution. The water produced is of excellent quality, twice less concentrated as per a conventional desalination, and PFAS free.

The presentation will explain the concept, principles and benefits of this solution.

PT 285

Transforming the water treatment market

Daniele Strongone

President of the Water Positive Think Tank and General Manager of AWC American Water Chemicals, Amaya Solutions Europe, C. Sant Elies, 29-35 – 08006 –Barcelona, Spain
Tel. +34 607 434945, dstrongone@membranechemicals.com

The Water Positive Think Tank (WPTT) is a global initiative composed of nearly 500 professionals from diverse disciplines, continents, and cultural backgrounds. Its mission is to identify, propose, and standardize processes that generate a positive impact on water resources, ensuring their sustainability for future generations within the Water Positive initiative. WPTT does not execute projects itself, nor does it represent any company or brand—instead, it serves as a knowledge hub that translates high-impact water stewardship processes into a structured Water Positive Framework.

This framework is designed to help both Water Benefit Purchasers (corporations, investors, and stakeholders looking to compensate for water use) and Water Benefit Providers (developers, NGOs, and local organizations implementing projects) align their efforts with Science-Based Targets for Water (SBTi). By ensuring that water stewardship initiatives follow a rigorous additionality principle, WPTT enables more effective, measurable, and fundable projects that contribute to net-positive water outcomes. This emerges due to the lack of viable Volumetric Water Benefit (VWB) market options and the need for SBT support for nature-based solutions. Even though these are based on the hydrological cycle, they must have a scientific foundation for additionality, from the baseline (initial environmental footprint) to the target.

PT 286

Sustainable water management: innovations in alternative water sources – case studies

Ajay Popat

President, Ion Exchange I Ltd
Mobile +91 9324002404, ajay.popat@ionexchange.co.in

With freshwater scarcity escalating, alternative water sources such as desalination, wastewater recycling, and industrial effluent treatment are critical for sustainable water management. This presentation through cases studies explores technological advancements that enhance water security while supporting the UN's Sustainable Development Goals (SDG 6 & SDG 12).

Desalination has evolved with energy-efficient Reverse Osmosis (RO) systems, innovative membrane designs, and energy recovery technologies, making seawater as an alternate source for industries and coastal communities. Municipal sewage, once considered waste, is now a valuable alternate resource through facilitating water reuse for industrial and non-potable applications. Decentralized sewage treatment further alleviates municipal burdens by providing affordable water recovery solutions.

For industrial wastewater, cutting-edge biological, membrane, and thermal evaporation technologies enable water reclamation as an alternative source of fresh water and also achieve Complete Zero Liquid Discharge (ZLD).

Case studies in the presentation demonstrate sea water, sewage and industrial effluents can successfully be used as alternative source of freshwater, reduce freshwater dependency while meeting stringent environmental regulations

Keywords: Alternative sources; Freshwater scarcity; Desalination; Sewage reuse; Industrial wastewater recycling; Zero liquid discharge (ZLD); Decentralized sewage treatment; Sustainable water management SDG goals

PT 287

Desalination of high-salinity organic wastewaters by membrane dialysis

Menachem Elimelech

Department of Civil and Environmental Engineering, Rice University
Houston, TX 77005, USA
Tel. +1 (203) 444-8554, menachem.elimelech@rice.edu

High-salinity organic wastewaters pose a major challenge for conventional wastewater treatment processes. In this study, we propose dialysis as an innovative solution to overcome this challenge. Dialysis uses an ultrafiltration (UF) membrane that allows the passage of salts while rejecting the organic substances, operating in a bilateral countercurrent flow mode without the application of hydraulic pressure. Using bench-scale experiments and a model for salt and water transport in leaky membranes, we demonstrate that dialysis can effectively desalinate high-salinity organic wastewaters without diluting the wastewater stream. By comparing the salt/organic selectivity of dialysis and UF using the same membrane, we show that dialysis can effectively fractionate salts and organic substances in high-salinity organic wastewaters. Additionally, we find that, unlike UF, dialysis is almost unaffected by membrane fouling, highlighting its excellent fouling resistance. We conclude by proposing potential high-salinity organic wastewater treatment schemes based on dialysis, paving the way for more sustainable and effective management of challenging wastewaters.

