
EUROMED 2024
DESALINATION FOR CLEAN WATER AND ENERGY
6-9 MAY 2024 - FOUR SEASONS HOTEL, SHARM EL SHEIKH
EDS
EDRC

ABSTRACTS

EuroMed 2024
Desalination for Clean Water and Energy

6–9 May 2024, Four Seasons Hotel, Sharm El Sheikh, Egypt

Contents

SH 1

Forward osmosis: an alternative sustainable technology and potential applications in water industry

Peter Nasr*, Hani Sewilam

*The American University in Cairo, Building 40, Nazih Khalifa St., Cairo, 11341, Egypt
pnasr@aucegypt.edu

This research presents an advancing sustainable membrane-based separation process, which is forward osmosis (FO). The review begins with an introduction of the basic principles of the FO process. Then, a comparison to the most currently well-known desalination technology (RO) is presented. Following section summarizes potential applications of FO in the water desalination field, producing either potable water or irrigation water from brackish/saline feeds. Next, two major FO applications in the domain of water reuse are discussed: wastewater and industrial applications. Wastewater applications are such as osmotic membrane bioreactor (OSMBR) and landfill leachate treatment; and Industrial applications include oil and gas, pharmaceutical, and food and beverage industries. These different FO applications are briefly reviewed and assessed. Although FO has attracted growing attention in many potential applications, it still experiences several considerable limitations, including concentration polarization, membrane fouling, reverse solute diffusion, and need for membrane and draw solution development.

Keywords: Forward osmosis, Desalination, Water treatment, Energy

SH 2

An energy-efficient desalination process concept to sustainably increase water availability for green hydrogen production

Christine Kleffner*, Gerd Braun

*TH Köln, Cologne – 50679, Germany
*Tel. +4922182754055; christine.kleffner@th-koeln.de, gerd.braun@th-koeln.de

In order to enable the production of green hydrogen on a larger scale, the availability of water is of key importance and at the same time a major challenge. To meet the necessary conditions for green hydrogen production, the treatment processes that provide the water must be extremely energy-efficient and environmentally compatible. Therefore, innovative technological approaches and process concepts are required. This study considers an innovative process concept for the production of desalinated water from seawater, which involves the use of high-pressure reverse osmosis using the latest energy recovery technology at 120 bar in a special combination with ion exchange softening as pretreatment. Due to the specification of standard membrane element equipment applied for a common seawater reverse osmosis (SWRO) process, the maximum recovery rate is limited to around 45%. As a result, seawater intake and pretreatment infrastructure are designed and built to handle approximately twice as much feedwater as freshwater produced, which is reflected in both CAPEX and OPEX. The energy required for seawater intake, pretreatment and brine discharge amounts about a third of the energy demand of the actual RO process. In this study, a high-pressure reverse osmosis (HPRO) process working at 120 bar allows increased

recovery rates of up to 75%. It is combined with highly efficient isobaric energy recovery devices (ERD) designed for ultra-high-pressure applications that have the capacity to reduce the energy demand of the HPRO process significantly. However, increased recovery rates lead to an increased risk of calcium salt deposition on the membrane. To avoid the dosing of anti-scaling agents and thus the discharge of this chemicals into the sea along with brine disposal, an innovative method to overcome the risk of scaling is proposed and investigated here: The seawater is softened by a cationic ion exchanger (IX) prior to HPRO by replacing calcium with sodium ions. In this case, a chemical-free regeneration can be realized using the calcium-free brine coming from HPRO, providing rather high salt loads for improved regeneration efficiency. A feasibility analysis was carried out on the basis of experimental studies. The performance of HPRO was examined with available 4"-membrane elements. A pressure exchanger operating at a flow rate of up to 6 m³/h was installed in the pilot plant to evaluate and demonstrate its ability to save energy at an operating pressure of 120 bar. The IX performance was analyzed in lab-scale applying common ion exchangers. The results clearly show how existing equipment and technologies can be innovatively combined and usefully applied under rather unusual operating conditions to facilitate an economical and ecological desalination process to increase water availability for green hydrogen production.

Keywords: High recovery seawater desalination; High-pressure reverse osmosis; Energy recovery; Ion exchange

SH 3

Potential and economic viability of green hydrogen in Algeria production

Nadjib Drouiche

ANVREDET, Algiers, Algeria
Tel. +21366062 1509; nadjibdrouiche@yahoo.fr

In April 2021, the Algiers Declaration on the green hydrogen plan was signed by Ministry of higher education and ministry of energy transition and renewable energies It represents the first step of a plan to develop the green hydrogen industry in Algeria. The Algiers Declaration's vision is to move gradually towards clean energies, including green hydrogen, and to prepare Algeria's energy transition for 2035. It also goes towards limiting the over exploitation of fossil fuels, which are in continuous decline, and their negative impact on the environment. In order to achieve that goal and despite the economic disruptions caused by the COVID-19 pandemic, there are a number of large-scale renewable energy projects ranging from 50 to 300 MW in the pipeline, amounting to 15000 MW, with over totality being solar power. The declaration would be a milestone towards a National Hydrogen Strategy. Indeed, compared to Europe, Algeria has world-class largely untapped solar resources, whereas Europe has a growing energy demand needing to decarbonize in line with the Paris Agreement and the UN Sustainable Development Goals. Moreover, the demand for green hydrogen in Europe is expected to be tremendous by 2030-2050. It is to notice that among the European states, Germany has a close interest in green hydrogen as part of its support for low emissions technologies. The value of Algerian green hydrogen including green ammonia (PtX technologies) exports is not estimated yet but represents a huge potential. Thus, Algeria has to position itself to take a sizable portion. This will is subjected to an effective political good will based on attractive policies such as win-win collaboration opportunities that would contribute

to the diversification the economy and offer jobs opportunities. Moreover, the Algerian green hydrogen could fulfill the local demand and supply Europe. Thus, to reach these objectives, a strategy should be initiated to build Algeria's green hydrogen industry. The strategy would begin with a plan to accelerate the replacing of grey hydrogen production by green hydrogen, the reducing of technical uncertainties, the build-up of a domestic supply chains, and the production capabilities. A strong domestic hydrogen sector will underpin Algeria's exporting capabilities to make it a leading global green hydrogen player. However, a detailed analysis of hydrogen production from renewable sources, considering the capital expenditure, the OPEX costs, and any other expenses seems a compulsory task to evaluate the project feasibility, its advantages and drawbacks.It is to notice that all the wilayas (province) of Algeria have excellent prospects for hydrogen production, have the possibility to switch to green hydrogen from the grey hydrogen used for the local market, notably for the production of ammonia and glass. Through adoption of such strategy, removing barriers to industry development and encouraging investments would consolidate the realization of the project. In the framework of the project, our consultations with different industries involved in hydrogen production and utilization showed that Algerian companies are ready to apply their ingenuity and considerable experience to produce and use of green hydrogen. The best way to start is an effective coordination and cooperation between the government and industry sector to work together to implement a national strategy. Algeria has qualified human resources, and the experience, to take advantage of increasing upcoming worldwide demand for clean hydrogen. An integrated low-cost renewable generation will reduce dependence on fossils fuels, and helps local reducing carbon emissions. A key element of Algeria's approach will be to create hydrogen hubs – clusters of large-scale demand. These may be at ports, steel and glass industry, ammonia production, or in regional or remote areas. Hubs would make the development of infrastructure more cost-effective and foster research and innovation. These will be complemented and enhanced by other early steps to use hydrogen in heavy transport, industry and gas distribution networks, and integrate hydrogen technologies into the electricity production in a way that enhances its reliability. Algeria aims at having an important renewable energy share in its electricity system and develops green hydrogen industry, and is well positioned to become a global leader in exporting renewable hydrogen if the appropriate research informed effective policies are put in place. A timely energy transition is needed to accelerate renewable uptake and advance the budding renewable hydrogen industry. Such efforts can support Europe to decarbonize its industry, meeting Paris Agreement and sustainable Development Goal agendas, while establishing an Algeria's economy diversification.

Keywords: Green hydrogen; Energy transition; Algeria; GHG

SH 5

Development of technology of the stabilization of the characteristics of RO elements during their long-term storage

Viacheslav Dzyubenko*, Pavel Vdovin

JSC RM Nanotech, 224D Dobroselskaya Str., Vladimir 600031, Russia
** Tel. +7(4922)474001; v.Dzyubenko@membranium.com*

The task of stabilizing the characteristics of RO elements during storage is very important due to the possible decrease in their productivity and the discrepancy between the initial data included in the projects and the actual characteristics when starting up the installations. As a result

of the studies, it was found that the main factor contributing to the decrease in the unreacted performance of RO elements during storage is the presence of residual traces of monomers in the membrane, in particular metaphenylenediamine (MPDA) and its oxidation over time. In addition, an important aspect is the toxicity of washed-out MPDA during operation. A spectrometric technique has been developed for assessing the content of colored components, including MPDA, and extractive methods have been developed for analyzing the residual content of MPDA in the membrane. In order to remove or immobilize residues of monomeric MPDA, 1) extraction with various acids (nitric, hydrochloric, acetic, citric, oxalic, aminosulfonic, etc.) was tested, 2) chemical transformation of MPDA into insoluble compounds by reacting its amino groups with aldehydes. It has been established that the method of acid extraction at elevated temperature (to speed up extraction) is technologically feasible and reproducible. In order to evaluate the effectiveness of the developed technology, a comparison was made of the characteristics of processed and unprocessed RO elements during their storage for 1 year. After storing RO elements for 1 year, the decrease in the productivity of the processed elements was 0.8–6.7%, the untreated control lot - 17.0–17.6%. In both parties, the number of elements was equal and amounted to 50 pieces. in each. Evaluation of the stability of the characteristics of processed RO elements for 1.5 years made it possible to increase the attractiveness of our products to end users. The developed technology makes it possible to achieve minimum values of the residual content of MPDA and stabilize the characteristics of RO elements over a long period of time.

Keywords: Reverse osmosis membrane; Stabilization of characteristics; Metaphenylenediamine

SH 6

Green hydrogen production optimized with membrane distillation

Bart Nelemans

Aquastill b.v., Nusterweg 69, Sittard 6136KT, The Netherlands
Tel. +3145705492; b.nelemans@aquastill.nl

Production of green hydrogen by electrolysis is gaining more interest as renewable energy source. Polymer electrolyte membranes (PEM) is one of the most promising technologies to produce green hydrogen on large scale. The process is fed with ultra pure water (UPW), often produced with reverse osmosis. The production of both UPW and the PEM process requires electricity which are an important contributing factor of the operational costs. At the same time the PEM process produces large quantities of waste heat. Membrane distillation is known for its capability to produce UPW from seawater and is driven by waste heat, making it a perfect complimentary technology with PEM to reduce electricity consumption. Based on the waste heat produced by the PEM it was estimated that the membrane distillation modules can produce 3 times more UPW than needed. The flexible Aquastill module design is able to optimize water production and thermal energy availability without compromising water quality. Results Primarily testing is preformed between 2019 and 2022 in a project named Sea2H2, executed by Wageningen University and Hydron energy subsidizes by the Dutch government using Aquastill membrane modules. The nominal power of the PEW was 50 kW (corresponding to approx. 1 kg H_2/h) required an estimated 10 kg/h of ultra pure water. The feed water of the membrane distillation system was pre treated with a simple sand filtration system. The membrane distillation modules were able to produce between 13 and 27 l/h depending on temperature profile, circulation velocity and salinity. During a test period of 700 hrs

seawater was used with a maximal conductivity of 180 mS/cm while producing with a conductivity of approx. 7 µS/cm.

Conclusions

These trials have shown the potential of membrane distillation techniques to produce UPW for green hydrogen production and further experiments are planned for 2023 in Asia.

Keywords: Hydrogen; Membrane; Distillation

SH 8

Janus superhydrophilic/superhydrophobic nanofiber hybrid (c-PVA/f-CNT) membranes for emulsified oil/water separation

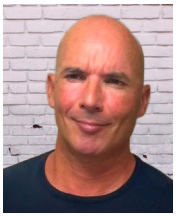
Hern Kim

Myongji University, 116 Myongji-ro Cheoin-gu, Yongin, Gyeonggi-do 170, Korea
Tel. +82-10-4323-7652; hernkim@mju.ac.kr

In summary we have demonstrated a facile and versatile approach to prepare Janus c-PVA/f-CNT hybrid membranes for emulsified oil/water separation. The fabricating technique of the Janus c-PVA/f-CNT nanofiber membrane via electrospinning then crosslinking and subsequent coating of CNT by vacuum filtration is remarkably facile, and effective. The obtained Janus c-PVA/f-CNT membranes can selectively remove a wide range of oils (and/or organic solvents) from water with high absorption capacity. Furthermore, the Janus c-PVA/f-CNT membranes can effectively separate both surfactant-stabilized water-in-oil emulsions and oil-in-water emulsions due to the anisotropic wettability of the membranes, and they display high separation efficiency and promising flux. The high sorption capacity of the membranes makes them promising candidates for various practical applications such as controllable oil/water separation.

Keywords: Hybrid membrane; Janus; Superhydrophilicity; Superhydrophobicity; Nanofiber; Electrospinning; Crosslinking; Oil-water separation

SH 9



Beyond digital in the water world

Jose Carlos Gil Jara*, Mike Dixon, Nick Herold, Miller Truby, Sandro Hansen

**Gradiant, Madrid 28008, Spain*
Tel. +34 680455040; cgil@gradiant.com

Gradiant will present its practical experiences with the digitalization of water treatment and distribution systems, as well as effluent treatment and water reuse with the AI-powered, integral, digital and Smart Operations Platform Management (SmartOps). The paper will cover the challenges operators face today, digital ways of dealing with these challenges and real examples of success, beyond digital monitoring and digital twins available in the water market, in the present time. It will also present the main risks, control mechanisms and key factors for the success of any digitaliza-

tion and automation process related to the future of the water world, applying the latest machine learning techniques, as a method to save energy for green hydrogen production and mitigating the carbon and water footprints.

Keywords: Digital; AI; ML (Machine Learning); Desalnation; Water treatment; Energy; Beyond digital twins; Green hydrogen production

SH 10

Machine learning process optimization in a 200,000 m³/d SWRO plant

Sandro Hansen[1]*, Nick Herold[2], Miller Truby[3], Belén Gutiérrez López[4], Antonio Garcia[5], Juan Arevalo[6], Daniel Montoro[7], Bartolome Marin[8], Victor Monsalvo[9], Mike B. Dixon[10], Enrique Solís Pérez[11], José Ignacio Aguado Sánchez[12], Abderrezak Goulmane[13], Miguel Alvarez Matilla[14]

[1]*The Turing Company, Application Specialist, Spain, shansen@gradiant.com*
[2]*The Turing Company, Application Specialist, Canada, nherold@gradiant.com*
[3]*The Turing Company, Customer Success Manager, USA, mtruby@gradiant.com*
[4]*GS Inima, Head of Desalination Department, Spain, bgutierr@inima.com*
[5]*FCC Aqualia, Head of Wastewater and Desalination treatments, Spain, AMGarciaL@fcc.es*
[6]*FCC Aqualia, Project Manager, Spain, juan.arevalo@fcc.es*
[7]*FCC Aqualia, Plant Manager, Spain, daniel.montoro@fcc.es*
[8]*FCC Aqualia, Head of the desalination department, Spain, BMarin@fcc.es*
[9]*FCC Aqualia, Head of Eco-efficiency Area, Spain, victor.monsalvo@fcc.es*
[10]*The Turing Company, CEO, Canada, mdixon@gradiant.com*
[11]*Dessalement Mostaganem, Director of Desalination Plant, Algeria, esolis@dessalementmostaganem.com*
[12]*Dessalement Mostaganem, Deputy Head of desalination plant, Algeria, jiaguado@dessalementmostaganem.com*
[13]*Dessalement Mostaganem, Production Director Desalination Plant, Algeria, agoulmane@dessalementmostaganem.com*
[14]*Dessalement Mostaganem, O&M Manager Desalination Plant, Algeria, miguel.alvarez@uteoymalger.com*

Although reverse osmosis stands out as the most energy-efficient method for extracting freshwater from seawater in desalination, the sheer scale of desalination plants necessitates substantial energy and chemical usage. With fluctuating seawater temperature and salinity, optimum set points in a plant can change on a daily, and sometimes, even hourly basis. When considering challenges such as membrane fouling and ensuring consistent permeate quality, the process of optimizing a plant to its intended conditions can potentially become a time-consuming distraction often resulting in suboptimal plant performance.

Aqualia and GS Inima, partners in the operation of the 200,000 m³/d Mostaganem Desalination Plant in Algeria, engaged with Turing in 2022 in an effort to optimize the operation of the plant. The optimization exercise was initiated by collecting information about the plant (design, instrumentation, and operating conditions), followed by historical data collection. Challenges associated with missing sensor data were addressed by enhancing the instrumentation and storage of operational data within the plant. Having access to the revised information enabled the identification of a potential decrease in specific energy consumption by 1.68%. During phase 2 of this project, which entailed implementing the algorithm's set points at the plant, a new challenge emerged: during winter, when

sea water temperature is low, plant production approached its contracted capacity more closely than anticipated, reducing operational flexibility. Additionally, the Turing team determined that solely focusing on the seawater reverse osmosis (SWRO) area of the plant would not suffice to achieve the goal of expanding savings during Phase 2 implementation. Therefore, the project scope was broadened to incorporate the utilization of Smart Ops technology platform for operational planning of production. This encompassed considering savings from various areas of the plant, including low-pressure pumping to the SWRO production zone. The project is currently in progress, with further outcomes anticipated in the summer of 2024, when operational flexibility at the plant is expected to increase.

In addition to presenting the case study, this paper also presents (a) the challenges associated with implementing artificial algorithms for plant optimization and (b) highlights the benefits of implementing this approach. While significant efforts are needed to implement such an approach for plant optimization, the technology has not only identified potential savings but also identified new avenues for more efficient plant performance.

Keywords: Artificial intelligence; Machine learning; Reverse osmosis; Energy saving; Machine learning Ops

SH 11

The feasibility of brackish water desalination for irrigation in Egypt

Mohamed Dawoud

Environment Agency - Abu Dhabi, P.o. Box 45553, Abu Dhabi, UAE
Tel. +971 503129571; mdawoud@ead.gov.ae

With a deficit of an annual volume of about 20 billion cubic metres (BCM) in 2022, Egypt is facing a sever water shortage due to the rapid increase in the population which is about 109.3 million by the end of 2022. Egypt started an ambitious programme for using on non-conventional water resources including treated wastewater, agricultural drainage water (ADW) and desalinated water. The desalination capacity was increased from 86,000 m^3/d in 2015 to 680,000 m^3/d in 2022 and it is planned to be increased to1,250,000 m^3/d by 2025 and 7,700,00 m^3/d by 2050. Despite the improvements in desalination technologies and cost, its high energy use and environmental impacts are still limiting its use. Egypt generates annually about 17 BCM of ADW, offering a significant opportunity for non-conventional water resource utilization in the country. While around 55% of this ADW is officially repurposed for irrigation, most of the drains are at risk of contamination from untreated domestic and industrial wastewater discharges. Consequently, the primary obstacle in effectively harnessing ADW lies in its variable quality, primarily attributed to pollution. The central challenge in ADW reuse initiatives revolves around establishing criteria to assess its suitability for reuse. A detailed assessment and analysis were done to evaluate the feasibility of desalination of brackish groundwater and agriculture drainage water for irrigation purposes. The results indicating that RO desalination for brackish groundwater and agriculture drainage water is technically mature and Capex costs ranges between 760–850 US$/$m^3$ and the Opex is as low as 0.55 – 0.63 US$/$m^3$ which is economically cost-competitive with other water supply sources for irrigation in remote areas. Results indicating that energy consumption can be reduced to be about 3.6–4.2 kWh/m^3

in desalination of brackish water with salinity less than 10,000 ppm. The assessment results also indicating that to sustain the energy supply, minimize environmental impacts and the cost, hybrid energy systems using solar and conventional energy sources is technical and economically viable. The study results recommend that shortly, RO desalination market of small to medium scale desalination in remote areas for irrigation will increase in Egypt if it is coupled with high efficiency irrigation and agriculture production systems such as greenhouses and hydroponic.

Keywords: Desalination; Brackish groundwater; Agricultural drainage water RO; Environment

SH 12

Integration of renewable energy surpluses in WWTP through biomethane production

Federico Ferrari*, Israel Diaz, Maria Luisa Ruíz, Raquel Iglesias, Maria Del Mar Mico, Jorge Malfeito

**Acciona Agua, El Prat De Llobregat 08820, Spain*
fferrari@acciona.com

The new European and national policies to achieve a carbon neutral Europe in 2050 are increasingly strict and call for increasing the use of renewable energy and implementing technologies based on hydrogen (H_2), biogas and biomethane. The BIOUP project will offer a "power-to-gas" solution not available until now, for the use in the form of CH_4 of green H_2 from surplus renewable energy, that may exceed conventional demand at certain times of the day. To this end, it will develop a technology that will biologically enrich WWTP anaerobic digested sludge biogas (60% in CH_4) from the anaerobic digestion of sewage sludge through the biomethanation of CO_2 contained in it, with renewable H_2, so that the upgraded biomethane generated have sufficient quality to be injected into the natural gas network (> 95% in CH_4) or used directly in transport vehicles (> 90% in CH_4). The BIOUP project aims to develop and validate a technology for the biological transformation into CH_4 of H_2, from renewable sources, and carbon dioxide (CO_2), generated in the anaerobic digestion of organic matter. This technology fits the particularities of WWTP, which have large volumes of anaerobic digestion of sludge and a clear need to increase the energy efficiency of their operation. MATERIAL AND METHODS BIOUP will address the assessment of in situ and ex situ biomethanation technologies. In the case of the in situ technology, laboratory tests will be carried out to determine the technical feasibility and the optimal design conditions and parameters of the biomethanation process, in order to determine the best operating conditions, together with the potential effect of the codigestion and different alternatives to improve H_2 transfer. The study of microbial populations of the processes will also take place through the project, in order to offer a deeper insight of the biodynamics of the system. Subsequently, with the data obtained, a 5m3 prototype will be designed and built for the validation of the technology on a pilot scale. It will be installed in a real WWTP, to use real sludge to feed the in situ biomethanation digester. For ex situ biomethanation, biotrickling filter (BTF) technology will be assessed as a way to support the specialized biomass that will metabolize the H_2 and CO_2 contained in the biogas, potentially coming from a conventional digester, or in the eventually poor biomethane coming from a previous in situ system with incomplete conversion. Again, the study of this technology will be addressed from lab and pilot scales approaches. To start with, the feasibility of using the centrate from the AD of sludge, rich in ammonium and micronutrients, as nutrient source for ex situ biomethanation will

be evaluated so that the use of chemicals for biomass subsistence is minimized. Together with this one, other operational conditions will be explored to obtain the best operational strategy and design for a 150L pilot plant that will also be installed in a real WWTP. In this case, biogas coming from the real scale anaerobic digestion or the eventually poor biomethane produced in the in situ pilot plant with incomplete conversion would be fed to the pilot BTF. Daily monitoring of the pilots will be carried out, analysing the critical physicochemical parameters to know the evolution of the process, measuring the quality of the biogas obtained. Thus, the conversion of biogas into biomethane will be studied and optimized. In parallel to the empiric work to be carried out in the project, BIOUP will also study the different energy supply options for the generation of green H_2 through HOMER and XENDEE energy simulators, in order to design a competitive strategy to implement this kind of technology in a real scale, depending on the renewable energy scenario of different locations. EXPECTED RESULTS The conclusions obtained in the project will make it possible to establish the application settings of the BIOUP technology in a real environment in existing or newly built WWTP. Among the main aspects and improvements to be achieved with the project, the following stand out:

- Through one stage or two stage strategies, to produce biomethane that meets the specifications for use as transportation fuel (>90% CH_4) and for injection into the network (>95% CH_4).
- Obtain a "power-to-gas" system that allows improving the energy performance of the WWTPs, generating 0.4 kW/m^3, with the aim of promoting the energy self-sufficiency of these facilities or becoming a source of extra income by injecting biomethane (which price ranges between 50 and 150 €/MWh) into the gas network.
- Demonstrate that an energy improvement of up to 25% per kg of TSS treated can be achieved compared to conventional systems by enriching the biogas stream and reducing the aeration needs to remove nitrogen.
- Contribute to the circularity of water sector by boosting the energy recovery of WWTP sludge.

Keywords: Power-to-gas; In situ; Ex situ; Biogas; Anaerobic digestion

SH 14

Making green hydrogen "greener": thin-film nanocomposite RO membranes for lowering energy use in ultrapure water production

Alvaro Lagartos

LG Chem, Barcelona 08329, Spain
Tel. +34 647674355; alagartos@lgchem.com

Climate change and global warming urgently require the adoption of low-carbon-footprint technologies to mitigate their impacts. One significant consequence of these environmental shifts is the increasing scarcity of water, notably in Europe and the Mediterranean region, which are particularly vulnerable to extended droughts. Hydrogen holds promise as a potential solution to reverse this trend. As a fuel for internal combustion engines, it emits no carbon dioxide, the primary greenhouse gas. Hydrogen can be sourced from various chemical processes, categorized by their environmental impact as grey, blue, turquoise, or green. Green hydrogen is produced through the electrolysis of

water, using electricity derived solely from renewable energy sources. Ultrapure water, characterized by an electrical conductivity of less than 1 µS/cm, is crucial for hydrogen production via electrolysis. An estimated 9 kg of ultrapure water is required to produce 1 kg of hydrogen. Various water sources, including groundwater, municipal water, surface water, wastewater, and seawater, can be treated to generate ultrapure water. Among the available water treatment technologies, reverse osmosis (RO) is a leading method for demineralization and desalination. Seawater is an ideal feedwater source for ultrapure water production due to its high availability. However, its high dissolved solids content necessitates significant energy expenditure for treatment. Lowering the energy requirements for seawater treatment can thus make hydrogen production more efficient. While RO is a highly efficient desalination technology, it demands considerable energy to generate the necessary pressure, especially when treating seawater. Optimizing energy use in RO processes can consequently lower the overall operational expenses (OPEX) of hydrogen production facilities. LG Water Solutions has developed RO membranes that utilize cutting-edge Thin-Film Nanocomposite (TFN) technology. These membranes achieve up to 99.89% salt rejection, the industry's highest rate. Because of their superior rejection capabilities, TFN membranes operate at lower feed pressures compared to conventional thin-film composite (TFC) membranes. This translates to energy savings, particularly in producing ultrapure water for green hydrogen. This paper will evaluate seawater RO systems that treat water from the Mediterranean Sea to generate ultrapure water in green hydrogen production. It will offer a comparative analysis of innovative TFN and conventional TFC membranes, focusing on differences in OPEX, capital expenditures (CAPEX), and water quality. The study aims to demonstrate how higher-rejection membranes can reduce energy requirements in hydrogen production, thereby making green hydrogen "greener."

Keywords: Green hydrogen; Ultrapure water; Desalination; Reverse osmosis; Thin-film nanocomposite; Renewable energy

SH 15

The role of emerging technologies in growing the desalination sector in GCC Countries

Mohamed Dawoud

Environment Agency - Abu Dhabi, al Maamoura Building,
Abu Dhabi, UAE
Tel. +971 503129571;
mdawoud@ead.gov.ae, dawoud.ead@gmail.com

Due to the rapid growth in population and economic development, it is expected that the total annual GCC water demand will increase by 40% in 2030 and may reach more than 50 Billion cubic meters (BCM). With the deficit in renewable freshwater, desalination is considered as the strategic option for water supply. The current daily GCC desalination capacity is about 18.2 million cubic meters (about 6.64 BCC annually) with a prediction to be increased by about 40% by 2030. Holding an impressive 54% of global water desalination capacity and about 40% of the total global production, GCC countries aim to boost this by 37% over the next five years, with an investment of about US $100 billion to address their water requirements and to overcome the gaps. The desalination industry in GCC countries experienced a substantial growth of about 17.3% (2-14-2017). By 2018, it achieved a remarkable total installed capacity of 95 million m^3/d. At present (2022), desalina-

tion plants fulfil the domestic and partially agriculture water supply needs of GCC countries. The popularity of this technology in the region is evident, with an anticipated annual capacity reaching 9000 million m^3 by 2030 (24.65 m^3/d), highlighting its pivotal role in addressing water demands in GCC region. About 65% of the desalination capacities at present (2022) are thermal and only 35% are RO membrane technologies. Desalination's energy needs depend on the process, scale, and efficiency. RO membrane technologies, more energy-efficient than thermal methods, and are gaining traction for future extension. They constitute 60% of capacity in Oman and around half in Saudi Arabia, reflecting a global shift towards sustainable desalination practices. The carbon footprint is 3.0 and 2.5 kg/m^3 for the thermal and RO desalination technologies respectively. GCC countries aim to boost their capacity by 37% over the next five years, by investing about US$100 billion to address their freshwater challenges. The GCC desalination sector capacities, socio-economic aspects, brine water discharge, carbon footprint, energy consumption and costs were discussed. The different GCC desalination policies, their environmental impacts, the emerging techniques, which could help to reduce the environmental negative impact, energy use and costs were also assessed. Different mitigation strategies to lower the environmental impacts and reduce the desalination cost are analysed. The results indicating that emerging and innovative technologies promise up to 17% annual energy savings in desalination sector in GCC countries by 2030. The study recommended to carry out detailed environmental impact assessment before the construction of any new desalination plant or prolonging the capacity of the prevailing one for limiting the adverse impact of the facility. It has been found that, the use of renewable energy in desalination is recommended as an impressive idea to reduce the environmental impacts and energy costs.

Keywords: Desalination; Carbon footprint; Environmental impacts; GHG emission; Emerging technology

SH 16

Sustainable green hydrogen production with Toyobo MC's hollow fiber membrane technologies

Takahito Nakao*, Joomi Han

Toyobo MC Corp., 1-13-1 Umeda, Kita-ku, Osaka 5300001, Japan
**Corresponding author*
takahito_nakao@toyobo-mc.jp; joomi_han@toyobo-mc.jp

1. Introduction

The worldwide transition to green hydrogen is vital for sustainable energy and climate action. One of the most promising hydrogen production processes is sourced from desalinated water, obtained through seawater desalination, as well as renewable sources like wind and solar power, providing a cleaner alternative. Recent research has primarily focused mainly on efficiently producing green hydrogen, often overlooking byproducts such as concentrated seawater and waste heat generated during the process. Exploring methods to repurpose these could boost process sustainability, trimming waste and enhancing efficiency. Our study introduces Toyobo MC's hollow fiber membrane technologies for more sustainable hydrogen production.

2. Toyobo MC's technologies applicable to hydrogen production process

Here, we assume the hydrogen production using seawater as a feed solution. We require a

two-step process: the first involves desalination and subsequent purification processes to generate ultra-pure water, while the second process entails electrolyzing the purified water to produce hydrogen. The desalination process produces concentrated sea water called brine, while the hydrogen production by PEM (proton exchange membrane) electrolysis process produces waste heat as byproducts. Concentrated seawater (brine) from desalination raises environmental issues. Proper management is crucial for sustainable water practices. In recent years, ZLD (zero liquid discharge) and valuable minerals recovery from brine have been under consideration. Toyobo MC has developed the hollow fiber membrane for OARO (osmotically assisted reverse osmosis) which is a highly efficient process for concentrating high salinity brines to nearly saturated concentration with far less energy consumption than the existing technologies.

Furthermore, We can leverage the waste heat generated during the water electrolysis process for desalination, specifically in the forward osmosis (FO) process, especially for the draw solution regeneration stage.

By using the waste heat from electrolyzer for the draw solution regeneration of FO process, we can effectively reduces the energy consumption in the desalination process. Ideally, producing water for electrolysis through FO could enhance the overall sustainability of green hydrogen production.

Additionally, we can help reduce the energy consumption during the hydrogen storage in salt cavern by our hollow fiber membrane technology. Hydrogen storage in salt cavern provides secure, long-term storage with minimal land use. The geological stability, impermeability, and low hygroscopicity of salt enhance safety and efficiency. This method is particularly effective in Europe and North America, supporting large-scale deployment of hydrogen for clean energy. The salt cavern is constructed artificially by injecting water into the underground rock salt layer. We can utilize the brine expelled from the salt cavern as an energy source for pressure retarded osmosis (PRO) energy generation.

We have successfully developed commercial-sized hollow fiber membrane modules for OARO, FO, and PRO, with numerous pilot and commercial applications worldwide.

3. Conclusion

Toyobo MC's hollow fiber membrane technologies hold the potential to be applied in a sustainable green hydrogen production process. We already developed commercial-sized membrane modules and have strong track records in commercial applications. We wish to introduce the applicability of our technologies to the green hydrogen process, including our commercial achievements.

Keywords: Hollow fiber membrane; Osmotically assisted reverse osmosis; Forward osmosis; Pressure retarded osmosis; Hydrogen

SH 18

Pushing the boundaries of innovation: membrane-based crystallization for sustainable brine valorization

Noura Chehab*, Nikolay Voutchkov, Hussain Bukannan, Mohammed Alsindi

NEOM, Neom 12435, Saudi Arabia
**Tel. +966 547047066, noura.chehab@neom.com*

NEOM is the planned independent economic zone in the Northwest of Saudi Arabia. NEOM will depend on desalination to produce drinking water. Desalination, however, necessitates the production

of brine, which is considered as valuable by-product by NEOM. Traditionally, brine was produced as a byproduct of desalination processes and was typically released into the sea. The emphasis, however, is gradually turning toward environmentally sustainable alternatives. This research proposes a revolutionary technology for brine valorization, with the goal of extracting individual minerals from brine. The membrane-based crystallization technology substitutes traditional thermal evaporation processes with brine concentration and crystallization technologies based on membranes.

The use of a membrane crystallizer based on forward osmosis (FO) principles allows for the extraction of a wide spectrum of minerals from seawater or brackish water brine. The process involves crystalizing the selected minerals on the surface of the membrane as a result of osmotic pressure difference created by draw solution with higher osmotic pressure than the mineral.

This device has three distinct advantages. Initially, the smooth-surfaced membrane prevents scaling and encourages the formation of small crystals, which eventually detach and amass in a collection basin. Second, an osmotically assisted reverse osmosis (OARO) system reconcentrates the diluted draw solution internally, allowing it to be reused for crystallization. Finally, the system shows the ability to extract commercially valuable minerals from seawater by employing FO. Energy associated with membrane crystallization is an order of magnitude lower than that needed for thermal evaporation and crystallization.

This novel technology of brine processing helps to a more sustainable and ecologically friendly desalination processes by boosting water recovery, improving energy efficiency, and recovering valuable minerals from brine.

Keywords: Brine valorization; Membrane-based crystallization; Advanced desalination technology; NEOM

SH 19

DMF media depth increase for the improvement of DMF performance

Eslam Alwaznani, Byungsung Park*, Abdulrahman Abutaleb

Saline Water Conversion Corporation, Al Khobar 31951, Saudi Arabia
Tel. +966 597207788; poet0921@gmail.com

Granular media filtration is the most commonly used pretreatment process of seawater reverse osmosis (SWRO) desalination plant in Middle East. DMF media depth is the critical parameter of DMF design. It affects its performance as shown in the Silt Density Index (SDI) and filter run time. Pilot testing was conducted for the effect of media depth on the filter performance. The performance of granular media filter was increased by media depth increase. When depths of sand or sand and anthracite were increased, SDI was decreased, and filter run time was increased. These results can apply to both existing plants and new plant design. In case of an existing plant, filter's performance will improve. But, in case of a new plant design, the required footprint of DMF can be reduced. This pilot test result applied to a new plant design in Shoaiba SWRO ph.4 plant. The filtration velocity of DMF increased to 9.1 m/h from 7.0 m/h. It reduced the number of filter unit. Accordingly, it reduced total backwashing time, rinse time and energy consumption. This pilot test result applied to the existing Ras Al Khair SWRO plant modification. Sand layer depth increased by 900 mm from 600 mm. It made lower SDI and longer filter run time.

Keywords: Dual media filter; Filtration velocity; Media depth

SH 20

Boron removal in a cascade by high seawater temperature

Aristotelis Komodromos

Vasilicos Desalination plant Manager, Electricity Authority of Cyprus, Vasilicos Power station, Limassol 3722, Cyprus
Tel. +357 24207050; email: akomodro@eac.com.cy

Boron removal during summer in the south of Europe is a very tough task and needs such an infra structure enables a plant operator to manage this very important part. Limits Values of Boron below 0.5 ppm is indeed a challenge for every operator in the south of Europe. in the presentation we will explain how an operator copes with and which parameter's are the most valuable and significant in order to meet the limits.

Keywords: Boron; Removal; Cascade; Temperature; Pressure

SH 21

Renewable energy-driven desalination by forward osmosis

Joomi Han*, Takahito Nakao

Toyobo MC Corp., 1-13-1 Umeda, Kita-ku, Osaka 5300001, Japan
Tel. +81-6-6348-3360; joomi_han@toyobo-mc.jp

Introduction

Currently, water and sustainable energy supply are among the most critical challenges. While reverse osmosis has become the mainstream technology in seawater desalination, there is a need for new advancements in terms of energy efficiency. Forward osmosis presents new possibilities. The adoption of forward osmosis (FO) offers an opportunity to use energy more efficiently. By combining FO and renewable energy in the seawater desalination process, it is anticipated that a more efficient and environmentally friendly water production can be achieved. This study introduces the use of FO desalination system using TOYOBO MC`s membrane and renewable energy.

FO desalination system with renewable energy

FO process is a technology utilizing an osmotic pressure difference between two types of solutions (i.e., Feed Solution: FS, and Draw Solution: DS) as a driving force and obtaining a water permeation through a semi-permeable membrane without applying any pressure. Therefore, compared to reverse osmosis (RO) process, FO process is expected to be an energy saving process. There are various types of solutions in DS, however regenerating them requires much energy. This energy can be supplied using renewable energy sources. Renewable energy sources for regeneration can include Concentrated Solar Power (CSP) and waste heat sources from factories, among others. By utilizing renewable energy for this purpose, not only can energy efficiency be achieved, but it also enhances the stability and sustainability of water supply.

Hollow fiber type CTA FO membrane and its commercial usage

TOYOBO MC has developed commercial sized hollow fiber type FO membrane module made of cellulose triacetate (CTA). This membrane module has great advantage in FO system with its characteristics. For example, hollow fiber type membrane has small wall thickness, and it minimizes concentration polarization of the membrane. Also, CTA has chlorine resistance which helps stable operation. We tested commercial sized FO membrane module and achieved stable operation result. TOYOBO MC FO membrane module has been introduced pilot plant with the product water capacity of 500 m^3/d using renewable energy in remote island where the transition to the renewable energy is required.

Conclusion

Green hydrogen, a pivotal component in the transition to a sustainable energy future, is often produced with water purified using RO driven by the combustion of fossil fuels. This practice raises concerns about the authenticity of "green" hydrogen. To address this, introduce FO systems powered by renewable energy sources as a promising alternative. TOYOBO MC has developed a commercial sized FO membrane module, and it has been implemented in commercial projects utilizing renewable energy sources. The utilization of a FO system powered by renewable energy sources contributes to a closer alignment with green hydrogen production principles.

Keywords: Forward osmosis; FO membrane; Hollow fiber membrane; CTA; green hydrogen; desalination; renewable energy

SH 22

Post-treatment optimization algorithm for large-scale desalination assets

Ratul Das*, Muhammad Ghifari Ridwan,
Hussain Basamh, Ahmed Yousry, Thomas Altmann

ACWA Power, Thuwal 23955, Saudi Arabia
**Tel. +966 500699425, rdas@acwapower.com*

In this century, the adage of water promotes life, energy fuels the economy, is widely echoed not only by the one with scarce resources but also by the abundant one. This phenomenon is driven by not only the population growth but also the increase in water and energy consumption per capita. In areas with limited freshwater resources, the dependency on low-cost and energy-efficient technology to generate freshwater is a critical issue. More importantly, for humans, sustained access to freshwater is a matter of life and death. Seawater reverse osmosis (SWRO) offers a proven technology to generate freshwater with a low-cost and energy-efficient process. However, there are many areas where this technology can be more efficient. One of the major sources of operational cost in SWRO is post-treatment chemical cost. In general, the post-treatment is a process to alter the chemical composition of permeate water to meet the final requirement of the potable water by dosing chemicals. The chemical type is divided into three main categories, which are remineralization chemicals, pH correction chemicals, and disinfection chemicals. While typical post-treatment chemical reactions are widely known, the feasibility of implementing such

a theoretical framework is limited. In day-to-day operations, the operator is facing thermophysical fluctuations such as temperature and pressure fluctuations. These fluctuations are not only changing the chemical reactions output but also changing the permeate quality output from membrane racks. These neglected fluctuations can lead to chemical underdosing or overdosing. Hence, we introduce an algorithm that can provide the feedback of real-time optimized dosing, anticipating the fluctuations during the operations. The algorithm is expected to minimize the chemical cost while maintaining the quality of potable water within the limit required by the off-taker.

Keywords: Reverse osmosis; Data-driven analytics; Diagnostic; Cleaning in place; Forecasting

SH 23

Ultrafiltration performance monitoring system

Hussain Basamh*, Thomas Altmann, Ratul Das

ACWA Power, Jeddah 23545, Saudi Arabia
Tel. +966 566362219; hbasamh@acwapower.com

Overcoming water scarcity is one of the main challenges, and seawater desalination is used globally to overcome it and provide safe and clean potable water. Now with almost all new desalination plants using reverse osmosis (RO), the pre-treatment processes become vital in order to maintain RO membranes performance and lifetime by minimizing the risk of membrane fouling. Depending on the design, one of the significant components used in pre-treatment is ultra-filtration (UF). Combining UF with RO system helps control the RO membrane fouling and provides filtered water at steady state conditions, enhancing RO desalination plant reliability. Having multiple UF skids in desalination plant requires monitoring several parameters to keep permeability, transmembrane pressure, feed flux, backwash and chemical enhanced backwash in check. To help achieve this goal, we present a data-driven approach which calculates, and monitors above parameters that can generate insights on the state of each UF skid. This approach is based on historical plant data. The software is expected to help reduce membrane fouling by providing data and insights that can help decide the frequency of backwash and chemical enhanced backwash cycles.

Keywords: Ultrafiltration; Permeability; Transmembrane pressure; Flux; Backwash; Chemical enhanced backwash; Reverse osmosis; Data-driven analytics; Diagnostic

SH 24

Isobaric and centrifugal energy recovery devices in multistage RO, OARO, batch RO and NF systems

Rolando Bosleman, Juan Cifuentes*

Energy Recovery, Inc., 1717 Doolittle Drive, San Leandro 94577, USA
** jcifuentes@energyrecovery.com*

In recent years, water conservation is becoming a key priority all around the world and is ramping up regulations around water treatment, wastewater discharge and water reuse for both municipal and industrial activities. As part of sustainability goals, regulations are focusing on limiting both the concentration of contaminants and discharge volume, therefore water and wastewater treatment

is a crucial but oftentimes expensive processes. Processes including semi-permeable membranes to remove dissolved salts and contaminants are widely used in the water treatment industry all around the world.

The recovery rate (recovery) of a membranes water treatment system is defined as the ratio of permeate to total feed flow. The recovery is a key design parameter which, for a given plant production capacity, will help define both: the infrastructure and equipment sizing as well as expected energy and chemical consumption. These factors relate directly to the desalination plant capital expense (CAPEX) and operating expense (OPEX) respectively and ultimately to the production cost of product water.

Higher recovery membranes systems are more CAPEX efficient while lower recovery systems required lower OPEX as they tend to use less energy. This relationship implies that a water treatment plant design, given a host of other factors, most notably water quality and power cost, will have an optimum recovery, which minimizes overall water treatment costs.

The purpose of this paper is to show how membranes systems can benefit from the energy savings and added operational flexibility provided by different energy recovery technologies, therefore achieving more sustainable operations. Single-stage, multi-stage, osmotically assisted reverse osmosis (OARO), batch or semi-batch RO using isobaric energy recovery devices (and state of the art RO membranes) will perfectly work at high recovery rates with different feedwater qualities, such as brackish water or industrial waste water; and from low to ultra-high pressure (UHPRO) applications. In addition it will provide to the plant designer with much more flexibility to find the perfect CAPEX/OPEX balance demanded by its particular project structure and technical constraints.

Different configurations using isobaric energy recovery devices, centrifugal devices or a combination of both ERD technologies will be presented in the research section and the results section will include the specific energy consumption evaluation along with the advantages and disadvantages for each case applied to several membranes processes: multi-stage NF/RO, OARO, batch RO, etc,

Finally in the conclusion section, we will present the findings of this study and will open the discussion on the innovative high recovery membranes systems mentioned above and their likeability of implementation by the designers in new plants.

Keywords: High recovery; Energy consumption; SWRO; BWRO; UHPRO; OARO; NF; Batch RO; Isobaric energy recovery devices

SH 25

Utilizing seawater desalination brine to produce vaterite calcium carbonate and simultaneously store carbon dioxide

Abdallatif Abdalrhman*, Seungwon Ihm,
Christopher Michael Fellows, Ammar Alnumani

Saline Water Conversion Corporation (SWCC),
Al Jubail 35417, Saudi Arabia
**AAbdalrhman@swcc.gov.sa, eng.latief@gmail.com*

In seawater desalination plants, fresh water is recovered from seawater leaving behind a more concentrated brine, which is usually discharged back into the sea after meeting environmental regulations. However, this brine contains many components of potential economic value. Many recent studies have focused on the integration of desalination and brine utilization/mining to reduce brine discharge while improving the desalination plant's economics [1].

Calcium carbonate ($CaCO_3$), which can either be obtained from natural limestone or precipitated from calcium containing solutions, is commonly used in various industries, including paper, plastic, paint, rubber, adhesives, sealants, building, and construction [2]. $CaCO_3$ exists in three polymorphs; calcite, aragonite, and vaterite. Vaterite-type calcium carbonate is of higher economic value and has a great potential for use as a drug delivery material and a filler for bone defects due to its superior properties [3]. However, the currently used methods for producing vaterite (biomimetic–synthesis and indirect carbonation) are hindered by some critical limitations such as the need for expensive additives, solvents, or heat/ultrasound irradiation which make the process less feasible [3]. Indirect carbonation (CO_2–bubbling) method for the production of vaterite calcium carbonate has recently attracted more attention due to the fact that the process will simultaneously result in carbon dioxide capture, utilization, and storage [4]. Recently, seawater has been successfully applied as a solvent during indirect carbonation process as a replacement for the more expensive and less sustainable solvents that are usually used during the process [3, 4]. While seawater has shown to be able to act as solvent for the production of vaterite calcium carbonate by indirect carbonation, the process needs to be further enhanced to reach higher vaterite contents/purity and to better control the particle size and shape before it can be used commercially.

In this study we attempted to improve the performance and economics of the indirect carbonation process for producing vaterite calcium carbonate by using seawater desalination brine as the solvent. Seawater desalination brine has a higher ionic strength than seawater which should have two beneficial effects on product quality. Higher ionic strength reduces the surface energy of vaterite, making its formation more favourable in comparison to calcite, and encourages rapid nucleation, giving a more uniform size distribution [4]. Generally, the saturation level of $CaCO_3$ in brine is much higher than in less salty water, therefore when brine is used as an indirect carbonation solvent, $CaCO_3$ with a higher vaterite content can be produced [4]. In the present study, different types of brines with different compositions (RO and NF rejects) have been investigated as solvents for the indirect carbonation process; these have different ionic strengths and also different concentrations of cations (Na^+, Mg^{2+}) which can have specific effects on $CaCO_3$ speciation and precipitation kinetics. Cement kiln dust (CKD), an alkali industrial by-product from the cement industry that is considered a waste, was used as the source of calcium. As well as assessing the quantity and quality of vaterite produced, we compared the CO_2 storage and $CaCO_3$ yield achieved by using RO reject, NF reject, and seawater.

The production of vaterite calcium carbonate by indirect carbonation using sweater desalination brine as a solvent, and cement kiln dust (CKD) as a carbon source can be considered a huge step towards reaching the goals of building a sustainable desalination industry and establishing a circular economy. The process utilizes three different undesired waste streams; brine, CKD, and CO_2, to produce a valuable product of high value (vaterite calcium carbonate) in a sustainable manner.

Keywords: Brine mining; Sustainable desalination; Carbon capture and storage; Economics of desalination

[1] Sharkh, B.A., Al-Amoudi, A.A., Farooque, M., Fellows, C.M., Ihm, S., Lee, S., Li, S. and Voutchkov, N., 2022. Seawater desalination concentrate—a new frontier for sustainable mining of valuable minerals. NPJ Clean Water, 5(1), p.9.

[2] Y. Boyjoo, V.K. Pareek, J. Liu, Synthesis of micro and nano-sized calcium carbonate particles and their applications, J. Mater. Chem. A. 2 (2014) 14270–14288

[3] Kim, S., Jeon, J. and Kim, M.J., 2022. Vaterite production and particle size and shape control using seawater as an indirect carbonation solvent. Journal of Environmental Chemical Engineering, 10(2), p.107296.

[4] Jeon, J. and Kim, M.J., 2019. CO_2 storage and $CaCO_3$ production using seawater and an alkali industrial by-product. Chemical Engineering Journal, 378, p. 122180.

SH 26

Comparison of analytical techniques for the analysis of seawater desalination brines and mined products

Christopher East*, Hyuk Soo Son,
Noura Chehab, Nikolay Voutchkov

NEOM, Neom 49643, Saudi Arabia
**Tel. +966 534538181, christopher.east@neom.com*

The use of seawater desalination to solve the increasing water scarcity issues around the world is common practice with the total global capacity of desalination plants set to reach nearly 100 million m3 per day of potable water production by 2028 (GWI 2023). Potable water is not produced alone with these desalination plants generating vast quantities of brine, around 110 million m^3/d by 2030, which, under current practices, will be returned to the ocean. With environmental regulations only increasing and questions about the impact of desalination brine on the environment (Pérez-González, 2012) becoming more central other options for brine management are being pursued around the world, with some areas forbidding discharge to the ocean entirely.

Seawater is known to contain larger quantities of various minerals and ions with good business potential for some material types (Sajna, 2023). Minerals like sodium chloride have been mined from the ocean for centuries however, modern desalination plants produce far more brine than is practical for traditional mining methods which do not consider the brine as a whole and are more material specific. When dealing with the challenges such large quantities of brine pose under minimal liquid discharge (MLD) and zero liquid discharge (ZLD) mandates accurate analysis of the brine is paramount. The optimum configuration for processing desalination brine depends on several factors, both technical and financial, and is still currently under development with composition of the desalination bine playing a large role. The analysis cannot stop at desalination brine since it must be processed, creating various streams and products all of which also need analysis with those results feeding back into the optimum configuration design.

For large scale seawater desalination MLD or ZLD scheme to be sustainable they must sell their produced materials or pass on any financial losses on to the consumer of the desalinated water. To sell the mined products buyers expect the MLD or ZLD facility to certify that each product meets particular quality standards. This may be final products or brine being passed from one section of the MLD or ZLD facility to another, owned by different entities.

Elements and ions can be grouped into major, minor and trace levels within the solution. Due to the high matrix, analytical challenges arise for all three groups. Most analytical techniques require large dilutions to be able to handle the high salt matrix which can introduce significant errors, particularly for the trace and minor constituents. Those that don't require large dilutions need special considerations to provide accurate results. Furthermore, limited analytical techniques for ions like chloride and bromide further compound the problem leading to large discrepancies in mass balance and charge balance of streams.

This paper discusses some of these challenges and offers some analytical solutions to increase the accuracy of analysis.

Keywords: Analysis; Brine; Zero liquid discharge; Sodium chloride; Bromide

References

GWI, DesalDATA, 2023. Market Focus Deck Desalination and Reuse October 2023

Pérez-González, A., Urtiaga, A.M., Ibáñez, R. and Ortiz, I., 2012. State of the art and review on the treatment technologies of water reverse osmosis concentrates. Water research, 46(2), pp.267-283.

Sajna, M.S., Elmakki, T., Schipper, K., Ihm, S., Yoo, Y., Park, B., Park, H., Shon, H.K. and Han, D.S., 2023. Integrated seawater hub: A nexus of sustainable water, energy, and resource generation. Desalination, p.117065.

SH 27

Control of bromate formation in desalinated seawater production and transmission

Christopher Fellows*, Ali A. Al-Hamzah,
Abdulrahman S. Al-Ofi, Abdulrahman A. Abid

Saline Water Conversion Corporation, Villa 208, Bajrai Garden Village,
King Abdelaziz Rd, Jubail 31951, Saudi Arabia
**Tel. +966 594171150; email: cfellows@une.edu.au*

A significant public health concern in any system where potable water is stored or transported is the possibility of the formation of disinfection by-products. Disinfection is a necessity to avoid bacterial contamination of drinking water, but the oxidizing species used can generate a range of potentially toxic and carcinogenic species from trace components of the produced water [1-4]. When water contains bromide ions, one of the most significant of these disinfection by-products is the bromate ion, BrO_3^- [5].

Historically, bromate control has been an issue primarily in surface and ground water treatment with ozonation, and there is a considerable body of research literature addressing control measures for this problem [6]. Recent interest in bromate control in the Kingdom of Saudi Arabia in waters treated by chlorination rather than ozonation arises from a unique combination of factors: (1) increasing use of seawater desalination by reverse osmosis (SWRO), rather than thermal methods, which leads to product water with a higher concentration of bromide; (2) mixing of product water with surface and ground waters containing significant amounts of bromide before transmission; (3) transmission of the majority of produced water over lengthy pipelines (>100 km) at relatively high temperatures, giving more opportunity for formation of disinfection by-products. While SWRO is a well-established technology in many parts of the world, outside of the Kingdom of Saudi Arabia it is used almost entirely to serve coastal centres where it is consumed in close proximity to its point of production. These factors have led to challenges in consistently meeting the 10 ppb maximum limit set by regulatory authorities in the Kingdom of Saudi Arabia [7].

One approach that has been successful in controlling bromate formation in ozonation of freshwaters is addition of ammonia [8]. This interrupts the process of bromate formation by converting the intermediates hypochlorite and hypobromite to haloamines [9,10]. Haloamines also act as disinfectants and are stable over typical timescales for storage and transmission of water in the Kingdom of Saudi Arabia.

This presentation reports on current trials of ammoniation of product water at the Shoaibah Phase 2 desalination plant, which provides water to an extensive network of pipelines leading to inland centres in Makkah al-Mukarramah province. In these trials we have demonstrated that ammoniation at levels of ammonia as low as 100 ppb can effectively control the formation of bromate

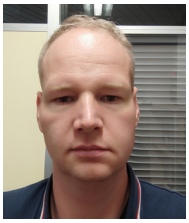
in water produced by seawater desalination on the commercial scale. Preliminary results suggest that the formation of brominated organic disinfection products was also controlled by this treatment. Trends in nitrate concentration suggest that the addition of ammonia is not contributing significantly to the nitrate load in the product water. Most importantly, bromate control effects of ammonia addition were observed at water storage sites hundreds of kilometers from the seawater desalination plants under summer temperatures, suggesting that the course of treatment employed will control bromate formation in the transmission lines. Further trials are ongoing within the SWCC network in order to explore ammoniation as a cost-effective method for control of brominated disinfection by-products.

Keywords: Bromate; Disinfection byproducts; Seawater desalination; Transmission; Post-treatment; Ammonia

[1] G.A. Boorman, 1999. Environ. Health Perspect. 107, 207-217.
[2] X.-F. Li, W.A Mitch, 2018. Environ. Sci. Technol. 52, 1681-1689.
[3] J.S. Benítez, C.M. Rodríguez, A.F. Casas, 2021. Phys. Chem. Earth A/B/C 2021, 123, 102987.
[4] E. Agus, D.L. Sedlak, (2010). Water Res. 44, 1616-1626.
[5] V.K. Sharma, R. Zboril, R., T.J. McDonald, 2014. J. Environ. Sci. Health B 49, 212-228.
[6] For example, M.G. Antoniou, C. Sichel, K. Andre, H.R. Andersen, 2017. J. Hazard. Mater. 323, 452-459; T. P. Bonacquisti, 2006. Toxicology 221, 145-148; M. Gregov, A. Jurinjak Tušek, D. Valinger, M. Benkovic, T. Jurina, L. Surac, L. Kurajica, M. Matošic, J. Gajdoš Kljusuric, M. Ujevic Bošnjak, J. Curko, J. 2023. Water, 15, 1516; F. Soltermann, C. Abegglen, M. Tschui, S. Stahel, U. Von Gunten, 2017. Water Res. 116, 76-85.
[7] Ministry of Environment, Water and Agriculture, A.H. 1442. Standards and Specifications for Water Types, Kingdom of Saudi Arabia; Ministry of Environment, Water and Agriculture, A.H. 1444. Guide to Monitoring Unbottled Drinking Water Quality Standards in the Water Service Delivery Chain.
[8] K. Ikehata, L. Wang, M.B. Nessl, A.T. Komor, W.J. Cooper, R.R. McVicker, 2013. Ozone Sci. Eng. 35, 438-447.
[9] C.T. Jafvert, R. L. Valentine, 1992. Environ. Sci. Technol. 26, 577-586.
[10] J. E. Wajon and J. C. Morris, 1982, Inorg. Chem. 1982, 21, 4258-4263.

SH 28

Ion exchange column eluates desalination: ZLD concept by using electrodialysis



Lukáš Václavík*, Lukas Sedlak, Katerina Knapcíková

MemBrain, Inc., Pod Vinicí 87, Stráž pod Ralskem 47127, Czech Republic
**Tel. +420606671828; lukas.vaclavik@membrain.cz*

The main objective of the our work was to contribute to the research on a project focused on desalting eluates from IEX (ion exchange column) using the Zero Liquid Discharge (ZLD) concept, which generates no liquid waste. Water treated in this manner has no negative environmental impact. The work involved the comparison of three types of membranes in a semi-operational unit for three different saline solutions. Each type of used membrane consists of a textile substrate coated with an ion-exchange material. Consequently, the membranes possess different properties such as porosity and thickness, which directly affect their ion transport capabilities.

The first two types of membranes were made from the same material but were coated on different support materials. The remaining two membranes also had different material compositions. Working conditions were kept constant for all experiments, and changes in pH values in the dilu-

ate and concentrate were monitored. The outcome of each experiment was the salt flux density through the membrane and the energy consumption for transporting 1 kg of salt.

The first saline test was conducted using a pure sodium sulfate solution with an initial concentration of 20 g/L. This test determined the process efficiency. In the subsequent two tests, a model mixture of multiple salts was used as the feedstock, with an initial concentration of 7.5 g/L in the first concentration test and a concentrate produced from the first test with a concentration of 26 g/L in the second concentration test. This approach allowed us to test all the membranes under three different conditions, providing insights into the most practical membrane to use and its limitations.

For the sodium sulfate salt test, the membranes MITI MEGA emerges as the best alternative, achieving a current efficiency of 92% on the positive side and 87% on the negative side. Both of these values are the highest when compared to the other membranes. The energy consumed for transporting 1 kg of salt in this test is 430 Wh. Similarly, for the first concentration test, the MITI MEGA membranes appears as the most suitable alternative. The salt flux density through it was 11% higher than with the other membranes, all of which exhibited similar values. As a result, the energy required to transport 1 kg of salt through this membrane was the lowest compared to the other membranes, at 583.5 Wh, which is 25.6 Wh less than the second-lowest value observed with the OASIS membrane. In the second concentration test, the best results were obtained with the MITI MEMBRAIN membrane. The energy consumed for transporting 1 kg of salt was 6% lower than with the OASIS membrane and 12% lower than with the MITI MEGA membrane.

The essence of this work was to select the most suitable membrane for desalination of eluates from ion exchange column. The research results suggest that the MITI MEGA membranes performs best at low concentrations (20 g/L or less). However, at higher concentrations exceeding 20 g/L, this membrane does not yield satisfactory results, and it is preferable to use the MITI MEMBRAIN membranes. These differences between the membranes are due to their distinct structures, as different support materials are used in their production, which can result in varying membrane porosity and thickness.

Keywords: Zero liquid discharge; Ion exchange column; Eluates; Ion exchange membranes; Electrodialysis reversal

SH 29

Experimental study and artificial intelligence modeling of a novel prismatic shaped solar distiller with feed spraying nozzles

Mohamed E. Zayed*, Ammar H. Elsheikh, Bashar Shboul, Ahmed Menesy, Kashif Irshad, Shafiqur Rehman

King Fahd University of Petroleum and Minerals, Room3065, B15, Box 76, Dhahran-31261, Saudi Arabia
**Tel. +966 50849951 4; mohamed.zayed@kfupm.edu.sa*

Augmenting the surface area for vaporization in solar distillers by implementing innovative configurations is a cost-effective approach to maximize the production of distilled water compared to traditional solar stills. This study introduces a novel prismatic-shaped solar distiller with wick materials and feed spraying nozzles to boost vaporization rates in the distillation basin, thereby increasing freshwater yield. Two solar distillers were constructed and tested: a modified double slope solar still with a prismatic wicked basin and spraying nozzles (MSS) and a reference double

slope solar still (RSS). Additionally, a hybrid machine learning framework was developed, integrating a relevance vector machine (RVM) fine-tuned through a simulated annealing algorithm (SAA). This model aims to predict saltwater temperature and associated freshwater output in the two examined solar distillers, considering time, solar flux, wind velocity, and ambient temperature as inputs. SAA optimizes the RVM model by determining optimal parameter values to enhance its performance. The experimental findings indicate that the daily freshwater production for the MSS reached 7.94 kg/m²/d, surpassing the RSS, which achieved 5.31 kg/m²/d. This signifies a substantial 49.53% improvement in freshwater production compared to the RSS. Furthermore, the daily energy efficiency of the MSS and RSS was assessed at 57.40% and 39.80%, respectively, while the daily exergy efficiency was 3.80% and 2.20%, respectively. These results represent a notable increase of 44.23% and 72.74% in energetic and exergetic efficiencies, respectively, over the RSS. Furthermore, the prediction findings demonstrated that, the RVM-SSA and typical RVM models predict the distilled production of the MSS with determination coefficient values of 0.9999 and 0.9821, and root mean square error values of about 0.00071, and 0.0029, respectively Consequently, the RVM-SSA model is recommended as a promising prediction tool in predicting the production of both solar distillers.