Keywords: High-salinity organic wastewaters; Dialysis; Ultrafiltration; Membrane

PT 288

Sorek 2 - Be'er Miriam Desalination Plant: Leading the way in sustainable desalination

Dotan Gur[1], Gregory Shtelman[2], Irina Zaslavschi[3], Naaman Cohen[4]

IDE Technologies
[1]Desalination Expert , dotang@ide-tech.com
[2]VP Project Engineering, gregorys@ide-tech.com
[3]Director – Sea Water Process, irenaz@ide-tech.com
[4]Sorek 2 - Be'er Miriam Chief Technology Officer, naamanc@ide-tech.com

As the demand for sustainable water solutions intensifies globally, IDE Water Technologies has taken the lead in this space, presenting a groundbreaking approach with the launch of Sorek 2 - Be'er Miriam, Israel's largest and the world's first steam-driven seawater reverse osmosis (SWRO) desalination plant.

The development and implementation of a Life Cycle Assessment (LCA) - based design at Sorek 2 enabled IDE to assess environmental impacts across all operational stages and drive continuous improvement in sustainability measures. This presentation will detail the innovative design and operational strategies that enable Sorek 2 to produce 200 million m³ of desalinated water annually at a record low cost of $0.405/m³ while meeting all environmental requirements and setting new benchmarks for sustainable desalination globally.

Utilizing patented steam driven direct drive (S3D) technology alongside an independent power system, a carbon capture system that recycles CO2 emissions for use in the remineralization process, and an electro-chlorination system for the generation of Hypochlorite, the plant achieves a 10% reduction in Specific Energy (SE) consumption and a 30% reduction in carbon footprint compared to similar facilities, such as the Hadera desalination plant.

Key takeaways for conference attendees include actionable insights into deploying advanced technological solutions that optimize resource efficiency and minimize environmental impact. Participants will leave with a comprehensive understanding of how innovative desalination technologies can be implemented to achieve sustainable and economically viable water solutions, providing a blueprint for future developments in the water treatment industry.

Keywords: Sustainable desalination; Reverse osmosis; Carbon capture; LCA

PT 292

Building the business case for industrial brine valorization

Christos Charisiadis

Founder & Principal Consultant, Brine Consulting, Amsterdam, The Netherlands
+31 640 471 325 christos@brineconsulting.com

As seawater reverse osmosis (SWRO) desalination expands globally, the concentrated brine it produces is shifting from a costly waste to a potential industrial resource. Rich in salts and minerals the industrial brines present an opportunity to generate new value through resource recovery. Building a compelling business case for brine valorization goes beyond technical feasibility—it requires a clear understanding of financial returns, market demand, infrastructure readiness, regulatory conditions, and environmental benefits. By applying a structured, multi-dimensional framework, stakeholders can assess the true potential of transforming brine from a disposal liability into a sustainable and profitable resource stream, aligned with circular economy and decarbonization goals.

PT 293

Clean water for the future – Plastics solutions for the entire value chain

Fechtig Daniel

agru Kunststofftechnik Gesellschaft m. b. H., Ing.-Pesendorfer-Str. 31, A-4540 Bad Hall, Austria
fda@agru.at

Clean water, especially drinking water is one of the most precious resources on a global scale. Desalination of sea water will therefore be a key enabling technology for important future industries. Clean water or even demineralized (purified) water will play a critical role in emerging market trends like hydrogen, microchip fabrication, battery production and data centers. Those industries should not compete with the demand of drinking water for the global population. Hence it will be necessary to install and operate desalination plants as well as safe, clean and reliable infrastructure to transport, store, use and recycle water in the most economic way. Plastics solutions provide corrosion and chemical resistance across the entire water cycle. The products range from PE, PP and Fluoropolymers piping for water intake, pre-filtering stations, RO membrane spools to storage tanks made from concrete protective sheets to store sea water, drinking water and finally to piping for the transport of potable water and sewage water. The resistance to corrosion and chemicals, it´s flexibility and standardized installation processes make plastics the most safe, reliable and long-lasting solution when operating global water infrastructure. In our presentation we will provide technical information and data why plastics are superior in many applications because of their flexibility, abrasion resistance, chemical resistance and flow characteristics. We will speak about case studies, successful installations in large scale desalination projects and highlight some of the most important material & design as well as installation considerations when using plastics solutions in desalination plants. Our presentation will conclude with novel application fields of plastics products in emerging markets like hydrogen (desalination, purification, water use in electrolysers), data centers (cooling systems) and batteries. We will focus on major references in this fields of application and highlight the role of reliable, leakage free products for water handling to reduce water losses and operating costs.

AUTHOR INDEX

Numbers denote the abstract number (**bold**) and page.