Keywords: Prismatic-wicked shaped solar distiller; Spraying nozzles; Comparative experimental analysis; Hybrid machine learning framework; Relevance vector machine; Simulated annealing algorithm

SH 31

BioPhree: next generation solution to remove and re-use phosphate; no more biofouling in membrane systems?

Pim de Jager*, Raimonda Busiauskaite, Koos Baas

Aquacare, Graaf van Solmsweg 56 – 58, 's-Hertogenbosch 5222 BP, The Netherlands
**Tel. 0644014789; pdjager@aquacare.nl*

Biofouling can cause a severe loss of performance in membrane systems. In many membrane systems periodic cleaning is done to remove biology that causes fouling. In this presentation we will present an alternative treatment method to prevent biology from growing in the first place. Biofouling can occur when a carbon source and essential nutrients are present in non-sterile water. Phosphate is one of these essential components in all forms of biology, being a building block in DNA and cell membranes. By removing dissolved phosphate from the influent water, the risk of biofouling can be greatly reduced or even prevented, thereby also reducing the need of chemical for biological cleaning drastically.

BioPhree is a process developed at Aquacare and Wetsus and is based on adsorption. Dissolved phosphate is adsorbed using an adsorbent material, and the effluent contains less than 10 ug/l phosphate, low enough to prevent eutrophication. The adsorbent can be regenerated for re-use, during which a very concentrated phosphate stream is produced that can be used as a resource. Aquacare has worked on developing this technique for years and the first pilot scale installations are currently operational. A new fully automated system is now being demonstrated in the EU project "Water Mining", where a BioPhree installation is treating effluent water as feedwater for a complex membrane system up to RO level. An overview of the technology together with achieved results and potential in membrane systems will be presented.

Keywords: P-removal; Fouling control; Water treatment

SH 32

Control of the ionic composition of membrane product water to improve its quality and reduce concentrate discharges

Alexei Pervov*, Htet Zaw Aung, Dmitri Spitsov

Moscow State University of Civil Engineering,
26, Yaroslavskoye Shosse, Moscow 129337, Russia
**Tel. +79857667644; ale-pervov@yandex.ru*

In drinking water supply to treat water that contains halogenocarbons, often ozone sorption technologies are used that require high operational costs. It was already proven that nanofiltration (NF) membranes easily remove color (high molecular organics) and volatile organics (presented by halogenocarbons). But the application of nanofiltration technology also has some disadvantages connected with the existence of concentrate effluents and the high rejection of ionic and organic species, which results in low hardness and TDS of the product water. It was already mentioned that divalent calcium and magnesium ions are better rejected by membranes, and monovalent pollutants and volatile organics (halogenocarbons) are poorly rejected. The article also demonstrates low rejection of trihalomethanes (chloroform) by NF membranes. Thus, to remove chloroform, a relatively high rejection membrane should be selected that produces low TDS and low hardness in the product water. This requires further conditioning of membrane-product water to meet WHO drinking standards. The presented research describes a new approach to separate poorly rejected and efficiently rejected water species to control product water composition: to increase TDS and calcium content with a low chloroform concentration. Chloroform was selected as a model halohenocarbon impurity that is easily determined using a well-known technique. The increase in product water TDS also reduces the amount of salt discharged with concentrate and facilitates further concentrate flow rate reduction and concentrate utilization.

A series of experiments were conducted to remove hardness and dissolved organic foulants from the surface water to demonstrate the efficiency of the newly developed method of ion separation. Experimental results of permeate and concentrate separation are presented that demonstrate the increase of calcium and TDS in the product water by 4–5 times compared to permeate produced using RO and high-rejection NF membranes. Experimental dependencies of different contaminants removal as a function of recovery values are presented. A flow diagram of the developed process is demonstrated based on experimentally obtained results.

The article also demonstrates the results of calculations to evaluate total operational costs for cases where concentrate is reduced by 100–150 times in volume and is withdrawn together with the dewatered sludge as sludge moisture.

The use of the developed method enables us to reduce operational costs due to lower membrane replacement costs, reagent consumption, and concentrate discharges. The presented data indicate that the application of the developed ion separation method reduces total operational costs by 35–45%. An economic comparison has been performed with the operation of conventional membrane installations that remove excessive halogenocarbons, hardness, and color from the surface water.

Keywords: Reverse osmosis; Nanofiltration; Membrane rejection; Concentrate disposal; Trihalomethanes removal; Sludge dewatering; Sludge moisture

SH 33

Membrane autopsies, an essential tool in you toolbox

Joshua Utter, Daniele Strongone*

American Water Chemicals, Barcelona, Spain
**Tel. +34 607434945; dstrongone@membranechemicals.com*

Membrane-based treatment processes are more often being called on to treat increasingly challenging waters while existing systems are being asked to tackle increased recovery and water quality demands. However, achieving these performance targets remains a struggle for many processes. Higher recoveries are leading to more challenging fouling and scaling conditions, while more exotic feed waters are requiring novel treatment solutions. Membrane autopsies can be an essential tool in a water treatment professional's toolbox in diagnosing process failures and correcting any productivity losses from these increasingly challenging conditions. This can range from identifying the required changes to pretreatment to changes in the cleaning protocol.

Autopsies can be performed on high pressure membranes like reverse osmosis (RO and SWRO) and nanofiltration (NF), or on low pressure membranes such as microfiltration (MF) or ultrafiltration (UF) and membrane bioreactors (MBR). Performing autopsies on pre-treatment cartridge filters, or even SDI filters can also provide very useful information about contaminants entering the membrane system.

To harness the full potential of autopsies, water treatment experts must comprehend the information autopsies provide and how it can be effectively utilized. This includes understanding what can be determined and what cannot. This presentation will feature an illustrative case study discussing the autopsy process and how to interpret and apply the results.

Keywords: Membrane autopsy; Reverse osmosis; High recovery; Scaling; Fouling; Laboratory

SH 34

Green and circular value creation from desalination brines

Antonino Campione*, Delia Pastorelli, Andrea Cipollina, Fabrizio Vicari, Fabrizio Vasallo, Giorgio Micale

**Suez International, Paris 75017, France*
Tel. +33787151283; email: antonino.campione@suez.com

Current environmental concerns push us towards the adoption of circular schemes able to mitigate the impact of desalination plants. At the same time, certain regions of the globe suffer from scarcity or difficulty of supply for certain chemicals that are either normally used in desalination plants or also applied in other industries. As an example, EU has identified a list of critical raw materials (CRM) for which the aim is to reduce the interdependency from other countries that put the supply at risk for geopolitical reasons.

A novel patented treatment line is hereby presented, being able to overcome the abovementioned criticalities of supply and sustainability. The line can treat a part of desalination brine with the aim of producing valuable products such as:

- CO_2 that can be back fed to the desalination plant to provide the drinking water with the desired alkalinity
- A mineral mixture of Ca and Mg that can be used to provide hardness to drinking water
- Magnesium-based compounds to be integrated in wider circular economy scheme (e.g. coupling with a wastewater treatment plant) or to be sold to the external market
- Acid and base to provide full circularity to the scheme and for general internal use in the plant (e.g. seawater feed pre-treatment, membrane cleanings, chemicals production, etc.)

Most of all, the chemicals production can be achieved by having a net reduction in the CO_2 emission, contributing to the sustainability of the plant.

The performances of the ResourSEAs-SUEZ co-invented solution are currently being tested in a dedicated pilot phase in order to optimize the integration of the different blocks. While the preliminary results have already shown that this scheme could provide an efficient and higher quality of the fresh water produced, along with an overall reduction in the water tariff, the ongoing tests are providing useful insights on the technical robustness of the processes involved.

Keywords: Brine recover; Valorization; Desalination; Remineralization; Magnesium

SH 35

The critical concentration polarization (CP) of colloidal biofilm precursors in seawater reverse osmosis (SWRO)

Harvey Winters*, Marisol Garcia, Eli Oklejas

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

Biofilm formation on seawater reverse osmosis (SWRO) membranes is dependent upon the concentration polarization (CP) of colloidal biofilm precursors and lectin-like organics at the boundary layer of the SWRO membrane. This CP value is dependent upon the membrane flux and crossflow velocity, as well as recovery and the permeability of the SWRO membrane. Any increase in the membrane flux or decrease in crossflow velocity increases the CP of these biofilm precursors and lectin-like organics at the boundary layer of the membrane surface.

There exists a critical CP value for these organics at the membrane boundary layer which determines whether the colloidal biofilm precursors are transformed into an attached membrane biofilm through the activity of the lectin-like organics. When the CP exceeds this critical value, the dissolved biofilm precursors aggregate and initiate biofilm attachment onto the membrane surface. Analyses of the CP at various SWRO plants has confirmed a critical CP value between 1.12 and 1.13 and that the membrane biofouling only occurs at the feed-end elements where the CP is the greatest and the CP exceeds the critical CP.

In a single pass SWRO design, in order to control membrane biofouling, the system recovery must be maintained below 40% when using low permeable membranes and recovery must be maintained below 35% when using high permeable membranes. However, recovery in SWRO can be increased to 50–60% and control of membrane biofilm achieved when using seawater brine-staging which incorporate bi-turbo energy recovery to boost the operating pressure in the second

stage. This brine-staging concept lowers the CP of the colloidal biofilm precursors in each of the stages to below their critical value which inhibits membrane biofilm formation.

Keywords: Critical concentration polarization; Membrane biofouling; Seawater reverse osmosis; Brine-staging in SWRO

SH 36

Best value for SWRO plants: pre-treatment selection among technology portfolio to address clients's global needs

Caroline Barbe*, Delia Pastorelli, Emmanuelle Filloux,
Rita Serra, Sophie Bertrand

SUEZ, Paris La Defense 92040, France
**Tel. +33 0632744940; c.barbe@suez.com*

The design of the pre-treatment of a seawater reverse osmosis plant is driven by many input data: seawater quality, local civil work costs, electrical costs, customs and imports rules, type of contracts, available footprint, construction duration requested.

Suez is also adding its own criteria to address environmental concern. The most efficient pre-treatment for the future of the SWRO desalination plants is thus always challenged by considering 4 key criteria:

- Carbon footprint
- Disposal (brine and sludge)
- Treated water quality
- The best TOTEX for the end-user

To ensure a sustainable and cost-effective operation and to determine the best treatment line for a project, SUEZ developed a tool to benchmark its own products as well as external technology to be integrated. This paper underlines the need of carrying out carefully such assessment before submitting proposal, with 2 case studies: one SWRO plant where ultrafiltration was selected as pre-treatment and one with a conventional gravity filtration.

The first case highlights the environmental consideration developed all along this project and the second case shows how we can be competitive also with robust media filtration pre-treatment while keeping high environmental standards.

Defining the best pre-treatment solution for a given SWRO plant is not as easy as it seems. Indeed, many parameters must be considered and that's why SUEZ mastered a large pre-treatment products portfolio either proprietary or to be integrated.

This paper is a preview about the approach we would like to share to select the best solution according to project specifications. Costs breakdown, details on operating conditions and environmental footprint calculation will be shared in our presentation.

Keywords: SWRO pretreatment; Benchmark; Ultrafiltration; Dual media filtration; Combined flotation and filtration

SH 38

Sustainable desalination: Addressing SWRO challenges through advances antiscalant technologies

Mike Sinfield*, Daniela Vidal

H_2O Innovation, 3 Aston Way, Middlewich, CW10 0HS, UK
mike.sinfield@h2oinnovation.com

Seawater reverse osmosis (SWRO) is the primary means of generating the high-purity water required for synthesis of green hydrogen. SWRO faces many challenges, not least capital outlay, power consumption, and brine discharge. But since the first SWRO plant was commissioned in 1975, iterative upgrades in technology, processes and engineering have led to gradual increases in permeate production as well as reductions in power consumption and capital cost.

Some of these advances have arisen from the development of speciality chemicals for the SWRO industry. Biocides, flocculants, membrane cleaners and preservatives, corrosion inhibitors and chlorine reducers all have their part to part in this complex evolution of an industry, but by far the category of speciality chemical which has most improved operational efficiency of SWRO is antiscalants. Antiscalants reduce membrane fouling and increase the possible recovery of SWRO systems. Different antiscalants have been developed for different environments and there are now so many antiscalants certified and recommended for use in SWRO, that it could soon become confusing why so many are required. It might even be tempting to view all SWRO antiscalants as equal; in this work the authors intend to demonstrate that this is far from the case and propose a logical method by which operators should select an antiscalant for use in their plant.

Keywords: Reverse osmosis; Membrane desalination; Antiscalant; Seawater reverse osmosis

SH 39

Enhancing RO system sustainability by implementing an effective clean-in-place strategy

Mike Sinfield*, Asif Sheikh, Bülent Zeytinoğlu, İlker Akbaş

H_2O Innovation, 3 Aston Way, Middlewich, CW10 0HS, UK
**mike.sinfield@h2oinnovation.com*

In reverse osmosis (RO) systems, it is all but inevitable that membranes will eventually become coated in a layer of foulant. The foulant will decrease membrane permeability and increase the high-pressure pumping required to maintain constant permeate production. It is therefore essential to periodically clean membranes, removing foulant and restoring performance.

Cleaning RO membranes has become something of an art form, with a wide range of techniques now employed to improve cleaning effectiveness. In this paper, a selection of techniques are discussed, and a case study is provided to demonstrate real-world benefits to RO clean-in-place (CIP).

Extended Abstract

Commodity cleaning chemicals such as sodium hydroxide can cause damage to polyamide RO

membranes. Speciality chemicals carry less risk of damaging membranes during CIP. For example, membrane manufacturers recommend safe pH levels for CIP. The pH range is a limit, not a target. Raising the pH might remove more organic foulant, but exceeding the safe operating limits can lead to irreparable membrane damage.

An enormous range of speciality cleaners exist for RO membranes. Choosing the 'best' one requires knowledge of the foulant, system design, feed water and extent to which foulant has been allowed to build up. Some experience in membrane cleaning would also not go amiss.

It is almost unheard of to have only one foulant in a real-world RO plant. Therefore, most speciality cleaners contain a blend of active ingredients; each of which contributes to the overall cleaning effectiveness by targeting a different foulant. An example product is presented which cleans membranes in four distinct ways: high and stabilised pH for removal of organics, microbubble generation to gently agitate and lift membrane foulants, chelation of metals, and high osmotic pressure driving normal osmosis which lifts foulants away from the membrane surface. A case study example where this cleaner was successfully used is presented. The 37 m^3/h brackish water reverse osmosis (BWRO) plant in Turkey experienced very low normalised flow due to excessive foulant accumulation. Cleaning with speciality cleaner briefly restored performance, but the re-fouling rate meant that the membranes quickly dropped back well below design specification. After replacing the membranes, a more preventative cleaning protocol was employed which maintained normalised differential pressure at acceptable levels for several months.

Keywords: Reverse osmosis; Membrane desalination; Clean-in-place

SH 40

Water positive strategies which maximize permeate production and minimize power consumption in RO systems

Daniela Vidal*, Alejandro Sturniolo, Nuria Peña García, Stéphane Jarrige, Mike Sinfield

**H_2O Innovation, 3 Aston Way, Middlewich, CW10 0HS, UK*
Tel. +44 1606837605; daniela.vidal@h2oinnovation.com

Recent advancements in reverse osmosis (RO) technology have paved the way for water-positive strategies, focused on maximizing RO membrane production and minimizing power consumption through efficient cleaning.

New membrane technology, characterized by increased surface area and reduced energy and water usage, offers significant potential for enhancing RO performance. Additionally, the optimization of RO systems, including flow configuration and feed water pretreatment, presents various opportunities for minimizing power consumption and reducing wastewater treatment costs.

The integration of membrane technology into water-positive impact management strategies is gaining traction among leading corporations, such as PepsiCo, Google, Microsoft, The Coca-Cola Company, and Tesla, reflecting a collective industry commitment to sustainable water management. While the concept of water positivity lacks a formal definition and precise accountability, it represents a proactive approach to water security, aligning with UN goals for ensuring adequate access to clean water. The emerging focus on water positivity, coupled with the adoption of innovative

membrane technologies, signifies a fundamental shift towards more sustainable and proactive water management practices.

Desalination: unveiling the power-pressure balance in seawater reverse osmosis

The process of seawater desalination through seawater reverse osmosis (SWRO) involves a significant increase in osmotic pressure, requiring operation at pressures exceeding 50 bar. This elevated pressure is primarily attributed to the concentration of seawater brine, which results in a substantial rise in total dissolved solids (TDS) and osmotic pressure. The power consumption breakdown in SWRO reveals that the reverse osmosis step is the most energy-intensive, predominantly due to the high-pressure pumps necessary to sustain the elevated pressure. Despite the implementation of energy recovery devices, reverse osmosis remains the primary consumer of electricity in the overall water treatment process. The energy consumption of SWRO is a critical consideration, with high specific energy consumption posing a significant barrier to the widespread expansion of this desalination technology.

Typical seawater, with total dissolved solids (TDS) of between 35 and 40 g/L, has an osmotic pressure, p, of approximately 30 bar. Once concentrated through SWRO, seawater brine possesses approximately 65–70 g/L TDS, giving an osmotic pressure of somewhere in the region of 50 bar. This means that SWRO systems must operate at >50 bar.

The approximate breakdown for power consumption in SWRO is given in table 1. Overall, the most power-hungry step is reverse osmosis, thanks mostly to the high-pressure pumps used to sustain the high pressure. Even with effective energy recovery devices, the reverse osmosis step is expected to be the main consumer of electricity in the overall water treatment process.

Pumping demand is increased when fouling has occurred on the membrane. This is due to the impenetrable foulant reducing the rate at which water can cross the membrane. To compensate for lower membrane permeability, pressure must be ramped up. In turn, this demands more power.

Amongst the range of methods used to maintain optimal SWRO performance is restorative membrane cleaning. Over time, foulants such as mineral scale and biological/colloidal matter are deposited on SWRO membrane surfaces. During cleaning, chemicals are used to remove these foulants, returning permeate flux and transmembrane pressure to design specification. The most efficient cleaning protocols rely on speciality chemicals, which have been designed specifically for the removal of common SWRO foulants.

In this work, the results from the cleaning of real SWRO plants are reported. The data is extrapolated to determine how much power consumption is saved due to reduced high-pressure pumping demand. Herein, two real SWRO plants are used as case studies to demonstrate the impact of chemical cleaning on the specific energy consumption of the two plants. In both cases, the reduction in power consumption is used to determine the saving in US$ and tons of CO2 emissions.

However, it is essential to consider the broader context of water positivity and the increase of water production. The pursuit of water positivity and the increase of water positivity and the increase of water production. The pursuit of water positivity and the increase of water production align with the need to enhance the energy efficiency of SWRO plants, ultimately contributing to sustainable water management and the generation of new water supplies.

Therefore, while the study focuses on the impact of cleaning on power consumption, it is imperative to situate this within the broader context of water positivity and the drive to increase water production through enhanced energy efficiency and technological innovation.

Keywords: Water positivity; Reverse osmosis; Membrane desalination; Clean-in-place

SH 41

Recent experiences of marine installations for desalination plants in Egypt

Eloy Pita*, Mario Sánchez-Barriga

INCREA, Avenida de Burgos 9. Office 3 (1st floor), Madrid 28036, Spain
**Tel. +34 630119812; epita@increa.eu*

In recent years, Egypt has become one of the countries most affected by the lack of water, so its government has proposed large investments in desalination plants, which respond to the strategy of North African Governments to exploit non-conventional water resources.

Marine installations for desalination plants have two aims: the intake gets water from the sea to feed the desalination plant and the outfall discharges brine back into the sea. A proper design of these works should accomplish its functional aims with enough safety, low affection to the environment and at the lowest cost.

The aim of this presentation is to show the experience of INCREA in the design of the marine installations of several desalination plants in Egypt. The different Projects in which INCREA has participated in Egypt will be explained, summarizing the characteristics and singularities of each of the works and the lessons we learned in these Projects (all of them constructed or under construction):

- El Alamein.
- El Arish.
- Negeelah.
- Taba.
- East Matrouh.
- Sharm El Sheikh.

In this variety of projects, the authors will describe different execution techniques (trench dredging and tunnel), different types of intake structures (passive screen and concrete structures), a variety of diameters, etc., so the experience in Egypt covers a wide range of designs for this type of offshore installation.

Many pictures of these plants will be shown, for an easy understanding of the works. Lessons learned in these (and similar) projects will be described.

Keywords: Outfall; Environment; Dilution; Desalination; Sealines; Pipelines; Intake; Brine

SH 42

Offshore desalination: twenty years of experience in the North Sea

Dan Freeman*, Fiona Finlayson, Joanna Walker,
Michael Urschey, Gill Bavister

*Kurita Europe GMBH, Theodor-Heuss-Anlage 2,
Mannheim 68165, Germany*
**Tel. +44 7840852817; dan.freeman@kurita-water.com*

Offshore wind has gained much attention as a potential energy source for green hydrogen production. The prospective advantages are clear: the ready availability of renewable wind energy in locations distant from human population and a practically limitless source of water. A major consideration is that offshore wind farms are known to provide significantly more power output than similar sized onshore units. Several schemes and projects have been proposed for the North Sea, notably in UK and Danish waters.

The offshore environment provides significant challenges for the operator in terms of set-up, operation and maintenance. Fortunately, much experience has already been gained in these areas in the Oil and Gas industry. A fact of particular relevance, but not necessarily widely appreciated, is that many North Sea oil platforms are already using large scale desalination processes, specifically membrane desalination, for their water injection systems.

This paper outlines the challenges associated with operating membrane desalination systems in the North Sea based on experience gained over more than twenty years. The focus is on the methods employed in maintaining the membrane condition, extending membrane lifetime and maximizing efficiency within the confines of remote platforms. It will demonstrate the solutions that have been developed to overcome operational and regulatory challenges specific to the sector and compare these specialist applications to more traditional desalination facilities.

Keywords: Offshore; Wind; Renewable energy; Membrane; Seawater desalination; Reverse osmosis; Chemical treatment; Water optimisation; Energy optimisation; Environmental discharge; Discharge regulations; OSPAR

SH 43

Resource recovery by sustainable and innovative brine concentration process using advanced hollow fiber membrane

Takahito Nakao*, Joomi Han

Toyobo MC Corp., 1-13-1 Umeda, Kita-ku, Osaka 5300001, Japan
**Tel. +81-80-4124-7672; takahito_nakao@toyobo-mc.jp*

I. Introduction

Resource recovery and recycling are essential for a sustainable society, reducing waste, conserving resources, and lessening environmental impact. Retrieving valuable materials from unconventional

sources, like seawater and wastewater, is crucial for building a sustainable society. Membrane-based concentration technologies, such as osmotically-assisted reverse osmosis (OARO), play a key role in resource recovery. OARO combines osmotic pressure and reverse osmosis to efficiently concentrate highly saline water, improving desalination performance and reducing energy consumption. TOYOBO MC has developed a chlorine-resistant hollow fiber membrane for OARO, minimizing biofouling and ensuring reliable performance in various resource recovery projects. This technology contributes to a circular and sustainable approach to resource management, with benefits including reduced carbon emissions compared to existing methods. In our presentation, we will highlight these advantages and share insights from commercial projects where this technology has been successfully implemented.

II. OARO process and advanced hollow fiber membrane

Energy consumption is a critical challenge in current brine management, increasing significantly with concentration levels. Some membrane-based concentration methods, such as forward osmosis and electrodialysis, compete with thermal methods, consuming 10–20 kWh/m^3. Osmotically assisted reverse osmosis (OARO) is a breakthrough, non-phase-change, membrane-based process. It concentrates feed streams over 200,000 mg/L with less than 5 kWh/m^3, far more efficient than other technologies. OARO uses two equal-concentration solutions on either side of the membrane, minimizing osmotic pressure and reducing required hydraulic pressure.

It can be staged to increase concentration, utilizing RO brine pressure, resulting in less than 5 kWh/m^3 for the combined OARO and RO system.

III. Large-scale commercial reference

At Toyobo MC, we have successfully developed a membrane specifically designed for the OARO process, now available as a commercial product known as the BC (Brine Concentration) membrane. Our BC membrane is a hollow fiber made from chlorine-tolerant material called cellulose triacetate. Additionally, we have produced a commercial-sized membrane module utilizing the hollow fiber BC membrane, and this module has already been installed in commercial projects worldwide.

Currently, our first large-scale commercial plant in Indonesia for food-grade salt production, with a capacity of 220,000 tons, is under commissioning. In addition to salt production, 27,120 m^3 of water will be produced daily, and the overall recovery rate is 78%.

We would like to highlight that the specific power consumption of this plant will be approximately 4.5 kWh/m^3 for the feed solution up to the OARO system, excluding the thermal system. Specifically for the OARO system, the water flow in the OARO process is approximately 6,500 m^3/d, utilizing 1,080 OARO membrane elements.

Construction has already been completed, and we anticipate completing the commissioning phase shortly. We are on track to initiate commercial operations within 2023.

IV. Other resource recovery applications

The rising demand for lithium-ion batteries, driven by the global push for decarbonization, especially in electric vehicles (EVs), is prompting a shift toward industrial production methods. Currently, lithium extraction relies on solar evaporation from salt lakes, but the time-intensive nature of this process has led to consideration of alternatives like membrane concentration. Recycling used lithium-ion batteries aligns with Sustainable Development Goals (SDGs), and membrane concentration methods are being explored for concentrating lithium solutions from spent batteries.

TOYOBO MC's BC membrane is utilized in Japan for lithium concentration in battery recycling projects, and we've successfully demonstrated lithium recovery from salt lakes in South America. Our future plans involve expanding the OARO method application for recovering various valuable materials, including lithium.

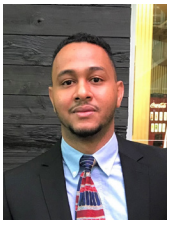
V. Conclusion

TOYOBO MC's BC membrane is the ideal choice for OARO, ensuring high concentration with minimal energy usage. Widely adopted globally, it's integral to various plants, notably the Indonesian salt production facility (220,000 ton/y). This plant, set for full operation in 2023, stands out for emitting less than half the carbon dioxide of traditional electrodialysis methods. Beyond this, we're actively pursuing projects like lithium recovery from Japanese used batteries and testing lithium recovery from South American salt lakes. Our future focus involves expanding into more material recovery projects, particularly those involving lithium.

Keywords: Osmotically assisted reverse osmosis; Hollow fiber membrane; Brine concentration; Lithium recovery; Lithium extraction

SH 44

Diagnosis and analysis for roto-dynamic machinery fault recognition and detection using artificial intelligence (AI)



Abdallatif Abdalrhman[#], Amr Ahmed*, Amin Saeed,
Reham Ibrahim, Ahmed Alghamdi, Basil Alrajhi,
Saeed Alzahrani, Sultan Ahmed

WTIIRA, Saline Water Conversion Cooperation (SWCC), Jubail, Saudi Arabia
**Tel. +966 560462431; amahmoud4@swcc.gov.sa*
[#]Presenter

In the domain of industrial machinery, predictive maintenance plays a pivotal role in minimizing downtime and optimizing operations. This comprehensive research explores an innovative approach to predictive maintenance by harnessing the vibration sensor signals analysis. The primary goal is to autonomously predict the timing and root causes of faults in roto-dynamic machinery, revolutionizing maintenance practices .

The methodology involves advanced artificial intelligence techniques , with a focus on deep learning, to analyse real-time vibration sensor data. Cutting-edge equipment with high-resolution data acquisition capabilities is employed, enhancing signal investigation and discrimination. Machine learning models like Convolutional Neural Networks (CNNs) and Transfer Learning are integrated for accurate fault prediction.

The research demonstrates the effectiveness of deep learning algorithms in predictive maintenance. These algorithms can autonomously identify fault timing and causes, reducing reliance on human expertise and enhancing accuracy. A practical case study involving a centrifugal pump within a reverse osmosis process validates the system's capabilities.

The benefits of predictive maintenance using vibration sensor signals are substantial, including cost savings, reduced unplanned downtime, and improved operational safety. The study emphasizes the importance of proactive maintenance in optimizing industrial efficiency and ensuring the longevity of critical equipment.

The device underwent rigorous testing at the Jubail pilot plant in WTIIRA premises, where it was installed in the pump of the SWRO unit for an extensive one-month trial period. During this testing phase, the device demonstrated its capabilities by promptly detecting an alarm signal related to the bearing of the pump. This early warning provided crucial insights into the machinery's health and potential issues, identifying breakdowns and facilitating timely maintenance interventions. The successful trial at the Jubail pilot plant underscored the device's practical applicability and its potential to revolutionize predictive maintenance practices in the industrial sector.

This research showcases the transformative potential of artificial intelligence and deep learning in predictive maintenance. Proactive maintenance practices are highlighted as essential for operational efficiency and the preservation of vital industrial equipment.

Keywords: Desalination; Pumps; Fault detection; AI vibration

SH 45

Pressure retarded osmosis (PRO) for energy recovery and power consumption reduction

Ghulam Mustafa[#], Ahmed Alghamdi, Amr Ahmed, Sultan Ahmed

WTIIRA, Saline Water Conversion Cooperation (SWCC), Jubail, Saudi Arabia
**Tel. +966 560462431; amahmoud4@swcc.gov.sa*
[#]Presenter

High energy consumption in the desalination process which converts seawater into freshwater using reverse osmosis and thermal distillation is a pressing concern that demands attention. Pressure retarded osmosis (PRO) holds promise as an innovative energy recovery technology for the reverse osmosis (RO) desalination process. PRO leverages the natural osmotic potential difference between solutions of different salinities using a semi-permeable membrane which drives water from the less concentrated side to the more concentrated side to generate energy from the salinity gradient. The hydraulic pressure and the permeated volume determine the useful work produced that can be used to drive turbines and generate electricity. Integration of PRO with RO desalination plants could significantly reduce the overall energy consumption of the process. This innovative synergy not only offers a sustainable approach to desalination, but also exemplifies the potential of harnessing nature's forces to address the world's growing water scarcity challenges, while promoting energy efficiency and environmental sustainability.

A bench scale test for energy recovery from pressure retarded osmosis (PRO) was conducted, with the aim of measuring its potential in reducing energy consumption within the desalination process. This innovative experiment involved diverting hydraulic pressure generated by PRO to assist the reverse osmosis (RO) system as a booster pump.

Rigorous testing was carried out to optimize the operational parameters. Two cases were considered with different feed and draw solutions. In the first case, seawater was taken as the feed solution with brine from a SWRO unit as the draw solution. Optimal performance was achieved at an operating pressure of 15 bar. The energy savings achieved exceeded 8%. This marked reduction in energy consumption highlighted the tangible benefits of integrating PRO technology with desalination processes, underscoring its potential for sustainability and cost-efficiency.

In the second case, municipal water was taken as the feed solution and the brine from a SWRO unit was taken as the draw solution. Through a rigorous process, it was determined that the opti-

mum operating pressure for this combination was 30 bar. This case yielded even more impressive results, with energy savings exceeding 26%, showcasing the potential of PRO in enhancing the energy efficiency of RO-based desalination systems.

These findings highlight the versatility and adaptability of PRO technology for different feed and draw solutions, and could prove to be a crucial tool in the quest for addressing water scarcity while lowering the carbon footprint and moving towards energy positivity by reducing the specific energy consumption (SEC) of the desalination systems.

Keywords: Pressure retarded osmosis (PRO); Booster pump; Energy recovery; Energy positivity; SEC

SH 47

Numerical investigation of forward osmosis-membrane distillation (FO-MD) hybrid process for seawater desalination

Muhammad Suleman*, Ahmet Halil Avci,
Basel Al-Rudainy, Frank Lipnizki

Lund University, Ällingavägen 3 H 1007, Lund 22734, Sweden
**Tel. +46 (0) 722716710; muhammad.suleman@chemeng.lth.se*

The global demand for freshwater has led to the development of emerging seawater desalination technologies. Among them, forward osmosis-membrane distillation (FO-MD) hybrid process has gained significant attention over the past decade. This work aims to numerically assess the performance of FO-MD hybrid process using in-house coding in MATLAB® environment. The process comprised of FO as the primary step, followed by a regeneration of the draw solution through MD. The draw solution for FO is based on poly (propylene glycol-ran-ethylene glycol) monobutyl ether (PAGBs) with different molecular weights. Both DI water and seawater containing 3.5 wt.% NaCl was used as feed solutions while PAGB 1000, PAGB 2000 and PAGB 4000 were used as the draw solutions with molecular weights of 1051g/mol, 1810g/mol and 3911g/mol, respectively. The thermo-responsive polymers, PAGB 1000, PAGB 2000 and PAGB 4000 exhibit phase separation at temperatures of 53, 52, and 53°C, respectively. In this numerical simulation, the initial draw concentration of the polymers varied from 40 to 70%. The numerical model was validated against the experimental data available in the literature with different concentrations of NaCl and urea as draw solutions. The results indicated that utilizing DI water as feed to FO with a 40% initial draw concentration resulted in flux values of 4.1 L/(m^2.h) for PAGB 1000, 3.2 L/(m^2.h) for PAGB 2000, and 2.3 L/(m^2.h) for PAGB 4000. Furthermore, PAGB 1000 revealed a maximum flux increase of 3 L/(m^2.h), by increasing the initial draw concentration from 40 to 70%. Overall, the FO-MD hybrid process can effectively desalinate seawater, and the study demonstrates that PAGBs have great potential to be used as a draw solution.

Keywords: Forward osmosis; Membrane distillation; Hybrid processes; Seawater desalination; Draw solution

SH 48

Treatment of textile wastewater with coagulation-flocculation process aided by a green flocculant — *Opuntia ficus indica*

Belkacem Merzouk*, Mohammed Tiaiba,
Mohammed Hamidou, Billal Khemila

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

Textile industry used a large variety of dyes and generated effluent with high COD, turbidity, suspended solids, color, and pH, which complicates further treatment of this wastewater. The use of natural flocculant in coagulation-flocculation (CF) treatment of wastewater shows many advantages over chemical agents, particularly biodegradability, low toxicity, low residual sludge production and low-cost.

In this study, the ability to remove a synthetic and a real textile wastewater using CF process with aluminum sulfate $Al_2(SO_4)_3$, ferric chloride ($FeCl_3$), industrial (anion) flocculent and a mucilage of *Opuntia ficus indica* as a natural flocculant aid has been investigated.

In order to clarify the CF process, experiments were performed to study the effect of operating parameters such as initial pH 3.5–10.5, coagulant dosage 50–500 mg/L, initial concentration of the dye 50–1400 mg/L, conductivity 2.5–6.5 mS/cm, industrial flocculant 5–150 mg/L, natural coagulant 2–60 mL/L, contact time 5–120 min and mixing conditions 150–250 rpm for 2 and 3 min mixing time for coagulation phase, 30–60 rpm for 20 and 30 min mixing time for flocculation phase. The results obtained showed:

- The stirring velocity for coagulation must be fast in a time of very short mixture (150 rpm — 3 min).
- The stirring velocity of flocculation must be slow in a time of average mixture (30 rpm —20 min).
- CF functions well, even with the highest dyestuff concentrations, going up to 600 mg/L (1959 NTU) for aluminum sulfate (Y_{Turb} = 99%) and 800 mg/L (2717 NTU) for ferric chloride (Y_{Turb} = 96.83%) under initial pH ranging from 8.5 to 10.5.
- The optimal amount of ferric chloride and aluminum sulfate is of 250 mg/L.
- The optimal amount of the anion flocculant for the elimination of turbidity with aluminum sulfate is 50 mg/L, and that of ferric chloride is 5 mg/L.
- The optimal amount of the natural flocculant agent (juice of cactus) is 12 to 15 mL/L.
- By adding 3 ml/L of *Opuntia ficus indica* as a natural flocculant aid, the efficiency increased by 10%.
- The application of the optimized parameters to a real textile wastewater showed an acceptable reduction of the turbidity (67%), SS (57.33%) and COD (94.81%).

The process of CF with the help of cactus *Opuntia ficus indica* can be used as a high-efficiency process as a treatment for textile wastewater.

Keywords: Coagulation-flocculation; Dye; Turbidity; Aluminum sulfate; Ferric chloride; Natural flocculant; Textile industry

SH 49

Liquid bromine production – most economical approach for brine mining

Ghulam Mustafa*, Omar Al-Raqibah,
Eslam Al-Waznani, Christopher Fellows

SWCC, 6, 2nd Floor Saudi Asas Building,
King Street Near Dawa Centre,
Jubail 31951, Saudi Arabia
**Tel. +966 549323348; gmmustafa@yahoo.com*

Seawater is an inexhaustible source of potable water and valuable minerals. In the desalination process, brine waste stream containing high concentration of minerals is normally drained back to the sea. However, brine mining for recovery of minerals offers an opportunity to promote the desalination industry by reducing the cost of water produced. Though brine mining facilitates the best use of seawater brine, only a few minerals in seawater which are scarce on earth, are economically suitable to be extracted [1]. Nevertheless, the recent development of innovative processes for recovery of minerals from seawater makes brine mining an attractive option for improving the economics of desalination. One of the most fascinating elements in seawater is bromide which can be extracted as liquid bromine relatively easily and provide a high rate of return.

Bromine has historically been extracted directly from seawater [2] and from the bittern remaining after solar salt production [3]. While there is currently no commercial production of bromine directly from seawater, this was historically achieved by oxidising bromide to bromine with chlorine under acidic conditions, followed by 'cold-blowing' with air and absorption of the volatile bromine with alkali or sulphur dioxide to give a concentrated solution of sodium bromide or hydro-bromic acid requiring further processing to liquid bromine. For the much more concentrated bitterns, which are still important industrial sources of bromine, oxidation can be followed directly by 'hot-blowing' with steam. The concentration of bromide in desalination brine is clearly intermediate between these two cases so there are challenges in finding the most effective technology for bromine extraction.

Water Technologies Innovation and Research Advancement (WTIIRA) of Saline Water Conversion Corporation (SWCC) has recently introduced an innovative process scheme to concentrate SWRO brine and recover valuable minerals. The process has been already tested and validated in SWCC's pilot facility at Jubail, Saudi Arabia. A brine mining demonstration plant has been designed and is under construction in the city of Haql, Saudi Arabia. The plant will produce about 6-10 ton/d of pure NaCl salt, 6-8 kg/d pure liquid bromine and up to 700 kg/d of magnesium metal from SWRO brine source. This paper details the process design and costing for production of pure bromine at the Haql brine mining project. It will also present a critical review of the current methods of extracting bromine from seawater brine generated in desalination plants, and suggest ways to overcome some of the limitations and challenges associated with the bromine extraction process.

Keywords: Desalination; Brine mining; SWRO; Brine concentration; Chlorination; Acidification; Bromine extraction

References

1. Abu Sharkh, B., Al-Amoudi, A. A., Farooque, M. A., Fellows, C.M., Ihm, S., Lee, S., Li, S., Voutchkov, N., Seawater desalination concentrate - A new frontier for sustainable mining of valuable minerals, NPJ Clean Water, 2022, 5, 9.

2. Fossett, H., Extraction of bromine from seawater, Chemistry & Industry, 1971, 35, 1161-1171.
3. Dave, R. H., Ghosh, P. K., Enrichment of bromine in sea-bittern with recovery of other marine chemicals, Ind Eng Chem Res 2005, 44, 2903-2907.

SH 50

SMR as a potential candidate for carbon neutral energy source to desalination plant

Christopher Fellows, Youngwook Yoo

SWCC-WTIIRA, PO BOX 8328, Jubail, Saudi Arabia
Tel. +966 534224123; yyoo@swcc.gov.sa

Small Modular Nuclear Reactor, SMR here below, was introduced in the market in 1950s, in line with the first introduction of nuclear power plant, ever since more than 50 SMR designs are under development and at least 10 SMR designs are for potential near term deployment. Nuclear power is the second-largest source of low-emission power worldwide today followed by hydropower, takes an important role as baseload supply in many countries, which makes it reasonable to consider SMR as a candidate for carbon neutral energy source to decarbonize various industries including desalination plants.

In this configuration study, comparison was made for one 80 MWe SMR unit coupled with various desalination configurations, such as SWRO, MED, and MSF plants. In this case, grid independent configurations were considered, so all electricity generated in SMR was used in desalination plant island. When it comes to thermal desalination configurations like MSF and MED, back pressure steam turbines were considered in the power island, and condensing extraction steam turbine was considered for SWRO case. Due to the altered turbine configuration for thermal desalination configurations, system capacity for SMR units were reduced by 28.8% for MED case, 28.2% for MSF case, makes levelized cost of electricity increased more than 40%, so levelized cost of water is 117% and 120% for MED and MSF respectively, compared to SMR-powered SWRO case.

Comparison with renewable energy sources were also made to see potential for decarbonization of desalination industry. To make a fair comparison, all renewable energy sources were considered to have energy storage system to supply continuous electricity to SWRO plant. Adding energy storage system to renewable energy sources increased capital expenses in the power system and it makes levelized cost of electricity 226% and 290% of SMR case for onshore wind and PV cases respectively. As a result, levelized cost of water for onshore wind and PV cases became 157% and 186% of SMR-powered SWRO configuration.

Finally, packaged SMR systems with various desalination configurations for industrial utilities applications were considered. In this case, also, due to the reduced system capacity from the power island in case for thermal desalination configurations, both levelized cost of electricity and levelized cost of water are increased for thermal desalination configurations, makes SMR-powered SWRO economically more reasonable configuration.

The reason for thermal desalination plants to phase out in recent years in desalination industry is applied the same to this configuration study. Steam extracted from steam turbine has certain energy level that could have generated electricity more unless otherwise extracted. When energy cost is small, this fact looks negligible but when energy cost is elevated, this cannot be ignored. Also, the fact that distillate from thermal desalination systems were produced by boiling seawater with

steams that was generated from nuclear power plant may make people uncomfortable. Preconception may be the biggest hurdle for SMR and thermal desalination system configurations.

Cost of electricity has the largest portion in water production cost followed by amortization of capital expenses, so finding competitive energy source is the key for success in desalination projects. With the same framework for the calculation basis for this study, LCOE between 60 and 70 USD/MWh might be the threshold to limit cost of electricity portion less than 50% from the cost of water.

Also, as the concern of global warming and instability of the climate is growing larger, finding carbon neutral energy sources is also important. Hydrogen is equally important energy sources that can decarbonize industries, but similar sorts of materials are being used to make electrolyzer, so unless the cost of batteries go down, so does electrolyzer.

From the case study for SMR as industrial utilities application, the same configuration can also be used to produce hydrogen, i.e., pink hydrogen. As electrical energy cost from SMR is already quite competitive, it is likely that hydrogen production cost is also competitive. However, in SMR cases, since it does not have regional preferences, relative competitiveness might be diluted unlike renewables. This means that there might be no difference between hydrogen production costs in Australia where renewable energy cost is considered competitive and east Asia.

Considering the facts for SMR with regards to carbon neutrality and the cost of electricity, SMR might be the most realistic way to decarbonize industries, particularly for desalination industry.

However, there are uncertainties in SMR as there are limited cases of deployment. Since the costing information for SMR used in this configuration study was based on Nth of a kind (NOAK) prediction, cost of construction needs to be proven, and cases need to be accumulated to see safety and technical stability of SMR.

Keywords: SMR; Desalination; Renewable; PV; Wind; SWRO; MED; MSF; Energy storage system

SH 51

Active ERD to lower the power consumption — MPE 70 operation results

Francisco Jimenez-Castellanos Lucena*, Javier Lorenzo Moral

Danfoss, Rafael de la Hoz Arderius, 4, Cordoba 14006, Spain
**Tel. +34 669927039; Francisco.jimenez-castellanos@danfoss.com*

Desalination stands as a pivotal solution in securing adequate freshwater reserves for our rapidly expanding global populace and myriad industrial needs. As stakeholders—from regulators to the water industry and consumers—pursue avenues to curtail costs and carbon footprints, the emphasis on refining energy efficiency and sustainable power sources grows more pronounced

While reverse osmosis (RO) remains the foremost method for extracting freshwater from seawater, its energy demands pose a significant challenge. Consequently, plant owners and operators are actively seeking strategies to optimize the performance of seawater reverse osmosis (SWRO) facilities across diverse operational scenarios. The goal? To enhance energy efficiency and calibrate the power mix effectively.

Energy recovery devices (ERDs) emerge as a linchpin in bolstering the sustainability of SWRO, with isobaric ERDs demonstrating superior efficiency over recent decades. Yet, challenges persist, stemming from factors like high/low differential pressure, variations in salinity, lubrication flow, etc, contributing to energy losses.

Escalating energy prices compels the desalination industry to scrutinize total plant lifetime energy consumption more intensely. In response, new isobaric ERD technologies have been introduced aimed at reducing overall plant energy consumption across the plant's lifespan.

In this presentation, the focus is on elucidating the energy-saving potential across a plant's lifetime through the utilization of the cutting-edge MPE 70 active ERD by Danfoss. We'll delve into how this innovation, integrated into various installations, contributes to substantial energy efficiencies within these facilities.

In this presentation, we aim to detail the energy-saving potential across a plant's lifetime through the utilization of the cutting-edge MPE 70 active ERD by Danfoss. We'll explore how this innovation, already installed in various Plants, contributes to substantial energy efficiencies within these facilities.

Keywords: Energy recovery device; ERD; Efficiency; Energy savings; Carbon footprint; Mixing; Salinity increase; Desalination; Seawater reverse osmosis (SWRO); Sustainable solutions

SH 52

Efficient evolution: piston high-pressure pump solutions for enhanced plant operations

Francisco Jimenez-Castellanos Lucena*, Javier Lorenzo Moral

Danfoss, Rafael de la Hoz Arderius, 4, Cordoba 14006, Spain
**Tel. +34 669927039; Francisco.jimenez-castellanos@danfoss.com*

In today's landscape, where energy consumption, CO_2 emissions, and global water scarcity intersect, contemporary desalination approaches prioritize optimization and maximum efficiency in plant configurations. Achieving minimal plant consumption hinges on equipment efficiency—a crucial factor in driving overall efficiency within desalination facilities.

Rising energy prices propel the desalination sector to intensify its focus on minimizing the power consumption of plants throughout their lifespans. Notably, high-pressure pumps (HPP) play a pivotal role, accounting for up to 80% of a seawater reverse osmosis (SWRO) plant's total specific energy consumption (SEC).

SWRO plants required enhanced flexibility to adapt to the fluctuating demands and operational conditions year-round. Therefore, ensuring optimal high-pressure pump performance across all operational modes becomes imperative for achieving maximum reductions in specific energy consumption.

The axial piston pumps (positive displacement technology) are used in a modular set up, offering the best efficiency in high-pressure applications. Unaffected by fluctuations in flow and pressure, this technology consistently delivers optimal efficiency and offers unparalleled flexibility in real-time operations, ensuring sustained high-performance throughout the lifetime of the plant

In this presentation, we delve into the undeniable advantages and cost-saving potential of employing axial piston high-pressure pumps within SWRO installations. By showcasing their efficiency and adaptability, we shed light on their pivotal role in driving substantial benefits and savings.

Keywords: High pressure pumps; HPP; Efficiency; Energy savings; Carbon footprint; axial piston pumps; Desalination; Seawater reverse osmosis (SWRO); Sustainable solutions

SH 53

Enhancement of the ion exchange capacity of the polyvinylidene fluoride membranes conjugated with chitosan polymer

Yousra Kotp*, Shimaa Elbakry, Hosam Shawky

Desert Research Center, El Matarria, Cairo 11753, Egypt
** yosra.Kotp@drc.gov.eg*

In this study, a novel adsorptive flat-sheet Zn/PVDF/Cs, Ti/PVDF/Cs, and Si/PVDF/Cs membranes were synthesized by modifying PVDF membranes with nanoparticles and then applying a thin coating of chitosan (Cs) to the PVDF membrane surface. All the membrane samples were characterized using X-ray diffraction, FT-IR, FESEM, and EDX. The hydrophilicity of the membranes was confirmed by contact angle measurements, which were enhanced upon modification. The prepared membranes were applied for the removal of phosphate (PO_4^{3-}), nitrate (NO_3^-), and fluoride (F^-) from contaminated water.

Keywords: Adsorption; Nanocomposite; Thin-film composites membranes

SH 55

Environmental aspects of brine discharge from SWRO at Costa del Sol area: a focus on the phanerogam, *Zostera marina*

Elena Crespo

Acciona, Plaza Landabaso n2 2 B, Bilbao 48015, Spain
elena.crespo.olazabal@acciona.com

The Spanish Mediterranean coast is facing a pressing issue when it comes to freshwater resources related to both tourism activities and agricultural resources. As climate change continues to impact the region, water scarcity is becoming a growing concern. To address this challenge, the construction of desalination plants has emerged as a viable solution. However, it is essential to recognize the environmental aspects that must be considered during the planning, construction and operational phases to ensure sustainable development and minimize ecological impact.

The purpose of this article is to present a case study of the planning, construction, and operation of a desalination plant in the Costa del Sol Mediterranean area, Málaga, Spain, with a special focus on the seagrass species *Zostera marina*, commonly known as eelgrass.

2. Introduction

South-east coast of Spain is suffering from severe hydric stress, due to the lack of fresh-water resources. It is crucial for the region to find a solution to increase the amount of fresh water for agricultural uses as well as tourism activities, so that the economic growth of the area can be maintained and balanced sustainable.

To address this challenge reverse osmosis desalination plants are considered as a viable solution to address water scarcity. In addition to the fresh-water, recovery brine is also produced with a

higher salt concentration.

Understanding the marine ecosystem, focusing on "endangered", "vulnerable" or "under special protection" species is crucial for developing effective mitigation strategies and sustainable management practices for SWRO desalination plants. This article highlights the importance of species identification, designing and assessing the long-term ecological impacts of brine discharge and the implementation of eco-friendly desalination technologies.

3. Material and methods

a. Legal framework

The Autonomous Community of Andalusia, through Decree 23/2012, of 14 February, which regulates the conservation and sustainable use of wild flora and fauna and their habitats, updates the Andalusian Catalogue of Threatened Species approved by Law 8/2003, of 28 October, and catalogues the threatened species included in this Plan for the Recovery and Conservation of Threatened Invertebrates and Phanerogams of the Marine Environment.

The Plan establishes conservation and protection measures for two "endangered" species (*Patella ferruginea* and *Pinna nobilis*), three "Vulnerable" species (*Dendropoma petraeum, Astroides calycularis* and *Charonia lampas*) and four species included in the "List of wild species under special protection" (*Posidonia oceanica, Zostera noltii* Hornemann, *Zostera marina* Linnaeus and *Cymodocea nodosa*).

b. Species identification in the area of the study

Seagrass meadows are habitats composed of higher plants. These plant species are characterized by seed production. These plants are of great importance to marine communities, as they provide a large amount of biomass and oxygen. They also protect the coast from erosion, as their leaves and rhizomes act to reduce hydrodynamism. Finally, seagrass meadows create a great diversity of environments in favour of a great variety of species.

Five species of marine phanerogams can be found in Europe: *Posidonia oceanica, Cymodocea nodosa*, *Zostera marina*, *Z. noltii* and *Halophila decipiens*. These species are native to the European coasts, and all of them are present on the Spanish coast. [Ref 1]

After consulting several sources of information, including the Junta de Andalucía, Ministerio de Transición Ecologica y Reto Demográfico, and the Spanish Institute of Oceanography, no evidence has been found that would allow to anticipate the presence of *Posidonia oceanica* in the study area. The nearest community of this phanerogam has been located some 22 km from the area of interest on the coast of Nerja.

However, there are indications of the existence of communities of the phanerogam *Zostera marina*. Nevertheless, this organism is much less sensitive to variations in the salinity of the water, as can be seen in the study [1], it is considered as specie under special protection similarly to *P. oceanica*.

Presence of phanerogams on the study area:

The distribution of *Zostera marina* in the study area is shown below, both from the underwater vegetation mapping of the Junta de Andalucía and the World Register of Marine Species (WORMS)

4. Conclusions

In conclusion, this article has showcased the importance of thorough research and identification when it comes to protecting marine species, with a specific focus on *Zostera marina* and mollusks and its crucial role in coastal ecosystems. By understanding the unique characteristics and habitat requirements, we have been able to design a brine discharge system that ensures the preservation and flourishing of these species.

The design considered for the discharge system not only addresses the immediate concerns of "under special protection

Keywords: Brine discharge; Seagrass; Environmental aspects; Brine modelling; *Zostera marina*; Eelgrass

SH 56

Use of brine for generation of green chemicals

Stasinos Chiotakis*, Nikolay Voutchkov,
Hyuk Soo Son, Noura Chehab

ENOWA – NEOM, Neom Community 1, NEOM 49643, Saudi Arabia
**Tel. +966 532713368; stasinos.chiotakis@neom.com*

NEOM a planned independent economic zone in the Northwest of Saudi Arabia. NEOM will depend on desalination to produce drinking water. Initially a ZLD Pilot is to be built in an effort to accommodate and test all possible variables that will result to the optimum parameters combination and furthermore lead to the desired outcome of having a zero liquid discharge system that in proportion will provide the desired freshwater volume, depending on the conditions and requirements. Success or failure of the plant does not only depend on the design efficiency, the quality of the construction, the procurement process, etc., but significantly can be determined by their operation and maintenance. They could become the weakest link in the process chain since they can be, if not the most critical, two of the most critical aspects of the procedure, since there have been many cases where the poor O&M had an extremely negative impact on the plant.

Through this study, significant O&M factors are to be identified that could reduce the efficiency of the plant, the production of the desalinated water as well the byproducts of brine. The benefits of such an experience contribute to the plant performance, convenience, production cost and further value in future investment. It describes the methodology used to develop the preventive maintenance schedule and the tasks included, creating a pattern for the constraints of operation, production and maintenance being fulfilled and the procedure being optimized.

Keywords: Zero liquid discharge; Desalination; Operation & maintenance

SH 57

Nanofiltration membranes for selective recovery of divalent ions from desalination brine

Nourhan Mohamed*, Mohamed Ali, Fathy Mohamed

Research Center, Cairo, Sumusta, Beni Suef,
Abd EL-Rahman Amin, Helmeyat AZ Zaytoun, Cairo, Egypt
** nourhan21m@gmail.com*

Brine discharge from desalination plants is challenging due to the high concentration of salts, which hinders using a second stage of the desalination process as well affecting the ecosystem. Nowadays, recovery of valuable elements, such as lithium, from this brine can reduce the cost of the cubic meter price of the desalination unit. However, interference of the divalent ions restricts the lithium adsorption process. Therefore, this work focuses on the separation process of divalent ions by using low-pressure and selective nanofiltration (NF) membranes, which is a crucial pre-

treatment stage in the entire recovery process. To conduct lab-scale experiments, a low-pressure handmade crossflow system of 10 bar and two types of commercial NF membranes (low rejection of monovalent and high rejection of divalent ions) were used. Synthetic single-salt solutions and actual brine water discharged from brackish (BW-RO), and seawater (SWRO) desalination plants were used as feed solutions for the NF system. The chemical properties of RO feed, RO brine, NF permeate, and NF reject were analyzed. The brine samples mainly contained soluble NaCl, $MgCl_2$, $CaCl_2$, and $MgSO_4$ salts. The results indicate that the NF membrane, with a denser polyamide layer, was the most effective at rejecting divalent ions with a high flux rate of 29.5 l/m^2. h. The salt rejection of the NF membrane follows the order of $MgSO_4$, $MgCl_2$, $CaCl_2$, and NaCl with a percent of 98, 94, 96, and 85.40%, respectively. In addition, there was no rejection of lithium ions that is favourable for the adsorption process.

Keywords: Nanofiltration membranes; Desalination; Brine disposal; Divalent ions removal; Lithium/magnesium interference

SH 58

Reusing old reverse osmosis membranes for different separation application

Rand Ghanoum*, Mohamed Ali, Reham Bosela, Abdelhameed Elaasar, Hosam Shawky, Dalia Abouzaid

Egypt Desalination Research Center of Excellence, Elobour city – Cairo, Desert Research Center, Cairo 11828, Egypt
**Tel. +20 1011500472; randgannomme@gmail.com*

Reverse osmosis (RO) membranes globally utilize over 2 million membrane module elements to produce around 68 million m^3/d, making it a leading desalination technology. Operational circumstances may require replacing the large quantity of elements within approximately five years. When this replacement is made, a lot of end-of-life RO elements build up because the membranes get permanently dirty, which makes RO work less well. These elements are primarily disposed of in nearby landfills, resulting in negative environmental effects. The objective of this study was to investigate the feasibility of repurposing the used reverse osmosis (RO) membranes. Membranium employed the cleaning procedure on a 4040 RO element that they acquired from a brackish water desalination facility in Hurghada. Prior to cleaning, the membranes underwent testing and demonstrated a water flux of 9.9 and 17.8 L/m^2.h, together with a salt rejection of 90.75% and 97.4% when exposed to a feed solution containing 2000 mg/l of NaCl and $MgSO_4$, respectively, at a pressure of 15 bar. The cleaning procedure entailed submerging (passive cleaning) the membrane in a sodium hydroxide solution with a concentration of 0.1 M and a pH of 10. Additionally, the membrane was treated with hydrochloric acid at a concentration of 0.1 M and a pH of 2 for varying durations of 2, 4, and 5.5 h. Submerging the membrane in a sodium hydroxide solution with a pH of 10 for 4 hours resulted in the most favourable outcomes. The water flux achieved was 11.2 and 22.4 L/m^2.h, while the salt rejection rates were 95% and 96.5% for NaCl and MgSO4 concentrations of 2000 mg/l, respectively. These finding can lead to reusing the membrane elements for different applications such as brackish water desalination, nanofiltration, or ultrafiltration purposes.

Keywords: Desalination; Reverse osmosis; Spent membranes; Recycling; Brackish water

SH 59

Uncovering the spectrum of microbial growth on various antiscalants used in seawater desalination

Maria Albarracin Ruiz[1#], Marian Castrillon Tobon[1#], Abdul-Hamid Emwas[2], Thomas Altmann[3], Ratul Das[3], Johannes S. Vrouwenvelder[1], Graciela Gonzalez-Gil[1*]

[1]*Biological and Environmental Science and Engineering Division (BESE), Water Desalination and Reuse Center (WDRC), King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia*

[2]*Advanced Nanofabrication Imaging and Characterization, King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia*

[3]*Innovation and New Technology, ACWA Power, 41st Floor, The One Tower, Barsha Heights, Sheikh Zayed Road, Dubai, United Arab Emirates*

[#] *Contributed equally*

[*] *Corresponding/presenting author: graciela.gonzalezgil@kaust.edu.sa*

During the process of desalinating seawater using reverse osmosis membranes, the entering seawater is dosed with antiscalants to avoid the formation of mineral deposits on the membrane surface, which leads to the detriment of membrane performance. Antiscalants, however, can inadvertently promote undesirable bacterial growth (i.e., biofouling) on the membrane system by providing an additional source of carbon and/or phosphorus for microbial growth. Selecting a proper antiscalant is a complex task because there are various antiscalants in the market, combined with the lack of information regarding to what extent those antiscalants promote bacterial growth.

Previous tests assessing the potential of antiscalants to promote bacterial growth were conducted in drinking water or seawater inoculated with model bacterial species. Unfortunately, such conditions do not accurately represent the diverse bacterial communities and conditions found in natural seawater. To reflect better on the conditions of desalination systems, we recently developed a new test method to determine the bacterial growth potential of antiscalants in natural seawater applying the autochthonous bacterial population as inoculum.

We researched a set of chemically diverse antiscalants as applied in practice to determine their impact on bacterial growth in natural seawater. The antiscalants ranged from phosphonates, polymers, and blends. Results show that our approach in combination with nuclear magnetic resonance (NMR) characterization of antiscalants allows an accurate determination of antiscalants' bacterial growth potential under relevant conditions. This work significantly contributes to our understanding of how antiscalants, based on their chemical composition, influence biological responses. Moreover, our research has the potential to address the challenges faced by the industry in choosing the most effective antiscalants, thereby contributing to the enhanced efficiency of seawater desalination.

Keywords: Seawater desalination; Biofilm growth potential; Flow cytometry; NMR chemical fingerprint; Seawater reverse osmosis (SWRO) membrane module

SH 61

Bipolar membranes electrodialysis for brine valorization: bases and acids obtention

Vicent Ayala [1], David Valero[2], Vicente García[3], Vicente Montiel[4], Naiara Hernández Ibáñez [5], Javier Hernández De La Rosa[6], Juan Arévalo* [7], Víctor Monsalvo [8], Frank Rogalla [9]

[1]*Instituto Electroquímica Universidad de Alicante, Spain, vicent.ayala@ua.es*
[2]*Institut Electroquímica Universidad de Alicante, Spain, david.valero@ua.es*
[3]*Instituto Electroquímica Universidad de Alicante, Spain, vicente.garcia@ua.es*
[4]*Instituto Electroquímica Universidad de Alicante, Spain, vicente.montiel@ua.es*
[5]*FCC Aqualia, Project Manager, Spain, naiara.hernandez@fcc.es*
[6]*FCC Aqualia, Researcher, Spain, javier.hernandez@fcc.es*
[7]*FCC Aqualia, Project Manager, Spain, juan.arevalo@fcc.es*
[8]*FCC Aqualia, Head of Eco-efficiency Area, Spain, victor.monsalvo@fcc.es*
[9]*FCC Aqualia, Director of Innovation and Technology Department, Spain, FRogalla@fcc.es*

**Corresponding author/presenter: juan.arevalo@fcc.es*

The Resilient Water Innovation for Smart Economy – "REWAISE" project, within the Horizon 2020 research and innovation program, presents the ambitions objective of creating a new "smart water ecosystem", integrating an intelligent digital framework for decentralized water services and decision-making, involving all relevant stakeholders to embrace the true value of water, reducing freshwater, decreasing the energy required in desalination and recovering energy, nutrients, and materials from water to result in a carbon-free, sustainable hydrological cycle, in line with the concept of a resilient circular economy.

This approach will be validated in different strategies, technologies, and fields of application. In specific, in the desalination field of expertise, several technologies will be tested for low-energy desalination strategies and mineral recovery from brine, creating a multimodular and flexible treatment train, adaptable to multiple situations and interests.

One of the specific objectives related to desalination in the Rewaise project is the recovery of minerals and metals from waste streams, usually brines from seawater or industrial water desalination. The extraction of new products and critical raw materials from waste streams will bring a circular economy to desalination, transforming desalination plants into chemical factories.

In this sense, electrodialysis with bipolar membranes (EDBM) is a variation of the conventional Electrodialysis process (ED) that incorporates one or more bipolar membranes and several homopolar membranes. In an EDBM system of a 3-compartment configuration, basic and acidic solutions can be obtained from the ions present in the feed solution.

To carry out the base and acid obtention by treating the brine with an EDBM system, a comparative study has been performed using three different commercial ion exchanges (cation and anion) and bipolar membranes to identify the more suitable membranes in terms of base and acid obtention performance and energy efficiency.

EDBM experiments were carried out working in a laboratory-scale pilot plant. The EDBM system consisted of a five-cell electrodialysis reactor with three membranes of different types (anion, cation, and bipolar). With a total active area for each type of membrane of 560 cm^2.

All experiments were conducted in a batch configuration working at constant potential mode, operating at 14, 17, and 20 V. Acid and base concentration, pH, temperature, and conductivity were recorded during the experiment.

At the same time, different pre-treatments have been studied to achieve the required brine quality to feed the system, to avoid $Ca(OH)_2$ and $Mg(OH)_2$ scaling during the EDBM process (Ca^{2+} and Mg^{2+} ? 10 ppm). The selected pre-treatment will be coupled to the EDBM pilot plant.

This study has proven that electrodialysis with bipolar membranes can be an efficient process to separate acids and bases on a monovalent rich stream, in a technically and economically suitable process after nanofiltration. Acid and base concentrations between 0.6 M and 1.2 M have been reached. In addition, as a by-product, a desalinated stream will be generated, to be used in a downstream treatment, like disinfection product generation, or returned to the reverse osmosis desalination plant to increase global water recovery, considering the low salinity and high quality of this stream.

Keywords: Electrodialysis; Bipolar membrane; Nanofiltration; Brine; Valorization; Rewaise

SH 62

Sea4Value: Moving Lab integration, operation, and first results for mineral and metal recovery from SWDP

Juan Arévalo*, Naiara Hernández Ibáñez, M. Sauchelli,
Javier Hernández De La Rosa, Víctor Monsalvo, Frank Rogalla

Aqualia, Departamento de Innovación y Tecnología,
Av. del Camino de Santiago 40, 28050, Madrid, Spain
**naiara.hernandez@fcc.es*

Industrial minerals, specific raw materials, and critical raw materials (CRMs) are of strategic importance for the European and global economy. CRMs are crucial for high-tech products (e.g., smartphones, aerospace, chemicals, renewable energy, medical equipment, etc.) used in everyday life and modern technologies. Sustainable, reliable, and unhindered access to CRMs is a growing concern in the EU and worldwide. The EU is currently dependent on imports of many minerals (especially magnesium) and critical resources (e.g., traditionally produced fertilisers). There is a need to move from traditional linear resource use and management to circular solutions by improving the recovery of important raw materials through the development of new sourcing solutions.

The recovery of compounds of interest for commercial purposes from SWDP brine is a potential innovative resource that has attracted considerable interest in recent years. The use of seawater brines for the recovery of compounds has the competitive advantage of using an already concentrated stream compared to the extraction of minerals and metals directly from seawater. The main benefits are a recovery of compounds of interest that can be reintroduced into manufacturing and industrial processing; and reduced environmental impact due to reduced brine discharges; reduced capital and operational expenditure (CAPEX and OPEX) of operating plants.

The challenge of extracting low-concentration elements from seawater lies in (a) the huge amounts of water to be processed and disposed of, which requires collection and discharge infrastructures and huge amounts of energy; (b) the preparation of commercial quality metals and minerals from complex matrices, such as seawater brines, requires a completely new generation of separation technologies capable of selectively recovering the target elements, which has proven to be technically and economically unfeasible with current separation technologies; (c) the need to develop flexible processes and technologies capable of working synergistically to recover different elements in the same integrated process increasing economic and environmental viability.

In order to meet these challenges, Aqualia's Innovation and Technology department is participating in the Sea4Value European project, which focuses on the reuse of brines produced in SWDPs to promote the circular economy through the development and implementation of more selective technologies and processes for the recovery of specific compounds that allow current desalination plants to be transformed into sustainable chemical plants. The project will prove the feasibility of next-generation technologies (including advanced concentration and crystallization processes and highly selective separation processes) for the recovery of Mg, B, Sc, In, V, Ga, Li, Rb, Mo, and set the basis for their future assimilation in already existing SWDP and those yet to come.

With this purpose, a Multi-mineral Modular Brine Mining Process (MMBMP) for the recovery of valuable metals and minerals from brines produced in SWDPs has been developed and installed in a SWDP operated by Aqualia in Tenerife (Canary Island, Spain), where the technologies are being validated using not only real brines from the Atlantic but also from the Mediterranean as well as from different countries (Spain and Israel). The tests carried out for the first stages of the process show very promising results in terms of selectivity and purity of the recovered compounds.

Keywords: Brine mining; Desalination; Sea4Value; Metal recovery; Brine

SH 63

Hydrogen-powered water desalination: a sustainable solution for fresh water and green hydrogen production

Abraham Negaresh, Yashar Hajimolana*
WRc, Frankland Road, Blagrove, Wiltshire, Swindon SN5 8YF, UK
** abraham.negaresh@wrcgroup.com*

The demand for clean and potable water has skyrocketed due to global shifts in weather patterns, rising temperatures, expanding industrial developments, and growing populations. Only about 3.6% of the Earth's water is freshwater, and most is not readily accessible for human use. The current climate crisis has made water scarcity a pressing global challenge, requiring innovative solutions. Membrane-based desalination technologies can potentially convert abundant salt water (97.4% of Earth's water) into freshwater, making it a viable solution.

Desalination has evolved from a niche concept to a scalable method of producing fresh water in the last two decades, thanks to advancements in technology and engineering. However, this technology has a high energy consumption rate, making it less economically viable. The use of green energy could partially or fully compensate for the energy demand of desalination technology.

Hydrogen production and its use as a fuel could be an attractive approach, particularly since this technology requires ultrapure water, which is produced in membrane-based desalination plants (reverse osmosis permeate). Combining these two state-of-the-art technologies could potentially provide desalination plants' long-term viability and sustainability.

In this work, the energy consumption of a large-scale brackish water desalination plant has been reviewed. The concept of producing hydrogen on-site and using green energy to partially or fully offset the energy required by the desalination plant has been discussed. This research innovatively integrates photovoltaic (PV) panels, water desalination, electrolysis and fuel cell technologies to simultaneously produce drinking water and hydrogen. The integrated system aims to enhance sustainability by utilizing renewable energy sources and ensuring a continuous water supply even during periods of limited solar power availability.

The system operates by harnessing solar energy through PV panels to power the electrolyser for hydrogen production while simultaneously generating power for the desalination plant. The excess hydrogen produced during sunny periods is stored and subsequently utilised through a fuel cell to meet the power demands of the desalination process during nighttime or cloudy days, ensuring a consistent supply of drinking water.

This research not only investigates the technical aspects of system dynamics and integration but also conducts a comprehensive techno-economic analysis to assess the feasibility and economic viability of the proposed system. The study explores various operational scenarios, considers the capital and operational costs, and evaluates potential revenue streams, including the sale of excess hydrogen.

The findings of this research contribute valuable insights into the development of sustainable and resilient systems for water and energy supply, with potential applications in remote and arid regions. The integrated PV-Water Desalination-Electrolyser-Fuel Cell system offers a promising solution to address both water scarcity and clean energy production challenges, paving the way for a more sustainable and environmentally friendly future.

Keywords: Hydrogen; Desalination; Green hydrogen production

SH 64

Design optimization of an autonomous hybrid renewable energy system for sustainable rural electrification and RO desalination

Ahmed S. Menesy*, Hamdy M. Sultan, Kotb M. Kotb,
Mohamed E. Zayed, Ibrahim O. Habiballah, Salah Kamel

King Fahd University of Petroleum and Minerals,
Khobar 31261, Dammam, Saudi Arabia
**Tel. +966 544367475; g202115590@kfupm.edu.sa*

In the quest for sustainable electrification and water resource management, especially in remote and rural areas, the integration of renewable energy sources and desalination systems presents a promising solution. This paper introduces an effective design of an autonomous hybrid renewable rnergy rystem (AHRES) optimized through a novel metaheuristic quadratic interpolation optimization (QIO) approach, specifically catering to the needs of rural communities and sustainable desalination processes. The proposed AHRES combines solar photovoltaic (PV) panels, wind turbines (WTs), diesel generator (DG), along with a battery energy storage unit. The system is designed to provide a reliable and continuous power supply for both electrical needs and a reverse osmosis (RO) desalination unit. The inclusion of multiple renewable energy sources ensures resilience against individual source variability and enhances system sustainability as well as the freshwater production capacity. The presented algorithm aims to address a multi-objective optimization challenge, seeking to minimize the cost of energy (COE), the reliability index characterized by the Loss of power supply probability (LPSP), and excess energy within specified constraints. The suggested hybrid system is proposed for deployment in the coastal residential community of Yanbu, located in the Medina province of Saudi Arabia (at 24.16° north latitude and 37.32° east longitude), with a planned operational lifespan of 25 years. To guarantee the precision, stability, and robustness of the proposed QIO algorithm put forth, careful consideration is given, it has been examined on different configurations of the proposed system, representing off-grid hybrid RES. Furthermore, a

comprehensive statistical measurement has been demonstrated to prove the effectiveness of the proposed QIO approach in solving the studied optimization problem. Furthermore, a thorough comparative analysis was conducted to assess the outcomes generated by the newly proposed optimization algorithm. This evaluation encompasses a comprehensive comparison with the results produced by several established optimization algorithms, including particle swarm optimization (PSO) and genetic algorithm (GA). The research thoroughly compares the impact of reliability indices on the optimal sizing of various hybrid systems. The findings indicate that the proposed algorithm successfully identifies the most efficient system design. Specifically, the stand-alone desalination plant configuration that includes solar power, battery storage, and a diesel generator is identified as the most cost-effective and environmentally friendly option, particularly at varying levels of unreliability index.

Keywords: Sustainable RO desalination; Autonomous hybrid renewable energy system; Quadratic interpolation optimization; Freshwater production capacity; Cost of energy; Loss of power supply probability

SH 65

The BARREL — the new generation of reserve osmosis (RO) and nanofiltration (NF) technology

Pedro Boulard

SIDEM, 1, rue Giovanni Battista Pirelli, Saint Maurice 94410, France
Tel. +33 626196860; pedro.boulard@veolia.com

SIDEM, the Veolia Water Technologies' subsidiaries, leader in the desalination market, has developed a cutting edge technology, the BARRELTM , an integrated plug-and-play reverse osmosis (RO) technology.

With increasing demand for fresh water and rising concerns over scarcity in the region, the BARRELTM meets the challenges and expectations of the desalination market while producing fresh water complying with all water quality standards. It is also suitable for wastewater reuse and low pressure RO applications. The Barrel will empower users with an economically viable and sustainable source of fresh water.

The BARRELTM was selected as a key technology for the first experiment in Europe in wastewater treatment for the supply of drinking water through the Jourdain programme, in France's Vendee region and for the municipal Reuse program of Sydney Water. The technology has also been in use at the Oman Sur desalination plant since 2019.

About the technology

The BARRELTM is a new multi RO element vessel that is designed to be a plug-and-play system. The carbon steel pressure vessel is manufactured and tested off-site, and is delivered as a single unit, so installation on-site can be fast-tracked and project schedules shortened. In addition, the modular design of the BARRELTM makes it highly scalable, offering varying capacities from 400 m^3/d to 50,000 m^3/d per unit. It can also be used in place of existing RO membranes and nanofiltration skids for a more economically viable, sustainable, and innovative alternative.

Compact and suitable for outdoor installations, the BARRELTM offers a footprint reduction of up to 25% and does not require a controlled environment. The sustainable solution also provides

a reduction in electrical consumption in the range of 0.05 kWh/m^3 of fresh water produced.

Beyond sustainability, the unique design of the BARRELTM also significantly reduces the number of high-pressure piping connections down to just two — the seawater inlet and the brine outlet. This design feature makes it safer for operators and minimizes risks on-site during the maintenance and operation phases. Corrosion is less likely to occur as seawater leakage sources found on the multiple high-pressure connections of traditional RO skids are reduced.

The BARRELTM also has a built-in digitalisation system with smart connectors providing real-time status updates on each membrane's condition. In fact, their performance can be monitored automatically and accessed remotely — helping operators to make better decisions, whether to shut down, rotate, or replace membranes, thus paving the way to optimized operation costs.

Keywords: Desalination; Reuse; Brackish water; Reverse osmosis technology; Capex and opex savings; Safety

SH 67

Pumping up green hydrogen: axial piston pumps' high efficiency advantage

Georg Herborg Enevoldsen

Danfoss, Nordborg 6430, Denmark
Tel. +45 21595233; georg.herborg@danfoss.com

Hydrogen is a promising energy carrier that is likely to play a significant role in the transition to a cleaner and more sustainable energy future. Hydrogen is a versatile fuel that can be produced from a variety of sources, including renewable energy sources such as solar, wind, and hydroelectric power. The production of hydrogen from renewable energy sources is a key component of a sustainable energy future, as it can help to reduce greenhouse gas emissions and mitigate climate change. According to the International Energy Agency, clean hydrogen is currently enjoying unprecedented political and business momentum, with the number of policies and projects around the world expanding rapidly.

Water demand for electrolysis Hydrogen production is of a different scale than water for industry, agriculture, and human consumption. A 100 MW electrolyser needs "only" about 20 m^3/h of ultra pure H_2O. For RO systems of this size, and future scaled up H_2 electrolysis systems axial piston pumps are the ideal choice of pump enabling standardizing serial production for RO modules for hydrogen production.

Axial Piston Pump technology can play an additional role in the ecosystem of hydrogen production. While the energy density of H_2 per unit mass is huge 120MJ/kg vs e.g. 44 MJ/kg for gasoline, the energy density per unit volume is not. In gaseous phase at 1 bar of pressure H_2 only contains around 0.01 MJ/L, vs e.g. 32 MJ/L of gasoline. Hence it's clear that the hydrogen produced from electrolysis needs compression and/or conversion to other more energy dense products like ammonia and methanol. This conversion typically also needs the hydrogen gas compressed for the process to run. Hydrogen is however difficult to compress with high energy efficiency due to its diffuse nature. It is there gaining interest to develop and build electrolysers that are able to operate at elevated pressures. If pressurized the ultrapure water fed into the electrolyser, the resulting in H_2 gas generated already at the feed pressure. And while H_2 gas can be challenging to compress energy efficiently, water is easily pressurized using energy efficient water pumps. The H_2 pressure

needed ranges from 10–20 bar for steel production to 100 bar or even higher for e-methanol production, pipeline transportation, salt cavern storage or ammonia production.

Axial piston pumps are super versatile water hydraulic machines that can operate over a large flow and pressure range, and are thus ideal for pressurizing ultra pure feed-water for electorlysers producing pressurized H_2. We will present a theoretical case study of pressurized H_2 production employing axial piston pump technology in both the RO stage and the electrolyser stage.

Keywords: Hydrogen; Efficiency; Desalination; Pumps; Axial piston; Electrolyser; SWRO; High-pressure

SH 69

Driving sustainable growth: economic models and levelized cost analysis of green hydrogen production in Saudi Arabia

Eydhah Almatrafi

King Abdulaziz University,
Faculty of Engineering at Rabigh King Abdulaziz University,
Jeddah 21589, Saudi Arabia
ealmatrafi@kau.edu.sa

The growing demand for clean and sustainable energy sources has led to increased interest in hydrogen generation using renewables. This study aims to develop relevant economic models for hydrogen production generation using renewables, specifically focusing on the projects announced by the Renewable Energy Project Development Office (REPDO) in Saudi Arabia. Additionally, the study aims to map the life cycle performance and cost associated with renewable hydrogen generation and assess the levelized cost of electricity and hydrogen generation for different renewable installations in Saudi Arabia.

To achieve these objectives, economic modeling techniques are employed to analyze the feasibility and profitability of hydrogen production using renewables within the context of the REPDO projects. The models take into account various factors such as capital investment, operational costs, energy conversion efficiencies, and market prices. By incorporating these variables, the economic models provide insights into the financial viability of renewable hydrogen projects and their long-term sustainability.

In parallel, a comprehensive life cycle assessment (LCA) is conducted to evaluate the environmental impacts associated with different stages of hydrogen generation using renewables. The LCA considers factors such as raw material extraction, manufacturing of equipment, transportation, operation, and end-of-life disposal. By mapping the life cycle performance, the study enables a holistic understanding of the environmental implications of renewable hydrogen generation, allowing policymakers and industry stakeholders to make informed decisions regarding sustainability goals and resource allocation.

Furthermore, the study delves into the levelized cost of electricity (LCOE) and hydrogen (LCOH) generation for diverse renewable installations in Saudi Arabia. Over 12 renewable energy technologies, including solar photovoltaic, wind, and geothermal, are analyzed to determine their respective LCOE and LCOH values. This analysis provides a comparative assessment of the economic competitiveness of different renewable sources for both electricity and hydrogen production. It also highlights the potential synergies and trade-offs between renewable energy deployment strategies and hydrogen generation objectives.

The findings of this study contribute to the understanding of the economic, environmental, and technological aspects of renewable hydrogen generation in Saudi Arabia. The outcomes will assist policymakers, investors, and industry leaders in making informed decisions regarding the implementation and scaling of renewable hydrogen projects in the region. Additionally, the insights gained from the economic models, life cycle assessment, and levelized cost analysis can inform the development of supportive policies and regulatory frameworks to accelerate the transition towards a sustainable hydrogen economy.

Keywords: Renewable hydrogen; Economic modeling; Life cycle assessment; Levelized cost of electricity; Levelized cost of hydrogen; REPDO projects; Saudi Arabia

SH 70

Exploring the potential of graphene ultrafiltration as an effective pretreatment for reverse osmosis desalination

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

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

Pretreatment processes preceding reverse osmosis (RO) desalination aim to ensure supplying high-quality seawater and maintaining the optimal functionality of RO membranes. Despite conventional pretreatment, (bio)fouling remains a challenge, leading to inefficient desalination and reduced membrane lifetimes. Compared to conventional pretreatment, ultrafiltration (UF), an advanced membrane filtration process, demonstrates superior removal of particles down to 0.01 micron. This approach offers higher-quality produced water with reduced fouling potential in terms of turbidity and silt density index, accompanied by long-term savings in space, chemical costs, and operating expenses. While traditional polymeric UF membranes may be prone to (bio)fouling, which undermines the advantages of reducing operational and chemical costs, novel graphene oxide membranes are claimed to exhibit enhanced mechanical strength, antimicrobial resistance, and hydrophilicity. Thus far, such membranes have not been tested or challenged with natural seawater to determine their capacity as a pretreatment method. Therefore, in this study, a graphene UF membrane was tested as a potential pretreatment solution for seawater desalination. Our preliminary analyses revealed its capability to eliminate nearly 100% of particles and over 95% of microbial cells. Furthermore, in comparison to conventional media filtration, assessments of microbial growth potential indicate microbiological stability in the graphene UF permeate for at least 3 days. This suggests a longer window for processing through RO, provided proper storage practices are maintained. The graphene UF membrane shows promise in mitigating seawater biofouling potential by reducing microbial growth potential, microbial cells, and particles, possibly including organic components. This exploratory study suggests that graphene UF membranes could serve as a viable alternative for future pretreatment processes, enhancing RO systems' capacity to handle high-quality seawater and minimizing (bio)fouling issues.

Keywords: Pretreatment; Ultrafiltration; Graphene oxide membranes; Biofouling mitigation; Microbial growth potential; Particle removal; Permeate stability; Silt density index

SH 71

Simulating the nanofiltration process of RO brine as a pre-treatment step for disinfectant and hydrogen production by electrochlor

Silvano Porto Pereira*, Esther J. de Kroon,
Luewton L.F. Agostinho,
José Luís Sanchez Lizaso, Mariko A. Carneiro

CAGECE, Rua Tomás Lopes, 85, Fortaleza 60060260, Brazil
**Tel. +55 8598608961 8; silvanopereira@terra.com.br*

Water scarcity has become an increasing problem of global scale. Alternative water sources are therefore needed in regions experiencing water scarcity, including the exploitation of less conventional water resources for the production of potable water, such as seawater or brackish water by desalination. The state of Ceará in Brazil is one of the regions affected by regular droughts and water shortages throughout the year, as it is located in the Brazilian semi-arid region. Due to its coastal location, the water and sewage company Cagece and the Government of Ceará aim for the realization of a large-scale desalination plant located in the city of Fortaleza to secure the freshwater availability for Ceará in the future. It will be the first desalination plant in Brazil of this size, therefore facing new environmental challenges for the realization of the desalination plant. One of the main challenges is the safe and cost-effective disposal of the brine produced during desalination. Coastal discharge of brine has been a common practice worldwide, since it is the most cost-effective option for brine disposal. However, this practice brings different environmental impacts, among other things, it could result in the deterioration of receiving marine ecosystems around the discharge point. An upcoming trend consists of utilizing brine for resource recovery. A possible process for utilizing brine is the conversion of NaCl into disinfectant products and Hydrogen by applying electrochlorination. The use of RO brine as feed for the electrochlorination process is a relatively new concept, and several aspects of this process require further specification. One of which is brine pre-treatment, since it contains several constituents that would result in reduced efficiency and scaling within the electrochlorination process. Given its novelty aspect, both simulations and experimental studies need to be performed to evaluate possibilities and consequences. In this work, nanofiltration (NF) was hypothesized as a possible technology for this purpose, since it can be used to separate divalent and monovalent ions.

Objective and main findings

The objective of the present work is therefore to provide insights in the pre-treatment steps of RO brine for the specific use of chlorine-based disinfectant production with electrochlorination, with the main focus on nanofiltration. Ultimately, this approach would be a possible implementation within the desalination plant of Fortaleza for on-site disinfectant production, to be reused in the desalination process itself, as well as supplying other (waste)water treatment facilities of Cagece in the state of Ceará.

This work involved the simulation of an NF process fed with RO brine, using the software 'Winflows 4.05'. After establishing the overall process design, the effects of recovery, brine/seawater feed mixtures and process design were assessed. The acquired data was evaluated for ion rejection, energy demand and permeate quality in accordance with electrochlorination feed requirements. Preliminary findings identified the occurrence of scaling and reaching a sufficient permeate quality to be the main challenges encountered. The inorganic salts $CaCO_3$, $CaSO_4$ and $BaSO_4$ were

shown to be the major constituents which might influence/cause scaling of the membrane. The high concentrations of calcium and magnesium in relation to the sodium chloride concentration in the permeate was shown to be the main obstacle in complying with the electrochlorination feed requirements. Although the application of lower recovery rates and using feed mixtures of brine and seawater reduced the scaling potential, a simple 1-step NF process was shown to produce an insufficient permeate quality. Simulations implementing a 2-step NF process design showed major improvement of the permeate quality, complying with the key feed requirements for electrochlorination. However, such solutions significantly increased the energy demand of the NF process.

Future perspectives

Simulations showed promising results for a 2-step NF process in providing sufficient permeate quality to serve as feed for electrochlorination. Future work would involve an economical assessment in order to justify its application as alternative brine treatment within the desalination plant in Fortaleza and providing disinfection products for other water treatment plants, as well the feasibility of hydrogen and chlorine combining production using a partitioned electrochemical cell (e.g. electrodialysis) and brine.

Keywords: Desalination; Brine treatment; Electroclorination; Chrorine production; Hydrogen production

SH 72

The performances of nanofiltration membranes on seawater: the Saline Water Conversion Corporation experience

Eslam Alwaznani*, Seungwon Ihm, Abdallatif Abdalehman

SWCC, Aljubail 31951, Saudi Arabia
**Tel. +966 545251566; ealwaznani@swcc.gov.sa*

With its characteristics of rejecting multi-valent ions better than mono-valent ions, the application of nanofiltration (NF) membranes in the seawater desalination industry has been discussed since 1990s. There were mainly two groups of studies, the first one is to use the NF as a pretreatment of membrane or thermal desalination [1–4], so that the risk of scale deposition can be minimized and thus a higher recovery and/or a higher efficiency design of the main desalination process could be achieved. A NF-SWRO, NF-MSF and NF-SWRO-MSF systems were tested in a pilot scale [1]. A higher recovery of up to about 80% was achieved for SWRO (although it was usually 50-55% during the long-term operation for 4,000 h). A higher temperature operation at 120°C was achieved for MSF which make-up water was either the NF permeate (1,600 hrs) or the SWRO reject after the NF (270 h), and the results allowed the design of a NF-SWRO-MSF hybrid system with a recovery of up to 90% of the NF permeate. Although the very high recoveries of the main desalination systems were discussed in [1], a high rejection NF membrane was employed there, and a concern on the scale deposition limited the recovery of the NF system below 45% at a typical operating condition, and 60% or higher recovery was tried with lowering the feed pH to about 6.8. A lower recovery in the NF implies still a larger intake and pretreatment system. In this regard, the ion rejection performance of 8 commercial NF membranes was evaluated to select a proper one for the commercial NF-SWRO project in Umm Lujj, Saudi Arabia [3], then further

tests were conducted which increased the number of the NF performance database as 11-13 [5, 6] in the Saline Water Conversion Corporation (SWCC), with categorizing into three groups: high, medium (moderate) and low rejection NF membranes based on its experimental study results on ion rejection performance using 4- or 8-inch membranes [6]. A moderate rejection NF membrane was considered for the Umm Lujj NF-SWRO project, and 65 to 85% recoveries were studied [5] with follow-up results and analysis of the field operation data [6, 7]. The NF performance databased has been extended with further pilot trials over time in the SWCC [8].

Another important application of NF membranes is on the seawater and brine mining. Extracting minerals from seawater and its brine has been discussed and studied by many researchers. B. AbuSharkh et al. [9] reviewed some technical and economic prospects for the utilization of commercially viable products from seawater where NF was considered as one of key technologies. A NF membrane with a higher divalent-ions rejection with a lower monovalent-ions rejection is preferred for the separation of the mono- and di-valent ions and the concentration of the divalent ions [8, 9]. A multi-stage NF system to extract Mg (and some of Ca) from seawater was developed utilizing the feature of a NF membrane, and the commercial NF-Mg system is under operation, supplementing 16.9-20.2 mg/L of Mg to the 400,000 m3/d of product water in Shoaiba Ph.4, Saudi Arabia [10, 11]. In addition, a modern membrane brine concentration (MBC) technology includes a high pressure NF membrane (usually a high rejection NF membrane or sometimes called as a low salt rejection (LSR) RO membrane), which can concentrate the SWRO or (U)HPRO brine further to a desired concentration, e.g. over 200,000 mg/L, suitable for a crystallizer to product high purity NaCl salt. In this paper, the SWCC experience, especially on the ion rejection performances on seawater and the further applications in emerging seawater and brine mining area will be discussed with detailed performance data and analysis

Keywords: Nanofiltration (NF); Ion rejection; Performance data base; Seawater desalination; Saline Water Conversion Corporation (SWCC)

SH 73

Preliminary economics of desalination and hydrogen production with renewable energy

Seifallah Elsaie*, Yahya Elsaie

Consulting Engineering Co., 19 Lotfy Lane, Cairo 11341, Egypt
**elsaiebulkymail@gmail.com*

Introduction

With the rising scarcity of freshwater and the goal for net zero carbon emission (decarbonization), combining green hydrogen production and desalination is a solution to meet water and energy demand sustainability. This paper examines different desalination technologies economics to supply green hydrogen production.

Desalination technologies

Desalination offers a potential solution to the water challenge in hydrogen production. The pro-

duction of hydrogen through electrolysis, is water intensive by transforming seawater into usable freshwater, desalination plants can provide a dedicated water source for electrolysis, alleviating the pressure on fresh water resources.

The desalination technologies that shall be considered are the following:

- MED (multiple effect distillation).
- MED-TVC (MED with thermal vapor compression).
- MSF (multi stage flash).
- RO (reverse osmosis).
- ED (electrodialysis) / EDR.

Current renewables coupled with desalination in Egypt

The combination of multi effect distillation MED parabolic trough collector (PTC) concentrated solar power (CSP) and a steam turbine (ST),– represents a threnody nomically efficient integration. In the configuration studied the exhaust heat from the ST is used as a heat source for the MED module, which essentially means all the conventional CSP cooling systems can be replaced by thermal desalination.

The studied cogeneration solar power and desalination system was installed at Borg El Arab City, Egypt through the MATS project.

Hydrogen Waste Heat Utilization:

The reuse of waste heat from electrolysis in thermal desalination can boost overall efficiency. Water electrolysers also produce heat during electrolysis. Reuse of this heat for desalination is possible.

Keywords: Desalination; Hydrogen; Renewable energy

SH 74

Effective lithium extraction via membrane capacitive deionization through $LiMn_2O_4$/activated carbon intercalation electrodes

Dalia Ahmed*, Amr Alahl, Nagwa Badwy, Mohamed Ali

Desert Research Center, 1 Mathaf El-Matarya St., El-Matareya 11753, Sharkia, Cairo 44616, Egypt
**Tel. +20 1280275794; daliasaid350@gmail.com*

Due to the increasing need for clean energy, especially with the extensive utilization of lithium-ion batteries in electric cars, there is a significant surge in the global demand for lithium (Li) resources. Currently, lithium, a natural resource, is sourced from RO desalination plant brine. Membrane capacitive deionization (MCDI) is an advanced electrochemical method that is now leading the way in extracting lithium from saltwater and desalination brine. Additionally, it exhibits remarkable cost-effectiveness and energy efficiency. Both $LiMn_2O_4$ and MnO_2 were synthesized by diverse chemical methods and subsequently employed for lithium-ion adsorption. The MCDI system effectively utilized a voltage of 1.2 V to selectively extract lithium ions. We used scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDX), X-ray diffraction (XRD), and particle size analysis

to figure out the materials' chemical and physical properties, as well as their composition. Two distinct cathode phases, $LiMn_2O_4$/AC and MnO_2/AC, were utilized at various concentrations (30%, 50%, 70%, and 90%). The anode was made of AC. The MCDI system utilized electrodes to extract lithium ions from a synthetic solution with a Li/Na ratio of 1/30. The results revealed that $LiMn_2O_4$ exhibited a much higher maximum adsorption capacity of 16.14 mg/g compared to MnO_2, which only had a capacity of 2.235 mg/g. Furthermore, $LiMn_2O_4$ exhibited a remarkable preference for lithium over sodium ions, with a minimal adsorption rate of only 0.02%.

Keywords: Capacitive deionization; MnO_2 nanospheres; $LiMn_2O_4$; Water desalination; Electrosorption; Lithium extraction; Membrane capacitive deionization; Electrochemical lithium recovery; Composite electrode; Lithium recovery from brine; Lithium recovery capacity; Salt lake brine

SH 75

Investigating the nano-crystalline structure of CB-PVA/PTFE for enhanced optical characteristics: applications for membrane distillation

Bassant Ebraheem*, A.A.M. Farag,
M.M. El-Nahass, S.M. Elbakery,
Hosam Shawky, Mohamed E.A.Ali

**Ain Shams university, Makreezy Street, Cairo 31511, Egypt*
bassant.elsayed@edu.asu.edu.eg

In this investigation, a novel (carbon black) C.B-(polyvinyl alcohol) PVA. film with highly adherent and advantageous properties was synthesized through spray gun pyrolysis on a PTFE substrate with a PP backing layer. Both computational and experimental methods were employed to characterize and analyze the film for various studies and applications. Density Functional Theory (DFT) calculations, utilizing the B3LYP basis set 6–311G, were conducted to predict the HOMO-LUMO gap of the C.B. Structural properties were examined through XRD analysis, revealing a polycrystalline structure with hexagonal lattice in both powder and film forms of C.B. Several techniques were employed to determine and compare average crystallite size, macrostrain, and dislocation density were calculated. SEM images of the film surface were acquired to investigate RMS roughness features and grain-boundary effects. Linear and nonlinear spectrophotometric measurements were employed to determine the optical constants of the C.B-PVA film. The relationship between absorption coefficient and photon energy was analyzed, revealing an optical transition is directly allowed with an energy gap of 2.16 eV. Furthermore, dispersion and oscillator energies were measured using the single oscillator model with the Wemple–DiDomenico relation, resulting in values of 3.8 and 1.7 eV, respectively. The unique properties exhibited by the C.B-PVA/PTFE-PP film suggest its potential suitability for water desalination applications. The comprehensive computational and experimental analysis presented in this study provides valuable insights into the structural and optical characteristics of the synthesized C.B-PVA film.

Keywords: TD-DFT theoretical investigation; Nanostructure; Structural characteristics; Optical dispersion; Single oscillator; Membrane desalination

SH 76

Innovating deep seawater desalination and cooling for sustainable water and energy management

Tor-Anders Rusvik*, Christian Abelsson

FSubsea AS, Oslo 0664, Norway
**Tel. +47 97586329; tar@fsubsea.com*

As global freshwater scarcity intensifies due to climate change and population growth, seawater desalination emerges as an essential solution. The technological advancement, particularly in seawater reverse osmosis (SWRO), offers a reliable source of fresh water. Despite its high energy consumption and costs, innovations in renewable energy and resource recovery are making desalination more sustainable and economically viable.

In regions plagued by water stress, often characterized by tropical climates, the demand for heating, ventilation, and air conditioning (HVAC) consumes an excessive portion of energy. The integration of SWRO with seawater air conditioning (SWAC) presents a dual solution, reducing both electricity consumption and CO_2 emissions. This paper introduces a subsea SWRO system, Flocean, designed for deep water operations.

Installed at depths of 300–600 m, in the nutrient-scarce dysphotic zone, where feed water is cool with a quality inherently high and stable, the design considerably diminishes the necessity for extensive pre-treatment and reduces biofouling issues. At these depths, the system utilizes the ambient hydrostatic pressure to reduce energy consumption by 30–50% compared to conventional SWRO systems.

Significantly, the cool, desalinated water produced is further utilized in a SWAC system, enhancing the efficiency of both water production and cooling. This integration into a Deep Seawater Cooling and Desalination (DCDS) system dramatically offsets the energy demands of desalination. For instance, a 50,000 m³/d Flocean Desal system can generate a cooling capacity of 15 MW with an electrical energy requirement of approximately 4.6 MW. This efficiency is starkly favourable when compared to traditional air conditioning systems, suggesting that the electricity savings from DCDS can essentially neutralize the energy footprint of the desalination process.

This paper details the Flocean design and explores the symbiotic energy relationship between desalination and cooling, emphasizing the life-cycle benefits of this innovative approach to address the pressing need for fresh water and energy-efficient cooling in hot and arid regions. Through Flocean's integration with SWAC, we demonstrate a nearly energy-neutral system that promises significant advances in environmental sustainability and resource efficiency.

Keywords: Deepwater desalination; Subsea desalination; Subsea SWRO; Deepwater air conditioning; SWAC; Deep seawater cooling and desalination; DCDS

SH 77

Coupling membrane distillation at pilot scale with green hydrogen generation

Guillermo Zaragoza*, Antonio Atienza-Márquez, Dereje Sendeke Ayou, Alejandro Bueso, Alberto Coronas, Alba Ruiz-Aguirre

CIEMAT, Plataforma Solar de Almería, carretera de Senes km 4, Tabernas - Almeria 04200, Spain
**guillermo.zaragoza@psa.es*

The generation of green hydrogen requires a source of high quality water. Desalination technologies are therefore proposed to supply the required water to electrolysers. In addition, there is a need to manage the waste heat produced by the electrolysis process, so by using it, thermal desalination technologies have an advantage compared to standard reverse osmosis which requires expensive electricity for operation. Membrane distillation (MD) is a thermal separation technology based on the hydrophobicity of microporous membranes that separate liquid water from vapour, so a temperature difference across the membrane results in the production of pure water. It has the benefit compared to other thermal desalination technologies of lower cost and size modularity, besides the use of low-grade heat (<80°C). The competitive advantage against other membrane desalination technologies lies in the lower mechanical pressure used and the higher quality of the water produced, since MD is based on evaporation, not filtration. This work examines the potential of MD for integration with water electrolysis to generate renewable hydrogen. The waste heat from a PV-powered electrolysis stack feeds a MD unit to produce the necessary water for the electrolysis process. Based on experimental results, the best MD technology is identified. Also, a case study for the integration is analysed, using model-based optimization to find the best global performance of the integrated system.

Keywords: Green hydrogen; Membrane distillation; Electrolysis

SH 78

Removal of sodium, chloride ions and hardness from saline water membranes incorporated with ZrO_2 nano sphere

Eman Sobhy Mansour*, H. Abdallah, A. Shaban

National Research Centre, 33 El Buhouth, Cairo 12622, Egypt
**eman_mansor31@yahoo.com*

Desalination of water is a crucial step in the process of obtaining potable water. One of the main challenges for the researchers is its efficient application and affordable preparation.

Different types of flat sheet membranes were fabricated using cellulose acetate as a base polymer, and poly vinyl alcohol (PVA) as additive with a dosing of (0.1, 0.3, 0.5 and 0.7 wt.%) from zirconium oxide (ZrO_2) nanoparticle. SEM, TEM, and XRD analyses were used to characterize the generated ZrO_2 nanoparticle in order to confirm its nano size and crystal structure.

The surface morphologies and existence of the dense layer, which is the typical property of the RO membrane capable of salt separation, were identified on the manufactured RO membranes by SEM. Membranes prepared by embedding 0.5 wt% ZrO_2 with PVA/CA was proved to be efficient as RO membranes using 2000 ppm NaCl and exhibited high salt rejection of 97% and water permeability of 12.5 LMH. Also, there is a decrease in the NaCl removal tendency was observed with the excessive dosages of ZrO_2 with 0.7 wt.%, which was due to the concentration polarization, which blocks the pores on surfaces of the membranes. Antifouling behavior of the prepared membranes was tested using bovine serum albumin (BSA), the results indicate the low irreversible resistance, total fouling resistance, and high flux recovery ratio compared to the neat membrane. The prepared membranes have a stable salt rejection and water productivity even after demonstrating with chlorine (25–100 mg l^{-1} of NaOCl for 120 min).

Keywords: Zirconium oxide; Poly vinyl alcohol; Cellulose acetate; Water desalination; RO membranes

SH 79

Enhancing green hydrogen projects by reducing energy and infrastructure demands via novel ERD technology

Erik Desormeaux*, Paul Lee, Azam Thatte

Energy Recovery, Inc., 1717 Doolittle Dr.,
San Leandro, CA 94577-2231, USA
**Tel. +1 5106485767; edesormeaux@energyrecovery.com*

Introduction

Green hydrogen requires renewable energy to separate water molecules and yield sustainable hydrogen fuel. The global importance of green hydrogen stems from commitments to comprehensive decarbonization per the Paris Agreement and other net-zero emissions goals. An energy efficient and robust water supply is key to implement green hydrogen production, and this paper will discuss that topic by 1) exploring how local water supplies integrate with key infrastructure, 2) identifying infrastructure challenges related to green hydrogen project development in countries leading the way, and 3) introducing new opportunities to reduce infrastructure demands enabled by recent innovations in commercial isobaric energy recovery device (ERD) technology. Isobaric ERDs are commonly used in the desalination industry, but new innovations in this technology and how it is used can make hydrogen projects more cost effective and resource efficient.

Projected water demand from seawater desalination for leading projects

The green hydrogen industry estimated in 2023 that 7.4 million metric tons per year of green hydrogen capacity will be installed in various locations (e.g., Spain, Brazil, Portugal and Oman) in the next 3–7 years that would rely on up to 1.8 million m^3/d of new seawater desalination capacity and that significantly more desalinated water could be needed in the next 7–12 years. More recent estimates from Global Water Intelligence in December of 2023 have increased the predicted demineralized water demand for the green hydrogen market to approximately 3.9 million m^3/d by 2030 and estimates that 65% (2.54 million m^3/d) will come from seawater desalination and another 15% (0.59 million m3/d) will come from water reuse.

Additionally, significant infrastructure is needed to supply cooling water to electrolzyers and other equipment used in hydrogen production, storage, cracking (if applicable), etc. Estimates used for cooling assume that 2-9 times more water will be needed for cooling than the high purity water that is converted into hydrogen. In coastal locations, it's likely that seawater can be used for cooling; however, regulations related to once-through cooling have become more rigorous in some locations (e.g., California), so new options for cooling may be necessary to implement green hydrogen in these locations. A three level analysis will be used to demonstrate how novel uses of ERD technology can change infrastructure requirements.

First, a high level analysis of 10 planned green hydrogen projects will be presented along with a matrix that categorizes these projects into three tiers for comparison from an infrastructure point of view. The matrix uses a ranking system related to the significance of renewable energy supplies, transportation, market size, grid integration, water supply, and other factors. For example, key considerations that emerge from this analysis include benefits related to Spain's substantial ongoing projects, Brazil's access to economical renewable energy, Portugal's evolving infrastructure, and India's challenges with water scarcity and timing.

Next, a more localized comparison analysis will be presented to indicate that existing infrastructure is key to reduce the cost of green hydrogen by providing 1) local hydrogen demand, 2) hydrogen supply (e.g., water and energy resources), 3) reduced export costs (e.g., existing storage, intake and offtake facilities suitable for retrofit), and 4) options for low cost cooling. Two example planned projects will be compared based on how existing infrastructure in each of these categories impacts local water and energy demand and opportunities to reduce project footprint. The analysis will include an assessment of energy demand and opportunities to reduce this demand assuming seawater desalination vs. reuse as the water supply. The analysis shows that water purification contributes only a fraction of the renewable energy demand for a project; however, it also shows that maximizing energy efficiency of the water purifications systems can still have a significant impact on project footprint.

Lastly, the analysis will present novel approaches to use isobaric ERD technology and will propose new applications to further reduce energy requirements. For example, new isobaric ERDs that can transfer energy from both liquids and gases at target temperatures and pressures can increase renewable energy from geothermal sources and to reduce energy requirements when using heat pumps to upgrade waste heat from electrolyzers or fuel cells for reuse via heat pumps for SWRO brine mining and/or local industry. The analysis will focus on benefits for hydrogen projects located near low grade geothermal resources that need to be upgraded for green energy production and in locations where waste heat from the hydrogen electrolyzer can be cost effectively upgraded and reused in nearby industry to significantly reduce cooling demands.

Keywords: Green hydrogen; Infrastructure; Desalination; Water reuse; Geothermal energy; Heat pumps

SH 80

Decarbonizing water desalination by optimizing renewable energy using artificial intelligence

Om Sanan*, Joshua Sperling, David Greene, Ross Greer

*Scarsdale High School, 3 Hanover Rd, Scarsdale, NY 10583, USA
om.sanan007@gmail.com

The increasing intensity and frequency of water scarcity, carbon emissions, and climate risks pose critical challenges necessitating increased uptake of and a paradigm shift to energy- and climate-smart water desalination processes. Desalination, particularly through reverse osmosis (RO), is an energy-intensive process, predominantly (~99%) reliant on non-renewable fossil fuels. Additionally, the high energy demands and costs of conventional desalination methods pose economic challenges. This study employs metrics and a decision framework to enable and accelerate the energy efficiency, decarbonization, and cost-effectiveness of RO water desalination processes. Integration and optimization of advanced artificial intelligence (AI) algorithms, hybrid renewable energy (RE) sources, and storage systems are utilized to explore tradeoffs and identify paths to maximize energy efficiency, while minimizing cost, energy inputs, and carbon footprint (by at least 50%) using multi-source, multi-metric data, modeling and analysis of four (4) U.S. water desalination plants (Alameda County, Tampa Bay, San Antonio-SAWS, Kay-Bailey Hutchison). This robust data- and analytical-driven approach provides the necessary tools to desalination plants for a sustainable transition to 100% RE, and to local governments and utilities to expedite the approval processes and provide continued rebates and innovative financing programs.

An essential step was analyzing various RE sources, such as photovoltaic panels, wind turbines, concentrated solar power, geothermal units, and hydro turbines; in addition, we examine battery storage systems to address the intermittency challenges associated with solar and wind energy. More specifically, we collected and sanitized information on top-of-the-line RE systems, including formulas for power generation, cost, carbon emissions, and specs. The feasibility of these diverse RE systems was assessed using 5 years of actual operational data from desalination plants including water production, energy consumption, water quality, and 10-year historical hourly weather data, establishing optimization functions and constraints.

In this research, to obtain optimal sizing of each RE system to satisfy the desalination plants' energy demand, methods including predictive modeling for water production, energy consumption, and long-term weather forecasting have been used. The plant data is preprocessed to account for variables like weather changes, plant shutdowns, and maintenance using statistical and AI tools, which form the core of the approach. Various machine learning models, including SARIMA, Random Forest, XGBoost, and Gradient Boosting, are employed for forecasting. The research also estimates the energy production potential of each RE source, factoring in surplus or deficiency management through battery storage and utility grid interconnection. This strategy aligns RE generation with the anticipated energy demands of the plants, facilitating a comprehensive optimization strategy that includes sizing and load forecasting of water desalination plants through AI models.

The results show that among AI models, Gradient Boosting and an innovative average method of XGBoost have the best accuracy. The root mean square error (RMSE) for weather prediction varied across different variables and locations. For temperature, with a range between –10.0-46.1°C, the RMSE values were 3.37°C for Alameda, 4.67°C for SAWS, 3.47°C for Tampa, and 3.62°C for

Kay-Bailey. In terms of Direct Normal Irradiance (DNI), measured within a range of 0–1.049 W/m^2, the RMSE values were 189 W/m^2 for Alameda, 234 W/m^2 for SAWS, 199 W/m^2 for Tampa, and 204 W/m^2 for Kay Bailey. For wind speed, spanning from 0–35.2 m/s, the RMSE values recorded were 1.72 m/s for Alameda, 2.48 m/s for SAWS, 2.79 m/s for Tampa, and 2.97 m/s for Kay-Bailey. For treated water flows, which range from 0–30 MGD, Alameda's RF model showed 1.49 MGD, SAWS's GB model 0.86 MGD, Tampa's GB model 1.17 MGD, and Kay Bailey's GB model 0.39 MGD. Finally, for energy consumption, Alameda's RF model recorded an RMSE of 59,000 kWh (range of 0–1,000,000 kWh), SAWS's RF model 711 kWh (range of 0–300,000 kWh), Tampa's GB model 6,751 kWh (same range), while Kay Bailey's GB model 10,185 kWh (range of 0–83,333 kWh).

By harnessing AI and RE, a scalable, sustainable solution to water scarcity and carbon emissions challenges are explored in terms of costs when using RE mix of 50%, 75% and 100%. At a 50% RE mix, it could halve the current annual CO_2 output, equating to a reduction of 16 billion gallons or 16,000 metric tons of CO_2, akin to the impact of planting 600,000 trees and cost reduction of over 50% for the four plants. The methods explored and results described contribute to environmental conservation, and enhance economic sustainability in water management, highlighting plausible transitions and decision-making considerations for future desalination.

Keywords: Energy optimization; Multi-source data-driven modeling; Desalination; Hybrid renewable energy systems; Renewable energy sources; Artificial intelligence; Water-energy nexus

SH 81

Innovative desalination process for integrated water, energy, and resource production

Olga Ferrer*, Luca Sbardella, Germán Santos, Inmaculada Ortiz, Simon Grasman, Jorge J. Malfeito

ACCIONA, El Prat de Llobregat (BCN) 08820, Spain
Tel. +34 607193608; olferrer@acciona.com

Water scarcity is becoming a worldwide issue, being water demand projected to increase by 55% between 2000 and 2050 [1]. Additional desalinated contracted capacity is expected to increase from 5 million m^3/d in 2023 to more than 6 million m^3/d in 2024, according to the GWI [2]. Reverse osmosis (RO) is the most implemented and energy efficient desalination technology for seawater desalination, and its permeate is suitable for municipal, agricultural and industrial uses. Seawater reverse osmosis (SWRO) energy consumption has significantly been reduced over the last 25 years, with an overall desalination energy consumption descending from ~5 kWh/m^3 to ~3 kWh/m^3 [2]. Nevertheless, continuous R&D efforts keep working towards pushing it forward down. Moreover, research in desalination also focuses on the increase of desalination circularity, to maximise the resources obtained during the desalination process.

In this context, the LIFE INDESAL project aims to develop and demonstrate a novel integrated and circular seawater desalination solution with reduced energy consumption, and able to recover valuable resources from brine. The main objective of the LIFE INDESAL project is to make the desalination process more sustainable and circular by: (i) reducing the energy footprint of seawater desalination, (ii) generating renewable energy from desalination brines, and (iii) valorising desalination brines by resource recovery.

The novel desalination scheme is indeed based on the integration of three different technolo-

gies, contributing to increase the sustainability of the proposed process: low-pressure multi-stage reverse osmosis (LMS RO), reverse electrodialysis (RED) and electrodialysis with bipolar membranes (EDBM).

The LMS RO process envisaged in LIFE INDESAL incorporates a 2-pass RO with multistage design. The 1st pass consists of 2-stage scheme with shorter pressure vessels (PVs) and a booster pump in between. The 2nd pass purpose is to achieve an optimum permeate quality which can be used for different purposes. This novel LMS RO design is meant to reduce the over-pressurization and its negative effect on overall energy consumption and flux distribution. The LMS RO design foresees to achieve a 0.2 kWh/m^3 specific energy consumption (SEC) reduction, compared to a conventional SWRO process, thus making it very attractive for its implementation in the market. The novel RED process will demonstrate the recovery of energy from brines, decreasing energy requirements of the desalination process up to 0.1 kWh/m^3. The concentrated outlet stream of LMS RO process is treated by EDBM to obtain NaOH and HCl to be used for pH adjustment prior to the 2nd pass and for membrane cleaning. Purity and quantity of the produced chemicals will enable an in situ self-sufficient supply, generating 100% of the NaOH and HCl needed for the pilot plant, thus reducing the external demand of reagents for desalination.

A demonstrative pilot plant (8 m^3/h nominal influent capactiy) comprising the integrated scheme has been designed and constructed and is currently being commissioned. It will be tested in a fully representative operational environment, using the same intake as a full scale plant from the Mediterranean sea, and working continuously since January 2024 for 2 years. An in depth characterisation of the 3 processes, individually and in an integrated way will be performed, followed by a life cycle assessment and a cost benefit analysis to quantify its benefits in comparison to a conventional SWRO scheme.

The consortium of LIFE INDESAL project is composed by ACCIONA AGUA (ES), University of Cantabria (ES), APRIA Systems (ES), REDstack (NL) and REVOLVE (BE).

Acknowledgment

The Mancomunidad de los Canales del Taibilla (MCT), an autonomous organism dependent on the Estado de Medio Ambiente del Ministerio para la Transición Ecológica y el Reto Demográfico, is acknowledged for enabling the installation of the pilot plant and supply of services.

LIFE INDESAL (LIFE21-ENV-ES-101074444) is funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or The European Climate, Infrastructure and Environment Executive Agency (CINEA). Neither the European Union nor the granting authority can be held responsible for them.

References

[1] OECD website. OECD Environmental Outlook to 2050: The Consequences of Inaction – Key Facts and Figures. Available on https://www.oecd.org/env/indicators-modelling-outlooks/oecdenvironmentaloutlookto2050theconsequencesofinaction-keyfactsandfigures.htm (accessed on 27-12-2023)

[2] Global Water Intelligence (GWI) (2023) Market focus deck Desalination and reuse October 2023

Keywords: Seawater reverse osmosis; Reverse electrodialysis; Electrodialysis with bipolar membranes

SH 82

Vacuum multi-effect membrane distillation for brine treatment at pilot scale

Alba Ruiz-Aguirre[1]*, Alejandro Bueso[1], Juan Antonio Andrés-Mañas[2], Isabel Requena[1], Guillermo Zaragoza[1]

1 CIEMAT-Plataforma Solar de Almería, Ctra. de Senés s/n, 04200 Tabernas, Almería, Spain
2 Universidad de Almería-CIESOL, Ctra. de Sacramento s/n, 04120 La Cañada, Almería, Spain
** Tel.:+34 950387900 (Ext: 998); E-mail: alba.ruiz@psa.es*

Under the framework of the European project intelWATT, a vacuum multi-effect membrane distillation unit is being evaluated at the facilities of Plataforma Solar de Almería (PSA) with the objective of concentrating brine effluents. Multi-effect configuration is based on the recovery of latent heat of condensation as latent heat of evaporation in consecutive effects, avoiding the detrimental effect on productivity that internal heat recovery has in spiral wound configuration with one single effect. Thus, the feed concentration factor and the thermal efficiency can be improved at the same time.

The pilot unit is formed by a flash chamber, four desalination effects, and a condenser, with an effective membrane area of 6.72 m^2. In it, the flash chamber or steam raiser, is separated from the rest of the module (desalination effects and condenser). The feed is directed first to the flash chamber and is heated in a heat exchanger using thermal energy from a solar field. In this flash chamber takes place the generation of the first vapour and the first concentrate that are directed towards the first effect. Moreover, this unit has the advantage of allowing to replace the membrane when needed. The unit has been characterized for different levels of temperatures, flow rates and feed salinities. The main parameters analysed are productivity, thermal efficiency (evaluated with GOR) and quality of permeate.

Results have shown optimal performance values at high salinities, demonstrating the suitability of the unit for brine concentration. For example, for a salinity of 115 g/L, GOR was between 2 and 2.6 and permeate production in the range of 2.7 L/h·m^2-3.6 L/h·m^2, with the corresponding recovery ratios between 18% and 27%. These values of recovery ratio were much higher than those obtained with spiral wound modules with comparable permeate production and GOR, and even in the case of spiral-wound configurations with maximum thermal efficiency. Finally, the quality of permeate was kept excellent, with values under 10 µS/cm even at high feed salinities.

Keywords: Vacuum multi-effect membrane distillation; Pilot plant; Thermal efficiency; Evaluation and characterization

SH 83

Deep speed filtration: a robust, reliable and low energy SWRO pre-treatment. From pilot plant to full scale implementation

Olga Ferrer*, Elena Crespo, Ander Sáez, Ibone Manzano, Jose A. Bidaurrazaga, Jorge J. Malfeito

ACCIONA, El Prat de Llobregat (BCN) 08820, Spain
Tel. +34 607193608; olferrer@acciona.com

Introduction

Seawater reverse osmosis (SWRO) pretreatment is of utmost importance to guarantee a proper functioning of a desalination plant. There is a great variety of proposed processes for pretreatment, among which the flotation, granular filtration and filtration by low-pressure membranes (microfiltration (MF) and ultrafiltration (UF)) stand out, each one with its advantages/disadvantages and operational limits [1] – [4]. Often preliminary pilot tests help in the selection of the most suitable one [5].

The design of a high speed filtration unit results in a robust and compact pre-treatment, with low energy consumption, capable of facing a wide variety of scenarios, while reducing plant's layout. The Deep Speed Filter® (DS Filter®) from ACCIONA has two major objectives. One is the protection of the reverse osmosis (RO) system while providing a robust pretreatment capable of face challenging seawater conditions. The other objective is to provide a reduced footprint filter which will allow to reduce generation of waste during construction and increase plant's sustainability.

The objective of this study is to determine the robustness and reliability of a new generation filtration process in quality terms.

Materials and methods

The pilot plant is composed by two parallel, independent and square-shaped columns made of fiberglass with an internal steel structure with a Leopold-like undertrain system. Each column has an internal surface area of 0.24 m^2 and measures 6.5 m in height. During the experiments reported, they have been working at 15 m/h until reaching a pressure loss of 5 m of water column or experimenting a breakthrough (effluent turbidity > 1 NTU consistently). Once the filtration cycle is completed, a backwash is performed, using RO brine, assisted with air if needed.

The filtering media can be easily changed in the pilot plant, enabling the assessment of different media and their combinations. The plant is equipped with a spiking system capable of dosing on-demand foulants, enabling the simulation of extreme influent seawater quality in a continuous way, such as storms or algae blooms.

Results

Pilot plant results

The configuration selected has been tested under extreme influent water conditions, in terms of total suspended solids (15–50 ppm), algae (0.1–5 $\cdot 10^6$ cel/L) and their combination, to assess the media behaviour under such conditions and hence, guarantee the warrantees required.

Very long runs are obtained regardless the high solids content faced. It is worth highlighting that no breakthrough occurred in any of the experiments. In terms of the effluent quality, the average turbidity and SDI15 values were 0.04 NTU and 3.0, respectively, proving a robust performance.

Regarding algae experiments, the runtimes are above 140 h for $0.5 \cdot 10^6$ cel/L and 40 h for $5 \cdot 10^6$ cel/L. In terms of filtered water quality, the average turbidity and SDI15, values were 0.18 NTU and 4.0, respectively. Both for the high TSS scenario and the algae bloom scenario, it is possible to improve the filtered quality in SDI15 and turbidity terms by optimizing the coagulation conditions.

Full scale design

After successful pilot testing, the DS Filter® has been implemented in a full-scale desalination plant located in Saudi Arabia, Shuqaiq 3 SWRO in which ACCIONA is involved throughout all the project cycle, from engineering, procurement, construction, commissioning to operation and maintenance.

Conclusions

Pilot plant testing at a demonstrative scale provides an additional warranty in the subsequent full scale design, construction and operation, by experimentally assessing the envisaged design performance even under extreme influent water quality.

DS Filter ® has proved to be an effective pretreatment for seawater RO applications, despite the harsh conditions faced, providing a proper removal of suspended solids, prior to RO membranes increasing plant robustness and reliability.

High speed quality filtration is achieved through a deep media filtration process. The coagulation process, to be fine-tuned in situ, will enable achieving even better filtered quality. Nevertheless, even without the final coagulation optimization, it has been shown that pretreated water by DS Filter® meets RO feed water criteria for water quality and confirms that high speed filtration are a suitable application for seawater reverse osmosis plants at a reduced footprint.

Acknowledgements

The Mancomunidad de los Canales del Taibilla (MCT), an autonomous organism dependent on the Estado de Medio Ambiente del Ministerio para la Transición Ecológica y el Reto Demográfico, is acknowledged for enabling the installation of the pilot plant and supply of services. SWPC and Almar are welcome for enabling the installation of the DS Filter® in the Shuqaiq 3 project.

Keywords: Dual media filtration; Desalination pre-treatment; Runtime; SDI15; Turbidity

SH 84

Understanding marine growth build up within seawater intake pipelines and developing a suitable pigging system and cleaning regime

Simon Bell, Paul Newbury*

iNPIPE PRODUCTS, Gatherley Road, Brompton on Swale, North Yorkshire DL10 7JH, UK
**Tel. +44 (0)1748 813270; paul.newbury@inpipeproducts.co.uk*

Clean pipelines are critical to the performance of any water treatment plant. Reductions in diameter, caused by biofouling and marine growth, reduce plant efficiency and can increase costs dramatically.

Pipeline cleaning or pigging ensures maximum return on capital investment and minimal production outages. Correct pigging design can ensure minimum disruption to production and seamless

cleaning of the pipeline ensuring zero downtime is achieved. iNPIPE PRODUCTS bespoke Phoenix pigs can be used to measure and view deposition and predict marine growth in order to validate pipeline cleaning frequency.

Established in 1984 and with almost four decades of experience in pipeline cleaning and isolation, iNPIPE PRODUCTS™ have developed an integrated and systematic approach to mechanical cleaning of large diameter pipes. This includes bespoke designs and cost-effective methods to introducing the cleaning tools into the pipeline, specific designs of cleaning tools in order to systematically remove problematic organisms and deposits. Inlet spools to integrate pigging into the seawater inlet pipeline system together with outlet options for the safe and environmentally friendly removal of the debris and the cleaning tool into the sea.

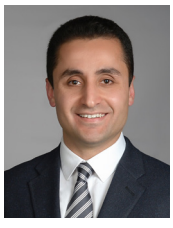
Discuss:

- Seamless introduction of the cleaning tools into the pipeline without production disruption
- Seawater intake designs which ensure simple, trouble-free exit from the pipeline systems for cleaning tools and debris
- Pipeline inspection and visual inspection techniques up to 3000 mm in diameter
- Pipeline joint integrity inspection
- Predictive deposition mapping software ensuring optimal pipeline performance over the lifetime of the desalination plant
- Interesting innovative case histories

Keywords: Seawater intake pipe; Intake pipe cleaning; Biofouling removal; Pipeline cleaning; Pipeline pigging; Marine growth inspection; Marine growth measurement; Camera visual inspection of marine growth; Cleaning validation; Reduced energy consumption

SH 85

Optimising the operation of renewable energy driven reverse osmosis: outcomes and lessons learned for large-scale implementation



Mohamed Mito*, Xianghong Ma,
Hanan Albuflasa, Philip Davies

**Arab Academy for Science, Technology, and Maritime,*
21 El Mosheer Ahmed Ismail, Alexnadria 21523, Egypt
mohamed.mito@aast.edu

Reverse osmosis (RO) is increasingly used worldwide to meet water security challenges. However, its dependency on fossil fuels has encouraged the transition to using renewable energy (RE) as a power source, especially for developing nations that do not have abundant fossil fuel supplies. Nonetheless, due to the intermittency and fluctuation of RE sources, the technology has been limited to either small-scale plants that rely on backup systems or large-scale plants that are grid-connected. Variable operation by operating RO systems as a variable load is the optimum approach to accommodate the stochastic nature of RE and decarbonise large-scale RO. This is based on two techniques that are used interchangeably depending on the extent of RE variation. The first technique is variable-speed operation, which involves controlling the production rate and permeate

recovery according to fluctuations in available power. The second technique is modular operation, which entails starting or shutting down RO units according to substantial power changes.

This study summarises the outcomes of an international research project between Aston University, UK, and the University of Bahrain, Bahrain, that aimed to optimise the operation of RE-powered RO by identifying technical challenges and proposing solutions for the variable operation of large-scale systems. Wind energy was used to represent a fluctuating and intermittent energy source not having a specific pattern. Initially, an industry-scale pilot plant that delivers similar performance to a single RO unit of a large-scale plant was designed and built at Aston University. A dynamic model of the RO plant was developed and validated for use in the simulation and testing of the proposed solutions. Variable-speed operation strategies were investigated to define the optimum change for the permeate and brine flowrates according to available wind power. An advanced control system based on Model Predictive Control (MPC) was developed for implementing the optimised operation strategy and compared to a conventional Proportional-Integral (PI) controller. In addition, a modular operation technique was developed to connect and disconnect RO units while adhering to a Standard Operating Procedure (SOP) that is defined according to guidelines recommended by the membrane manufacturers. A neural network was also designed to predict wind speeds 24 hours ahead and schedule the modular operation of a three-unit RO system. The scheduling approaches were defined to either maximise production or minimise unplanned shutdowns during modular operation.

In terms of variable-speed operation, the results showed that operation at variable recovery with constant brine flowrate was the optimum operational strategy as it delivered the lowest energy consumption and widest operation range. MPC also offered enhanced performance and improved energy utilisation compared to a PI controller, resulting in a 2.35% increase in permeate production for a Gaussian wind-speed distribution with a standard deviation of 15% about a 6.5 m/s mean. As for modular operation, scheduling the RO units according to wind speed prediction was shown to minimise the start-up/shutdown cycles and deliver stable performance based on the SOP. Specifically, the high- and low-output scheduling reduced the number of start-up/shutdown cycles by 37.5% and 75% compared to unscheduled operation, leading to a 1.9% and 2.3% improvement in specific energy consumption, respectively. This is essential to handle high-magnitude power variation from RE sources. Overall, the solutions investigated by this project are a step towards sustainable operation of large-scale RE-powered RO and reducing their reliance on fossil fuels or backup systems.

Keywords: Reverse osmosis; Renewable energy; Variable operation; Model predictive control; Wind speed prediction

SH 86

Successful retrofit operation result at operational troubled SWRO plant by CTA hollowfiber 8 inch RO membrane

Nobuyuki Masumoto*, Mohammad Saeed Al Harthi,
Ahmed Radwan, Toshitaka Tanaka, Yuuki Miura

**Arabian Japanese Membrane Company,*
P.O.Box 295313, Riyadh 11351, Saudi Arabia
Tel. +966 545490347; nobuyuki_masumoto@ajmc.com.sa

The cellulose tri-acetate (CTA) hollow fiber (HF) reverse osmosis (RO) membrane has excellent characteristics such as large membrane surface area, anti-biofouling, high fouling tolerance with superior chlorine tolerance and high salt rejection. CTA HF RO membrane has more than 30 year experiences in the Middle East (ME) region and applied wider range of seawater RO (SWRO) plants.

CTA HF RO membrane made by TOYOBO MC was particularly designed 10-inch diameter for the conventional SWRO plants. In order to apply to the current SWRO plant design and serve CTA HF RO membrane benefit to more wider plants/clients, 8-inch diameter type CTA HF RO membrane was developed.

This developed CTA HF RO membrane has followed the same characteristics with the conventional CTA RO membrane, and, as a new remarkable characteristic, interchangeable with other membrane type which directly replaceable.

In the recent years, water security by desalination is one of the most keen issues in the ME region. Although there has been rapid growth in installation of SWRO technology all over the world, there are certain number of SWRO plants facing operational difficulties in the half-closed seawater region such as the ME, due to regional specific seawater condition eventually resulted in plant unstableness and high operational cost.

The main reason for SWRO operation difficulty in half-closed sea is that:

1. difficulty to prevent severe membrane fouling caused by organic and biological matter in RO feed water,
2. high chemical cost due to frequent membrane cleaning,
3. high environmental impact by chemicals injected into RO feed water to prevent membrane fouling, and
4. high membrane replacement ratio due to membrane performance deterioration.

A SWRO plant located at Al-Lith, South of Jeddah in the Red Sea area, Kingdom of Saudi Arabia, was consisted of conventional designed SWRO system (Canal intake, Pressurized Sand Filter, Micro Cartridge Filter, 1st pass RO) using polyamide spiral-wound (PASW) type RO membranes. This plant has been suffered severe operational troubles due to membrane bio-fouling since the plant start up in 2012.

In order to overcome the fouling trouble and contribute the plant high efficiency, one of streams has been retrofit by CTA HF membrane in 2023 Mar. Thus, under the same seawater and operating condition, the plant has been operating over 9month with different type of membrane at each SWRO unit respectively.

During whole operation period, it is observed the CTA HF 8" RO membrane has been performing following higher efficiency comparing to the other type membrane;

1. less power consumption,
2. less chemical cleaning requirement,
3. high water production, and
4. high product water quality.

This paper will review the operation states of the SWRO plant in Al-Lith and membrane performance comparison between CTA HF RO membrane and PASW RO membrane .

Keywords: Cellulose tri-acetate (CTA); Hollow fiber (HF); Reverse osmosis (RO) membrane; Large membrane surface area; Anti-biofouling; Fouling tolerance; Superior chlorine tolerance; Energy consumption; CIP frequency; Production availability; 8inch RO membrane; Seawater RO; The Middle East; Saudi Arabia

SH 87

Increased resilience of food production through agrivoltaics coupled with subsea desalination

Christian Abelsson*, Alexander Fuglesang, David Pinchin

FSubsea AS, Oslo 0664, Norway
**cab@fsubsea.com*

Food production is the largest consumer of freshwater worldwide, accounting for about 70% of all water use. The need for freshwater for food is expected to increase by as much as 60% by 2050 due mainly to population increase.

Agrivoltaic systems, which integrate agriculture and photovoltaic technology on the same land, have gained increasing attention as a sustainable approach for food and energy production. Growing agricultural plants under solar panels has been shown to increase water use efficiency by 65%. It can be mutually beneficial across food, water, and energy systems and particularly allow for food security in dryland areas — regions that experience food production challenges and water shortages but have an overabundance of sun energy.

Sustainable desalination technologies can play a crucial role in improving water availability for agrivoltaic systems, especially in regions with limited freshwater resources. Integrating sustainable desalination technologies with agrivoltaics can lead to a more efficient use of land and resources, while increasing food and energy production. The best effect of this comes from subsea desalination, where land use is nearly eliminated, costs reduced, and environmental benefits are vast.

By coupling solar-powered subsea desalination with agrivoltaics, farmers can potentially produce fresh water for irrigation and other purposes while generating clean energy for the power grid.

This paper explores the link between agrivoltaics and water availability by analysing the existing literature and adding a new, more sustainable desalination technology, subsea desalination, to the analysis. The paper describes the benefits of integrating subsea SWRO system with agrivoltaics, whereby the subsea desalination technology improves energy consumption, reduces water costs, increases reliability, and improves environmental sustainability.

In summary, coupling solar-powered subsea desalination, the most sustainable SWRO technology, with agrivoltaics can provide a sustainable solution to the challenges of water scarcity and food security.

Keywords: Agrivoltaic; Desalination; Food security; Water resilience; Foodtech; Deepsea desalination; Subsea SWRO

SH 88

Cost optimization of electrodialysis desalination systems for point-of-use applications

Melissa Brei*, Amos G. Winter, IV

Massachusetts Institute of Technology,
70 Vassar St 31-380, Cambridge, MA 02139, USA
**mbrei@mit.edu*

Around the world, point-of-use water treatment systems are used to produce clean drinking water in a variety of settings—urban to rural, desert to tropics. The primary technology used is reverse osmosis due to its high contaminant rejection, global supply chain availability, and maintenance simplicity. At best, these systems can achieve a 50% recovery ratio but most consumer units only reach 15–20%. This inefficiency increasingly jeopardizes groundwater supplies amid escalating water scarcity issues globally. India, a leader in the point-of-use market and a water scarce region, now mandates systems to have a minimum recovery ratio of 40–60%. With priorities shifting towards high-recovery systems, additional desalination technologies, like electrodialysis, are being explored. While electrodialysis is able to achieve over 90% recovery rates, the cost, driven by the stack of membranes and flow spacers, has historically prevented its widespread adoption for small-scale applications. In this work, MATLAB's genetic algorithm was used to select flow path length, flow path width, and number of membranes in the stack that minimize cost while producing drinking water that meets Indian standards. Multiple configurations, including hydraulic and electrical staging, were analyzed using cost and volumetric footprint to determine the feasibility of electrodialysis for high-recovery point-of-use applications.

Keywords: Brackish water desalination; Point-of-use; Electrodialysis

SH 89

The megaton demonstration plant in Duba: The success and challenges of a 10,000 m^3/d high water recovery plant with novel energy

Abdallatif Abdalrhman*, Seungwon Ihm, Thomas Burke, Yohito Ito

Saline Water Conversion Corporation (SWCC),
Al Jubail 35417, Saudi Arabia
**AAbdalrhman@swcc.gov.sa, eng.latief@gmail.com*

In recent years, many studies have investigated novel ways to enhance seawater desalination with more focus on reducing the energy consumption, optimizing the reverse osmosis (RO) membrane process, and utilizing/reducing the generated brine. As part of these global efforts, a research project called the "Megaton Water System," was initiated ten years ago with the aim of developing sustainable advanced desalination and water treatment technologies [1]. Starting from 2016, the Saline Water Conversion Corporation (SWCC) has joined the Megaton project by conducting pilot-scale trials to prove some of the concepts that were proposed to enhance the performance of the RO desalination process [2]. More recently SWCC started a collaboration with the New

Energy and Industrial Technology Development Organization (NEDO) of Japan to design and build a 10,000 m^3/d demonstration plant in Duba region on the Red Sea to further verify the effectiveness of some of the Megaton concepts at a full-scale level. The plant construction has been completed in January 2023 and is currently in operation.

The technologies installed in this demonstration plant were used to achieve a reliable, high water recovery rate operation in the RO process (>50%) while reducing the energy consumption. In many seawater desalination systems, the water recovery rate is set at around 35% to maintain stable operation. Thus, the intake and pretreatment capacities are almost triple the amount of water produced leading to increased investment and operation costs. Increasing the water recovery rate in the desalination system is usually targeted for optimizing seawater RO processing and reducing the cost. However, high water recovery operation with conventional RO systems causes the flux at the lead element to increase and sometimes it even exceeds the membrane-specified design criteria. Increasing the lead side element flux also accelerates membrane fouling and makes the operation less reliable. To control this lead side element flux issue, the installed SWRO configuration consisted of two stages and was composed of a relatively short vessel for the first stage and a relatively long vessel for the second stage. It is based on a two-stage configuration with applied permeate back pressure. The first stage module is operated at lower pressure to reduce the permeate flux of the lead element and the second stage module is operated with normal pressure. Additionally, a novel energy recovery device (ERD) was applied in the permeate line to exchange permeate pressure to the RO feed pressure without any salt mixing.

The results obtained by operating the plants for a couple of months have indicated that the Megaton configuration used in this demonstration plant was able to achieve a high-water recovery rate of 52% at normal operation conditions. This recovery rate could be increased to around 54% with further optimization and with operating at relatively higher, but acceptable, pressure for the 1st RO stage. The plant maintained excellent produced water quality with total dissolved solids (TDS) of less than 150 mg/L. The novel permeate-side energy recovery device (P-ERD) operated effectively and with negligible TDS mixing. The specific energy consumption for the system was maintained at around 2.95 kWh/m^3, which could be further reduced with additional optimization.

[1] Kurihara, M.; Hanakawa, M. Mega-ton Water System: Japanese national research and development project on seawater desalination and wastewater reclamation. Desalination 2013, 308, 131–137.
[2] Miyakawa, Hiroki, Mohammed Maghram Al Shaiae, Troy N. Green, Yohito Ito, Yuichi Sugawara, Makoto Onishi, Yoshinari Fusaoka, Mohammed Farooque Ayumantakath, and Ahmed Saleh Al Amoudi. "Reliable sea water RO operation with high water recovery and no-chlorine/no-SBS dosing in Arabian gulf, Saudi Arabia." Membranes 11, no. 2 (2021): 141.

Keywords: Desalination; Reverse osmosis (RO); High water recovery; Energy recovery device (ERD); Energy consumption

SH 90

Waste cigarette buds based PRO TFC membrane for sustainable osmotic power generation from desalination waste

Syed Javaid Zaidi*, Asif Saud

UNESCO Chair on Desalination and Water Treatment, Center for Advanced Materials, Qatar University, Doha 2713, Qatar
** szaidi@qu.edu.qa, smjavaidzaidi@gmail.com. Tel: +974 44037723.*

The research undertaken presents a novel application of waste cigarette butts in the fabrication of thin-film composite membranes. Utilizing a sustainable and straightforward method, the study focuses on the purification of cigarette butts to extract cellulose acetate polymer. This extracted polymer is then employed as the casting polymer in the preparation of membranes, tailored specifically for utilization in pressure retarded osmosis processes. The polymer mixture was cast onto a hot-pressed polyester mat, providing a compact and durable structure to the membrane. Three variants of TFC membranes were produced: single-layered (STFC), double-layered (DTFC), and a non-casted pristine membrane (PTFC). These membranes were specifically tested for their performance in pressure retarded osmosis. The evaluation focused on their efficiency under different operational conditions, including variations in temperature, draw solution concentration, and applied pressure. Experimental data showed differences in permeate flux across membrane types at specific temperatures. At 30°C, peak permeate flux values for PTFC, STFC, and DTFC were 550, 490, and 500 LMH, respectively. PTFC membranes displayed superior power density, with values of 16.67, 30.56, 33.88 W/m² at 20, 30, and 40°C, respectively. However, increased feed side conductivity was observed, indicating reverse salt flux which can compromise membrane functionality. At different draw concentration (0.5, 1 and 1.5 M) the PTFC membrane demonstrated superior water flux and power density, but with a drawback of poor salt rejection. The STFC membrane faced challenges with concentration polarization, while the DTFC membrane, with its dual-sided cellulose acetate coating, offered a balanced performance in terms of maintaining water flux at various concentrations. The enhanced performance of the STFC membrane at 6 bar suggests changes in its pore structure under elevated pressure, possibly through pore enlargement or deformation. This hypothesis aligns with the observed rapid increase in feed side conductivity during the experiment. This conductivity surge could indicate a weakening in the membrane's structural integrity due to insufficient cellulose acetate concentration or the effects of external concentration polarization (ECP), potentially forcing salts into the membrane pores under high pressure, causing damage. In contrast, the DTFC membrane exhibited more stable and favorable performance in terms of both flux and power density, even at increased pressures. This stability is likely due to the inherent compactness of the DTFC membrane. Atomic force microscopy (AFM) results supported this, showing that the double-sided casting caused inward contraction of the polymer, reducing surface energy and providing additional rigidity and strength to the membrane's pores and overall structure. This structural integrity allowed the DTFC to maintain performance under high-pressure conditions. Despite its overall stability, the DTFC membrane was not immune to ECP. Its effects were particularly pronounced at a pressure of 3 bar across different concentrations. The decline in flux at this pressure in the DTFC was attributed to the combined impacts of increased hydraulic pressure and ECP.

The results contribute significantly to the field of membrane technology, offering a sustainable approach to membrane fabrication using cigarette buds waste and highlighting their applicability in environmentally critical areas such as osmotic power generation and water purification.

Acknowledgments

This Publication was jointly supported by QNRF grant number NPRP13S-0205- 200263 and Qatar University project number (IRCC-2023-129). The findings achieved herein are solely the responsibility of the authors.

Keywords: Pressure retarded osmosis; Cigarette buds; Waste; Sustainable membrane

SH 91

Comparison of batch and semi-batch operation with membrane distillation modules in V-AGMD for brine concentration

Isabel Requena*, Jeb C. Shingler, Juan Antonio Andrés-Mañas, Kerri L.. Hickenbottom, Guillermo Zaragoza

**CIEMAT-Plataforma Solar de Almería, Ctra. de Senés, km 4.5, Tabernas 04200, Spain*
isabel.requena@psa.es

One of the current challenges of desalination is to obtain fresh water achieving a zero liquid discharge (ZLD) process. In this way, in addition to reducing the environmental impact, it is possible to valorize the residual brine from the desalination process, while increasing the volume of water obtained. In order to achieve this goal, technologies are required that allow high levels of brine concentration, and membrane distillation (MD) is presented as a promising option. To date, the best performance in pilot scale membrane distillation has been achieved by the use of multi-envelope spiral-wound modules operating in vacuum-assisted air gap (V-AGMD) configuration.

Modules with a longer residence time of the feed inside the module have been shown to be the most efficient in terms of thermal efficiency. This is because a longer residence time results in greater internal heat recovery, thus reducing the specific thermal energy consumption (STEC). Among the modules with similar and long residence times, those with a higher number of channels with shorter lengths are the most efficient. This is because the hydraulic pressure drop in the channels is lower, which reduces the specific electrical energy consumption (SEEC) and allows the feed flow rate to be increased. Increasing the latter improves the performance of the modules at high salinity, which is beneficial for brine concentration.

In order to assess the performance of MD for concentrating high salinity feeds, a module with these characteristics was evaluated in batch and semi-batch operation. In this type of operation all of the distillate produced is extracted. The difference is that in batch mode, the volume of the feed to be treated decreases and the salinity increases as distillate is produced. In contrast, in semi-batch operation, feed (at initial concentration) is continuously added to the tank as the distillate is produced, so the salinity increases more slowly. As salinity increases during the operation, the permeate production decreases and the STEC increases. Therefore, in batch operation, less time is required to reach a high concentration than in semi-batch operation, but the STEC increases more rapidly due to the decrease in permeate flow with salinity. In semi-batch operation, the increase in STEC is less pronounced, but more time is required to reach the same final concentration, however the volume of water treated and produced is greater than in batch operation.

To compare the two modes of operation, the following operating conditions were chosen: initial salinity of 70 g/L (as the reverse osmosis residue has approximately this concentration), feed flow rate of 1100 L/h, and evaporation channel inlet temperatures of 70 and 80°C. The advantages and

disadvantages of both processes will be discussed, since the most appropriate mode of operation depends on whether the main objective is to obtain more fresh water or to concentrate the brine for its valorization.

Keywords: Membrane distillation; Pilot plant; Vacuum-assisted AGMD; Dynamic model; Batch operation; Semi-batch operation

SH 92

Enhancement of permeate flux and evaporation efficiency of AGMD by introducing the electromagnetic effect

Mohamed Ibrahim Ali*, Kabbir Ali

Khalifa University, Abu Dhabi 127788, UAE
**Tel. +971 529192514; mohamed.ali@ku.ac.ae*

This study utilizes a sophisticated computational fluid dynamics (CFD) model to investigate the impact of electromagnetic fields (EMF) on the air gap membrane distillation (AGMD) process. The study examines the effects of EMF on the permeate flux, evaporation efficiency (EE), and temperature polarization coefficient (TPC) of AGMD by employing a comprehensive theoretical model coupled with the CFD model. The CFD model is verified by conducting experiments with and without the influence of EMF with zero air gap thickness. Increasing the strength of the magnetic field results in increased turbulence in the feed channel, which in turn enhances the transport of vapor to the condensate side. When the magnetic field strength was increased from 0 to 0.5 tesla, there was a 20% increase in permeate flux and a 9% increase in EE at lower feed velocity (0.01 m/s), shorter module length, and air gap thickness (0.1 mm). However, at higher feed velocity (0.0625 m/s), longer module length, and high air gap thickness (1 mm), the improvement in EE was 5%, and permeate flux increased by 8% with the same potency of 0.5 T. This study aims to clarify the impact of electromagnetic fields on separation techniques like MD.

Keywords: Air gap membrane distillation; Electromagnetic field effect; Theoretical modeling; Computational fluid dynamics

SH 93

DCMD fouling performance via innovative TPMS spacer designs

Mohamed Ibrahim Ali*, Kabbir Ali

Khalifa University, Abu Dhabi 127788, UAE
**Tel. +971 529192514; mohamed.ali@ku.ac.ae*

Innovative spacer designs show promise in enhancing the performance of direct contact membrane distillation (DCMD) by improving heat and mass transfer. However, the incorporation of these spacers introduces a formidable challenge—the risk of an increased pressure drop and impurities perception such as calcium carbonate (CaCO3) and others. To address this challenge effectively, computational fluid dynamics (CFD) associated with surface chemical reaction is developed and validated with earlier experimental studies. The evaluation of four TPMS topologies—Fischer-Koch S, IW-P, Gyroid, and diamond—at a constant relative density emphasizes the favorable performance

of the Gyroid topology, achieving high flux while maintaining the lowest pressure drop. Further exploration of TPMS designs involved incorporating heterogeneous TPMS porous structures and functional grading, presenting promising avenues for optimizing process performance. TMPS structure has shown a significant impact on the impurities perception on the spacer and membrane surfaces.

Keywords: DCMD; CFD; Spacer design; Fouling; Pressure drop

SH 94

Experimental assessment of a membrane element to implement an osmotically assisted reverse osmosis (OARO) process

Rafael González Almenara*, David Sánchez, Lourdes García-Rodríguez

University of Seville, ETSI, Camino de Los Descubrimientos, s/n, Seville 41092, Spain
**Tel. +34 649640536; rgalmenara@us.es*

This paper deals with the experimental assessment of a membrane element to implement an osmotically assisted reverse osmosis (OARO) process. In this work, OARO technology has been considered to perform off-grid industrial wastewater treatments, driven by renewable sources, as well as brine concentration processes. This research activity is framed within the REMIND project (H2020-MSCA-RISE-2017; Grant Agreement: 823948), focused on the environmental challenges associated with the mining industry at locations such as Chile or Ecuador, which generates serious problems of contamination of aqueous effluents. The experimental assessment has been addressed through a test rig designed for this application. The study includes, first, an evaluation of the selected membrane element at rated conditions. Subsequently, the characterisation of the off-design performance, including operation under part load conditions considering different feedwater salinities. Finally, an analysis of the membrane transient performance, considering both load rises and drops and pressure variations until reaching the new steady state. To assess the study of the transient behaviour, which recreates the intermittent availability inherent to renewable sources, the frequency variators manage the power consumption of main pumps, replicating some exemplary days and alterations in weather conditions through different load patterns as well as failure shutdowns.

Keywords: Industrial wastewater; Brine concentration; Osmotic assisted reverse osmosis; Experimental assessment; Transient performance; Off-design performance

SH 95

Experimental assessment of a low-cost zero liquid discharge system based on micro gas turbines

Rafael González Almenara*, David Sánchez, Lourdes García-Rodríguez

University of Seville, ETSI, Camino de Los Descubrimientos, s/n, Seville 41092, Spain
**Tel. +34 649640536; rgalmenara@us.es*

In previous works by the authors, the synergies between zero liquid discharge and a solar micro gas turbine have been described. Additionally, a preliminary experimental proof of concept has been developed by the authors. This paper focuses on the second phase of the experimental proof of concept for a zero liquid discharge system applied to seawater desalination through brine concentration powered by the exhaust gases of a micro gas turbine. Similar to the earlier evaluation, the engine installed in the test facilities is a conventional micro gas turbine, capable of simulating the

variable working conditions of a solar micro gas turbine based on either, a recuperative or non-recuperative power cycle to increase the exhaust thermal power if needed.

This new evaluation builds upon lessons learned from the previous experimental work, during which some flaws were identified. These include the need to prioritise specific materials over lower costs to ensure reliability when operating with high-salinity feedwater and arranging a freshwater collector in the flue stream. Furthermore, in order to fully characterise the performance of the system, the experimental tests have been developed in batches, even though this process would be operated continuously in real applications.

Keywords: Brine concentration; Zero liquid discharge; Experimental evaluation; Industrial wastewater treatment; Industrial water reuse

SH 97

Innovative configurations for high-recovery seawater desalination and brine concentration: energy and economic assessments

Lourdes García-Rodríguez*, Arturo Buenaventura-Pouyfaucon

University of Seville, ETSI, Camino de Los Descubrimientos, s/n, Seville 41092, Spain
**Tel. +34 626986292; mgarcia17@us.es*

This paper deals with innovative configurations of reverse osmosis systems aimed at enhancing energy efficiency in different applications with focus on osmotically assisted reverse osmosis and its coupling with reverse osmosis desalination in comparison to conventional solutions. To this end design modelling is developed to analyse different plan locations and working conditions.

Innovative configuration proposed are compared with conventional systems concerning energy efficiency and costs. Both, capital and operating and maintenance costs are assessed considering conventional energy as well as renewable energy applications. Recommendations of the most suitable configurations are discussed considering: i) seawater desalination application with emphasis in achieving high recovery rates. ii) brine concentration. ii) industrial wastewater treatments for promoting water reuse.

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

SH 101

Investigating the photothermal efficiency of conjugated polyaniline coated PVDF membrane for solar membrane distillation

Nada Abdelmageed*, Emad A. Elshehy,
Fouad Zahran, Hosam Shawky, Mohamed E.A. Ali

ERC, Cairo, Egypt
**drnadaabdelmageed@gmail.com*

The significance in increasing desalination process efficiency is essential to solving the world's water scarcity problems. Problem revolves around the necessity to improve water desalination techniques are needed, particularly with membrane desalination technology, since the current approaches might not be enough to meet the increasing demand for water. Over the past two decades, membrane desalination has gained a lot of attention as freshwater is extracted from extremely salty sources using low-grade heat energies to power the filtration process. In order to achieve this, membrane desalination technology requires a highly porous, thin, and hydrophobic membrane. This work includes the surface modification of polyvinylidene fluoride (PVDF) membrane. The modification of PVDF membrane was carried out through coating with a thin film of polyaniline polymer using a suitable cross linker like glutraldehyde. The coating process was created using a container of polymer solution that has been specifically engineered for this purpose to form a thin film around the membrane. Based on our research, the coated PVDF membrane with polyaniline has a permeability of 0.38 L/m^2 h (supporting 0.22 um) and a contact angle of 103.5°. As the membrane's porosity increases, so does its permeability. Moreover, the water flux decreased as the feed temperature increased.

Keywords: Water desalination; Photothermal membrane; Polyvinylidene fluoride; Conjugated polyaniline

SH 102

Fabrication and characterization of carbon nanocomposite materials from organic waste and their application in MD

Sara Ahmed Qenawy*, Yousra H. Kotp,
Abdel Mawgoud M. Mohamed,
Hosam A. Shawky, Mohamed E.A. Ali

Desert Research Center, Hadyaq El Quba, Cairo 24240140, Egypt
**ahamedsarah75@gmail.com*

Due to the global increase in water consumption, as well as the huge population increase, every drop of water must be exploited and not wasted; therefore water must be desalinated by all possible techniques. So in this research, carbon nanotubes (CNTs) and carbon nanocomposite materials (CNC) were prepared using thermal treatment of sunflower seed husk as starting materials. The fabricated (CNTs and CNC) were characterized by using Fourier transform infrared (FT-IR) to study the functional group, transmition, refraction, and absorption were studied by

using spectroscopy , investigating the structure by X-ray diffraction (XRD), and scanning electron microscopy (SEM-EDX) for surface morphology, and stoichiometry of matter. Effects of various nanocomposite materials in the improvement of water flux and salt rejection of polysulfone (PSF) distillation membrane were investigated.The as- synthesized nanocompsite membrane has significant potential in water desalination.The membrane was prepared from polysulfone, with adding of the prepared (CNTs), the permeability results ranged from 0.0387 to 1.372266 kg/m^2.h (surface area of membrane 0.003, the reading was taken every ten minutes, at 40.50°C).

Keywords: Carbon nanotubes; Hydrothermal; Sunflower; Membrane distillation

SH 104

Blue energy: renewable energy production from desalination brine

Patricia Terrero*, Simon Grasman, Sofia Pastor,
Hendrick Swart, Frank Scheepers, Clara Calvo

** SACYR Agua, Madrid 28046, 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.

In this way, the hybrid process proposed in the LIFE HyReward project will make it possible to recover up to 20% of the energy used in the RO process, reducing the mains energy demand of desalination processes.

The new hybrid process will be eco-friendly, generating 100% clean energy without negative consequences to the environment, contributing to the EU effort for the reduction of GHG emissions and climate change mitigation.

Keywords: Reverse electrodialysis; Blue energy; Salinity gradient

SH 105

International experience in the use of desalination for agriculture

Patricia Terrero*, Domingo Zarzo

** SACYR Agua, Madrid 28046, Spain*
Tel. +34 618103386; pterrero@sacyr.com

Food security is one of the main challenges for the future. Expectations from United Nations indicate that it is necessary to double food production in the next years. This means that water needs will grow even more than expected and the use of the non-conventional water resources will be absolutely crucial for the sustainability of water resources. Desalination for agriculture is almost irrelevant globally (with values close to 3% according to IDA/GWI), although countries such as Spain have demonstrated that desalination can be used for supplying a rich agriculture based on high value crops and a high-tech agriculture. The use of desalinated water for agriculture in Spain represents more than 21% of the produced capacity and it is growing year by year. In this paper we will analyze this application with the experiences and knowledge acquired in the last 25 years, including the history of desalination for agriculture, technical and economic aspects, success stories and innovation. In the field of innovation, 2 main projects related with agriculture will be shown; Deseacrop (funded by the European Union program LIFE) which was developed to demonstrated the feasibility of the use of desalinated water for agriculture, increasing production and quality of the products, and SOS-AGUA-XXI, a 6 Million € R&D project funded by Spanish Government with European Next Generation Funds, which contains, among 35 research lines, studies about effects of Boron over different crops and soils, study of the effects of Boron using drones and feasibility of Boron reduction in site. Along with this, other projects such as membrane recycling and energy production from brines help to increase the sustainability of desalination.

Keywords: Desalination; Agriculture

SH 106

Semi-batch reverse osmosis for home-scale desalination

Jonathan Bessette*, Sahil Shah,
Masarah Ahmedhussain, Giuli Pertuz,
Maya Ayoub, Amos Winter

MIT, 70 Vassar St, Cambridge, MA 02139, USA
** jbessett@mit.edu*

In India, the National Green Tribunal has set lower limits on the water efficiency (recovery ratio) of home-use reverse osmosis (RO) desalination systems, starting at 60% and increasing up to 75% in future years. This is a significant challenge for existing home-scale RO purifiers, which cannot meet the recovery requirement without rapid scaling and/or decreases in the water production rate. Some new purifiers, including Unilever's Pureit models boast higher recovery while maintaining higher water production rate via increased membrane area; however, this higher recovery is not at high feed salinities, up to 2000 mg/L, which can be typical in India.

We present semi-batch reverse osmosis as a cost-effective, high recovery, and low scaling propensity solution for implementation at the home-scale in India and generally in other home purifiers. The semi-batch architectural additions include a recirculation pump, solenoid valve, and pressure transducer – all of which can be purchased for a fraction of the system cost. We developed a control scheme suitable with existing, commercially available components and demonstrated recoveries up to 80% with production rates varying depending on our operating pressure threshold. We experimentally explore the operation parameter space to understand the tradeoffs between recovery, production rate, and scaling propensity, and we demonstrate the system on synthetic, 2000 mg/L, brackish groundwater in a long-term test until membrane failure. This work has the potential to bring high recovery desalination to home-scale units at a marginal increase in cost.

Keywords: Semi-batch; Reverse osmosis; CCRO; Home-scale; Small-scale; Brackish water

SH 107

Comparison of pre-RO filters for process optimization and cost reduction

Oren Heymans, Günter Haas*

Entegris, Moirans 38430, France
**Tel. +33 6 74 90 63 69; ghaas@entegris.com*

This study presents results of an investigation of different cartridge filters rated "1 µm" used for membrane protection in a RO system.

RO water treatment plants typically use cartridge filters as last step of pretreatment to protect the high pressure pump and RO membrane from suspended particles, e.g. from brackish well water, multimedia filters or system components. In cases of higher load at inlet the cartridge filters also help to remove solids and reduce SDI.

Cartridge filters typically have ratings in the 1–10 µm range, and changeout intervals of 3–4 months.

However, the filter rating does not provide reliable information to predict actual solids removal performance of filters in a water treatment process.

Choosing the most adequate filter based on real data of particle size and distribution as well as RO membrane operation allows to optimise cost by reducing fouling of the RO membrane, improving time interval between CIPs and reducing the pressure budget of filtration.

Keywords: RO pre-treatment; Cartridge filtration; Desalination

SH 109

A waste-heat integrated multi-effect distillation technology: a conceptual analysis through modelling

Xander Schwarze, Supriya Mhatre, Jiajun Cen, W.F. Janssen*

Desolenator B.V., Maastricht, Limburg, 6222NL, The Netherlands
**william@desolenator.com*

The focus of this work pertains to the feasibility study of a novel concept based on a low-temperature waste heat integrated, solar powered desalination system that uses multi-effect distillation (MED) coupled with a flash vessel (FV) and mechanical vapour compressor (MVC) to supply the system motive steam. A steady state mathematical model has been developed in Python and Aspen to investigate its design, behaviour, and operation. The concept is based on a grid dependent, scaled-up version of Desolenator's demonstrator plant project, which would see the installed capacity of produced ultra-pure distillate (TDS <2 ppm) boosted multiple times to at least forty-fold to a total of 1000 m^3/d (averaging ca. 40 m^3/h). Results indicate that the decrease in performance observed by operating with a higher number of effects is outweighed by the decrease in the specific power consumption (SPC) of the MVC, where an increase from four to eight effects lowers the SPC by 44.6% — crucial in reducing the PV-T array size and switching to on-site available waste heat. The integration of waste heat allows for a continuos distillate production without additional storage requirements. The analysis points to the need of a flexible motive steam control scheme and its related system components.

Keywords: Waste heat

SH 112

Integration of a pre-filter into DuPont™ IntegraTec™ PES inside–out ultrafiltration effectively reduces the total cost of water

Guillem Gilabert-Oriol*, Michael Hoffmann,
Christian Staaks, Jan Radel,
Harith Al-Omar#, Martin Heijnen

**DuPont Water Solutions, Tarragona 43110, Spain*
Tel. +34 682 015 166; guillem.gilabertoriol@dupont.com
#Presenter

Ultrafiltration and microfiltration (UF/MF) membrane processes are used in various water filtration applications, like desalination, municipal drinking water and wastewater, and industrial use. A prerequisite to protect the UF/MF membrane is a pre-filtration step. This is necessary to prevent membrane degradation and blocking or matting the membrane fibers. This process step is realized by a filter apparatus with a mesh size typically between 100 and 300 microns. It can be seen as a separate treatment step, which requires energy, water, and air for cleaning and, in some cases, chemicals for fouling control of the pre-filter itself. This pre-filter system typically occupies a considerable physical footprint and needs regular maintenance. The innovation described and presented in this paper showcases the combination of both above-described processes into one

by integrating the pre-filter into the UF module. As a result, the pre-filtration step occurs within the UF module. A UF/MF system, based on the DuPont™ IntegraTec™ poly-ether sulfone (PES) In-Out ultrafiltration modules, is backwashed and chemically cleaned regularly to guarantee stable operation. The integrated pre-filter is positioned within the membrane module to be cleaned hydraulically and chemically regularly simultaneously with the hollow fiber membranes. The overall system is less complex. Consequently, instruments, piping and engineering can be reduced, resulting in lower capex. This study tested the integrated Pre-Filter with surface water in three locations in Germany and Spain. Raw water quality was good to moderate, with seasonal turbidity peaks representing typical surface water quality. All pilot studies showed excellent results, and the integration had no impact on the performance of UF membranes. It turned out that the integrated pre-filter's pressure drop was mainly negligible and consistently significantly lower than that of traditional pre-filtration systems. The results indicated that introducing an integrated pre-filter in the DuPont™ IntegraTec™ PES In-Out modules can lead to significant overall savings in energy and water usage, as well as in maintenance and physical footprint. Although the results described in this paper will focus on surface water, the benefits will be equally crucial for seawater desalination. The UF/MF is often preferred as the stage before reverse osmosis membranes. Integrating the pre-filter within the UF/MF module leads to an overall reduction in the carbon footprint and a reduction in the total cost of water.

Keywords: Polyethersulfone ultrafiltration; Surface water; Desalination; Pre-treatment

SH 113

Inline dosing of powdered activated carbon (PAC) prior DuPont™ Multibore™ PES ultrafiltration membranes for water reuse

*Josef Wunram, Christian Staaks, Max Zimmermann,
Michael Hoffmann, Martin Heijnen,
Benedikt Aumeier, Thomas Wintgens

**DuPont Germany*
josef.wunram@dupont.com

A cost-effective and low-energy solution is needed to remove organic micropollutants and pathogens, to meet future regulations for high-quality water reuse and protect the ecosystems. Powdered activated carbon (PAC) is regularly utilised in wastewater treatment applications to eliminate non-biodegradable micropollutants that exceed background levels, including pharmaceuticals, pesticides, and various anthropogenic chemicals. As mentioned in the literature, PAC dosages between 10 to 20 mg/L are typically adequate for the removal of most micropollutants. The tertiary effluent containing residual PAC must be clarified before reusing or discharging into the environment. The polishing step can be carried out with sand filters or low-pressure membranes, whereas the retentate can be recycled back to the biological treatment, thus creating a recirculation of the PAC. The use of ultrafiltration (UF) membranes results in many advantages over sand filtration, among them footprint savings, removal of pathogens such as protozoa, spores, bacteria, and viruses, and facing the emerging topics of multi-resistant bacteria and microplastics, whilst sustaining constant low filtrate turbidity. In comparison to conventional treatment processes, there is no risk of breakthroughs regardless of feed water turbidity.

Dosing fine PAC before UF eliminates the need for costly construction of separate contact reactors and spacious sedimentation basins. Dosing PAC and coagulants before UF membranes is crucial in achieving optimal performance and efficient adsorption behaviour without impeding one another and increasing operational expenditures. Achieving these goals requires exploring optimal operating conditions to control membrane fouling precisely while maximising the adsorption efficiency of the PAC. Choosing the appropriate ultrafiltration membrane is the first crucial step in a well-working hybrid process that combines the benefits of a physical barrier for pathogens and particles with adsorbing micropollutants using PAC. It will be demonstrated that DuPont™ Multibore™ polyethersulfone inside-out Ultrafiltration (UF) membranes are an excellent fit for retaining PAC and remaining intact. Long-term cycling tests of PAC and PES membranes demonstrate that these membranes do not lose performance or integrity.

The recirculating principle of the PAC into the biological treatment has been investigated for direct inline dosing of fine PAC and a separate contact reactor in a multi-train pilot. The hybrid process has undergone operation for more than two years with highly fluctuating and challenging tertiary effluent water quality, providing a comprehensive evaluation of the process. Positive results have shown that combining fine PAC with UF improves the removal efficiency of micropollutants, utilising the full adsorption capacity of the PAC in the recirculation principle.

Keywords: Ultrafiltration; PAC; Water reuse; Coagulation

SH 114

Introducing the new software suite designed for smart monitoring of reverse osmosis performance

Guillem Gilabert-Oriol*, Gerard Massons, Zac Jensen, Sylvia Caram Insogna, Leaelaf M. Hailemariam

**DuPont Water Solutions, Tarragona 43110, Spain*
Tel. +34 682 015 166; guillem.gilabertoriol@dupont.com

Fouling is a phenomenon involving the deposition and accumulation of various substances onto the surface of the reverse osmosis membrane. Fouling lowers water quality and increases operational costs. Deep understanding and effective management are required to maintain the efficiency and sustainability of the system.

The new platform is designed to help users evaluate their historical plant performance, to detect chemical cleaning events in the dataset, and to identify the fouling that the system is suffering. The efficiency achieved for each cleaning event is calculated. Furthermore, the platform is also equipped with a cleaning prediction feature that provides recommendations to improve the cleaning schedule and estimates the financial benefit of those recommendations.

Various datasets were analysed with the software suite to prove its functionalities and reliability. The selected datasets included different fouling types, confirmed by element autopsy, and a comparison of documented cleaning events versus software predictions.

This comparison demonstrated the high accuracy of the algorithm in identifying chemical cleaning events. Additionally, it was found that the significant fouling types predicted by the algorithm

matched the ones determined analytically from the fouling samples obtained after post-operation autopsy of the reverse osmosis elements. Thus, the software

Keywords: Fouling; Chemical; Cleaning; Normalization; Performance; Reverse osmosis

SH 115

Introducing the new FilmTec™ EXLE-440 reverse osmosis element to save energy in municipal drinking water application

Harith Al-Omar*, Guillem Gilabert-Oriol,
Claudia Niewersch, Brittany Fisher

**DuPont Water Solutions, Tarragona 43110, Spain*
harith.alomar@dupont.com

The latest DuPont FilmTec™ EXLE-440 reverse osmosis membrane element is designed to treat municipal drinking water sustainably and helps to lower energy costs. A new and improved reverse osmosis element has been developed that reduces energy consumption to an even lower level than the currently available element (FilmTec™ XLE-440). This paper presents the FilmTec™ EXLE-440 reverse osmosis innovation, which can offer 10% energy savings due to a lower feed-concentrate pressure drop from an improved module design. Additionally, the new FilmTec™ EXLE-440 is more resistant to biofouling. A side-by-side comparison revealed that the FilmTec™ EXLE-440 required 30% fewer cleanings than FilmTec™ XLE-440 when operating in continuous mode with river water. The estimated total cost of water for river water treatment with FilmTec™ EXLE-440 is 3% lower than with FilmTec™ XLE-440. Furthermore, it is estimated that the new FilmTec™ EXLE-440 causes 7% lower CO_2 emission during river water treatment and 15% less chemical consumption. The new FilmTec™ EXLE-440 reverse osmosis membrane element, which is dry-tested, can provide longer storage time, improve its environmental footprint, and enhance safety.

Keywords: Energy savings; Reverse osmosis; Pressure drop

SH 116

Sino Iron Project, Australia, achieves outstanding reliable desalination operations at remote mining site

Alaa Eldeen Elsayed[#], Guillem Gilabert-Oriol*,
Santosh Ramalingam, Jiahan Wang

**DuPont Water Solutions, Tarragona 43110, Spain*
Tel. +34 682 015 166; guillem.gilabertoriol@dupont.com
[#]Presenter

Cape Preston is a small mining town with a high demand for process water for mining activities and potable use. Located in an arid region, the only reliable water source is the Indian Ocean. Continuous mine operation demands a durable, reliable desalination process to withstand frequent cleanings during seasonal algal and coral blooms. Citic Pacific Mining chose FilmTec™ SW30HRLE 400 reverse osmosis membrane elements for their proven track record and durability. With four

trains producing a combined 144MLD SWRO permeate, the plant was designed to meet local water requirements. Despite seasonal algal blooms, the plant operated consistently with conventional pretreatment followed by FilmTec™ SWRO membranes. Sound operation discipline by the Sino Iron desalination crew and reliable membrane performance enabled consistent permeate production for over ten years with marginal flux decline. Long membrane life provides additional savings on replacement costs exaggerated by remote location.

Keywords: Desalination; Reverse osmosis; Reliability

SH 117

DuPont WaterApp: Sustainability Navigator: a new tool for estimating sustainability impact of water technologies during user phase

Maria Pérez Maciá*, Guillem Gilabert-Oriol, Claudia Niewersch, Yolanda Cuenca, Ankit Gupta, Feddy Zhu, Veronica Garcia-Molina

DuPont Water Solutions, Tarragona 43110, Spain
maria.perezmacia@dupont.com

Sustainability is becoming increasingly important in the selection of water treatment technologies. The DuPont Water App Sustainability Navigator offers the possibility of estimating five sustainability- related impacts: CO_2 emission during the use phase, chemical consumption for cleanings and operation, water consumption, solid waste generation related to membrane and resin disposal and footprint referred to as active area physically occupied, by each technology. A third-party company verified the calculation of CO_2 emission for ISO 14020-21 to ensure a consistent methodology. The same type of certification is right now in the process of being realized for the other outputs. The estimations can be made for up to five scenarios at the same time, for several relevant water treatment technologies: reverse osmosis, nanofiltration, ultrafiltration and ion exchange, dual media filtration, and membrane bioreactor. The tool also offers the option of including complex MLD scenarios.

The new tool will be demonstrated using an example that compares the use phase of different reverse osmosis systems.

Keywords: Sustainability navigator; User phase; Reverse osmosis; Nanofiltration; Ultrafiltration; Ion exchange

SH 118

New generation RO projection software with free design function

Harish Warsono*, Yoshiyuki Kawashima, Takumi Kobayashi, Kazunori Tomioka

** Toray Membrane Middle East, Dammam 34857, Saudi Arabia*
Tel. +966 53668901 2; harish.warsono.p6@mail.toray

RO Projection software has been developed by many RO manufacturers and other third parties to satisfy the needs of simulating the performance of RO membrane when it is operated in a specific system.

Up until recently, most of the RO system has always been designed in a specific template of the usual configuration: 1 Pass RO system, and 2 Pass RO system, and all the available RO projection software are only based on this 2 mainly used system configuration, including their slight variation.

However, with the advancement of RO membrane system technology, in pursue of efficiency in designing an RO membrane system that fit to a specific demand of the user, many novel unique and complex designs have been proposed and developed which unfortunately are not able to be simulated by most of RO Projection software available in the market.

In this paper, we will explore how the newly released projection software, AquaGRID, with its free design platform enable the user to design a complex RO membrane system with ease which may bring the development of RO membrane system technology to a new level.

It is confirmed that AquaGRID can accommodate several existing complex systems that could not be done easily by the existing software, such as: 4-stage partial 2-pass SWRO system, system with multiple ERD, and high recovery industrial wastewater recycle system with multiple feed source.

It can be concluded as well that the software has the prospect to enable more efficient RO membrane system design and to contribute to the industry as pioneer of the new generation RO projection software.

Keywords: RO; RO projection; Free design; Complex RO design; AquaGRID

SH 119

Ce-MOF enhanced with polydopamine for improved antifouling performance and selective separation of NOMs in PES UF membranes

Dana Kadadou*, Lina Tizani,
Thanigaivelan Arumugham, Shadi Hasan

** Khalifa University, Abu Dhabi, UAE*
Tel. +971 508239652; dana.kadadou@ku.ac.ae

Globally, the risk of surface water contamination and pollution has escalated. The primary contributors to this issue include pollutants, natural organic compounds, industrial substances such as heavy metal ions and dyes, and persistent organic contaminants. In the filtration process, the entrapment of organic pollutants within membrane pores occurs due to hydrophobic interaction forces, resulting in notable fouling caused by pore blockage. Thus, the demand for antifouling membranes is significant due to the adverse impact of fouling on the efficacy and longevity of ultrafiltration membranes. Metal-Organic Frameworks (MOFs) have recently emerged as effective additives for the fabrication of ultrafiltration (UF) membranes. However, a thoughtful approach is crucial to harness their benefits and address their drawbacks. In this study, polyethersulfone (PES) UF membranes were tailored with polydopamine (PDA)-modified cerium (Ce)-MOF (PDA@Ce-MOF) to achieve enhanced antifouling properties and improved removal of biological macromolecules such as bovine serum albumin (BSA) and humic acid (HA) from wastewater bodies. PDA@Ce-MOF nanoparticles exhibited elongated leaf-like morphology, as seen by SEM imaging, and EDX elemental mapping as well as XRD and FTIR confirmed successful synthesis. The non-solvent induced phase separation (NIPS) method was employed to simultaneously fabricate and modify the membrane with various PDA@Ce-MOF concentrations, ranging from 0.05 to 0.50 wt.%. Results demonstrated substantial improvements in the membrane's morphology, hydrophilicity, porosity, and pore size at a 0.10 wt.%

loading of PDA@Ce-MOF. In terms of wettability assessment, the inherently hydrophobic pristine membrane exhibited a higher contact angle (76.9±0.9°), which significantly decreased upon modification, with PES/PDA@Ce-MOF reaching the lowest value (61.1±0.2°). Introduction of hydrophilic functional groups enhanced hydrogen bonding with water molecules, resulting in higher surface free energy for the modified membranes compared to the pristine membrane. This increased surface free energy implies improved wetting characteristics, contributing to enhanced filtration and resistance to fouling. The synergistic effect of PDA and Ce-MOF on the membrane significantly enhanced the pure water flux (337 LMH) with a low contact angle of around 66°. As for filtration performance, when dealing with Bovine serum albumin (BSA) and humic acid (HA), the membranes showed a permeation flux of 145 and 164 LMH and rejection rates of 98% and 88%, respectively. Moreover, the water-attracting functional moieties of PDA@Ce-MOF played a key role in impeding the deposition of BSA protein on the membrane surface, resulting in an outstanding flux recovery ratio (FRR) of approximately 87%, along with mitigated irreversible fouling. The pristine membrane exhibited an FRR of 84.3% in cycle 1, which declined to 46.7% by cycle 5 due to its rough, hydrophobic surface, making it prone to foulants that adhere strongly. Conversely, membrane modification with MOFs maintained high FRR values. PES/Ce-MOF and PES/PDA@Ce-MOF membranes showed FRR values of 78.4% and 87.9%, respectively, after five filtration cycles. This sustained high FRR is attributed to enhanced hydrophilicity, resulting in improved antifouling capabilities.

Keywords: Polyethersulfone; Ultrafiltration; Polydopamine; MOF; Antifouling

SH 120

Optimal operation and planning of energy hub integrated with water networks

Luay Elkhidir*, Ahmed Menesy, Fahad S. Al-Ismail

**King Fahd University for Petroleum and Minerals, Dahran 34464, Saudi Arabia*
g210707630@kfupm.edu.sa

Nowadays, energy hubs (EHs) are recognized as one of the most promising solutions for optimal and sustainable operation of multi-energy systems. The purpose of this study is to boost the efficiency, cost-effectiveness, eco-friendliness of EHs, ensuring optimal power system operations. To do so, a robust model that optimizes operation and planning of an EH system, considering the uncertainties of wind power and EH's prices is proposed. The studied EH integrates wind, heat, hydrogen, gas and water networks. The objective function is formulated to minimizes system's operational and emissions costs subject to different equality and inequality constraints of the EH's model. Meanwhile, the size of the battery energy storage system (BESS) is optimized to attain a minimum levelized cost of energy (LCOE) with acceptable share of wind generation system. A hybrid approach based on mixed-integer linear programming (MILP) optimization algorithm and Monte Carlo simulation method is applied to solve the optimization problem and to address the model uncertainties. The obtained results demonstrates the effectiveness of the solution approach in optimal scheduling of the EH system elements at lowest daily operation cost. .The approach also succeed to maintain an adequate level for the power supply reliability with a least LCOE. Conclusively, it is expected that this could be promising benchmark model in improving affordability and sustainability of the power systems, particularly with the continuous rise energy demands and carbon emissions.

Keywords: Energy hub; Optimization; Hydrogen system; Water desalination; Mixed-integer linear programming

SH 121

Heavy metal removal by capacitive de-ionization using hybrid electrodes based on graphene

Anissa Aouni*, Amor Hafiane

Centre for Water Research and Technologies (CERTE), Résidence Nour 2, Bloc B 3-1, Soliman Touristic Road, bp°273, Borj Cedria, Mourouj 1, Ben Arous 8020, Tunisia
Tel. +216 95604784; email: aouninoussa@hotmail.com

In this study, a carbon-based nanomaterials (reduced graphene oxides rGO) were successfully prepared using two different chemical reductants (ascorbic acid (rGOA) and hydrazine (rGOH)), in order to apply capacitive deionization process using electrodes based on rGO to remove heavy metals from different synthetic metallic solutions. In this work, different types of synthesized electrodes based on rGO and activated carbon (AC) were used. The synthesized materials show a porous structure with specific surface areas equal to 17.8490 m^2/g for rGOA and 17.7893 m^2/g for rGOH and a microporosity of 13.02 m^2/g for rGOA and 11.90 m^2/g for rGOH, respectively. The conductivities of rGOA, rGOH, (rGOA+AC) and (rGOH+AC) are equal to 1401.4778 S/m, 1231.527 S/m, 1411.82 S/m and 1253.94 S/m, respectively. The electrochemical characteristics obtained from rGOA, rGOH, (rGOA+AC) and (rGOH+AC) based electrodes indicate specific capacitances of 117.64 F/g, 111.11 F/g, 100 F/g and 90.90 F/g at a scan speed of 10 mV/s. Using cyclic voltammetry mesurements, experimental results showed the best amount is 50 mg for rGOA and 10 mg for rGOH, with a constant phase element (CPE) equal to 102 mF and 177 mF, respectively. The capacitive deionization (CDI) tests show a decrease in conductivity and an increase in pH. As a result, the heavy metal removal rates (%) of the synthetic metllic solutions ($Pb(NO_3)_2$, $Cd(NO_3)_2$ and $Fe(NO_3)_3$) are significant, equal to 46.72%, 73.01%, 56.54%, 97.67% and 74.53%, respectively. Concerning electrosorptive capacitances, excellent results were obtained, with abatement values equal to 140.1 mg/g, 291.7 mg/g, 273.26 mg/g, 261.6 mg/g and 247.6 mg/g, respectively. The experimental results confirmed the electrochemical potential of the rGO material can be further improved by incorporating a minor amount of rGO. The resulting electrode material was found to be efficient for cost-effectiveness in CDI technology, which appears to be considerably performant for heavy metals removal.

Keywords: Capacitive deionization; Reduced graphene oxide; Electrodes; Hummer method; Heavy metals

SH 122

Nuweibaa seawater reverse osmosis desalination plant 15,000 m^3/d

Amr Seoudy*, Hatem Seoudy

Water Treatment Consulting Office (WTCO), Cairo 11762, Egypt
Tel. +20112867000; a.seoudy@wtco-eng.com

The increasing demand for fresh water in desert and remote areas in Egypt highlights the importance of utilizing non-conventional water resources. One of the most efficient and effective methods of desalination is through the use of reverse osmosis (RO) systems.

This study presents a 15,000 m^3/d RO desalination plant located in Nuweibaa City in Sinai. The plant utilizes a reverse osmosis system with a recovery rate of 42%, in addition to a pressure exchanger used as an energy recovery unit. This advanced design allows the plant to effectively treat seawater with a high salt content (46,000 mg/l), addressing the growing need for fresh water in the area.

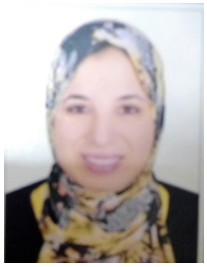
Nuweibaa Desalination Plant comprises several treatment facilities, including a seawater intake system, pretreatment system for raw water, RO skids, flushing and chemical cleaning system, post-treatment through re-mineralization, and a wastewater disposal system. These systems work together to provide a comprehensive treatment process, making it a reliable and effective solution for desalination.

This paper provides a description of the design and construction of Nuweibaa Desalination Plant, delving into the technological features and capabilities of the plant in addressing the fresh water demands in desert regions. The study also highlights the potential of RO desalination systems as a sustainable solution to water scarcity in remote areas.

Keywords: Desalination; Reverse osmosis; Nuweibaa; Egypt

SH 123

Optimizing the fabrication conditions for low-pressure reverse osmosis membrane for brackish water desalination



Reham Bosela*, Mohamed E.A. Ali,
Mustafa Eissa, Elsayed A. Soliman, Hosam A. Shawky

Desert Research Center, 1, Mathaf El Matrya St.,
El Matrya, Cairo, Egypt
**Tel. +20 1003594662, reham_bosela@yahoo.com*

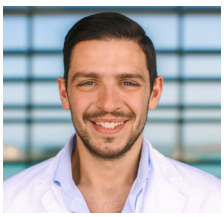
The interfacial polymerization (IP) used to generate thin film composite (TFC) polyamide (PA) membranes is particularly sensitive to the interactions between synthesis parameters. In this research, three parameters were investigated namely m-phenylene diamine concentration and 1,3,5 benzene tricarbonyl trichloride concentration. Moreover, the influence of post-treatment on membrane surface by controlled degradation of polyamide layer to enhance membrane flux using hydrogen peroxide (H_2O_2) was studied. The concentration of hydrogen peroxide and exposure time were investigated. The membrane properties were evaluated using attenuated total reflection Fourier infrared (ATR FT-IR) spectroscopy, scanning electron microscopy (SEM), contact angle (CA) as well as cross-flow reverse osmosis tests. The results revealed that a rise in the MPD/TMC ratios leads to an increase in crosslinking and salt rejection while concurrently resulting in a reduction in water flux. The salt rejection exhibited an increase as the concentration of TMC increased from 0.05 to 0.15 wt%. However, it subsequently encountered a notable decrease at a 1,3,5 benzene tricarbonyl trichloride concentration of 0.2 wt%. In contrast, the water flux decreased with increasing concentrations of ,3,5 benzene tricarbonyl trichloride. Furthermore, by increasing H_2O_2 concentration the water flux increases from 24.6 l/m^2.h for the original PA membrane without treatment to 31.9 l/m^2.h and by raising the exposure time from 3 h to 24 h, there was a slight decrease in salt rejection, and the water flux increased as the time increased from 3 to 5 h. After

that, there is a decrease in water flux by increasing exposure time at 10 bar applied pressure and 2000 ppm NaCl testing solution.

Keywords: Low-pressure membrane; Reverse osmosis; Thin film composite membrane; Brackish water desalination

SH 124

In-situ observation and quantification of membrane deformation in reverse osmosis, using optical coherence tomography



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

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

Among the main desalination technologies, membrane reverse osmosis (RO) represents the most commonly state-of-the-art technology for the desalination of brackish and seawater. The process of RO requires the application of pressure beyond the osmotic pressure of the feed solution (brackish or seawater) in order to selectively allow the passage of water molecules across a semipermeable membrane while simultaneously rejecting the salts and other impurities. However, the applied pressure used in RO to desalinate water can cause severe membrane deformation due to membrane "compaction", and "embossing" or "intrusion into the permeate spacer". To this extent, RO membrane deformation impact on the geometry of the system and transport characteristics of the membrane, resulting in negative effect on pressure drop and dramatic loss of water permeability and salt rejection.

Therefore, it is worth noting that the monitoring and characterization of membrane deformation assume a fundamental role for the assessment of loss process performance.

In literature, scanning electronic microscope (SEM) has been employed thanks its ability to provide the topographic information, allowing the inspection of both membrane surface (i.e., membrane morphology) and the cross-section of the membrane specimen (i.e., membrane compaction); However, SEM can be performed only ex-situ. Thus, a non-invasive monitoring or assessment of membrane morphology is highly required to acquire information in real-time during operation.

Optical Coherence Tomography (OCT) has been proposed in the last few years as an advanced and non-invasive in-situ technique to monitor membrane filtration systems. The OCT has been mainly used to monitor the development of fouling on the membrane surface. In this study, the OCT was proposed for first time to evaluate the effect of feed pressure allows acquiring cross-sectional and 3D scan of the membrane, providing a powerful feature to evaluate the effect of feed pressure on the structure membrane-permeate spacer in RO.

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

SH 125

Seawater brine valorization with FilmTec™ membranes. System configurations and innovative membrane design

Maria Pérez Maciá*, David Arias, Guillem Gilabert-Oriol*, Claudia Niewersch, Harith Alomar

**DuPont Water Solutions, Tarragona 43110, Spain*
maria.perezmacia@dupont.com

Seawater brine recovery is a promising process that allows the recovery of natural resources from seawater reverse osmosis brine while maximizing the production of fresh water. Moreover, seawater brine recovery also supports the transition into a circular economy. As we move towards a more sustainable future, it is essential to find ways to conserve our natural resources and reduce waste. Seawater brine valorisation allows to achieve both goals, as it enables us to reuse materials that would otherwise be discarded as waste.

Seawater brine valorisation process enables the separation of the valuable minerals and the further concentration of those minerals in order to make them economically attractive for the industry. This work aims to assess and compare different seawater brine valorisation process schemes using reverse osmosis and nanofiltration membranes, as well as to showcase the performance of different innovative brine recovery reverse osmosis and nanofiltration membranes. The performance of the seawater brine valorisation process when installing a selective nanofiltration stage before or after the conventional seawater reverse osmosis system is assessed. In addition, this work also compares the system's performance when using low salt rejection reverse osmosis membranes versus ultra-high pressure reverse osmosis membranes for the brine concentration stage. The evaluation is performed using Water Treatment Design Software (WAVE).

Keywords: Seawater brine; Brine recovery; Brine valorization; FilmTec™ SWBR; Desalination

SH 128

Project RIKovery – recycling of industrial saline waters through ion separation, concentration and intelligent monitoring

Yuliya Schiesser*, Christine Kleffner, Matthias Woyciechowski, Christoph Kirsch, Herbert Bassek, Christian Linnartz, Gerd Braun

**Covestro Deutschland AG, Kaiser-Wilhelm-Allee 60, 51365 Leverkusen, Leverkusen 51373, Germany*
Tel. +49 2146009546 1; yuliya.schiesser@covestro.com

Chemical production and mineral processing industries are closely related to the use of a significant amount of water. This produces large quantities of wastewater containing high concentrations of the inert salts. Currently, more than 6 million tons of chloride are discharged into surface waters

via wastewater in Germany every year. More than 3/4 of these come from the chemical (51%) and mineral processing (26%) industries.

The rising water scarcity and competing use of water resources increases the need to reduce the discharge of these high salt loads, especially into surface waters, and to reuse the water and its valuable components.

Since the salt contamination is often present as a mixture of different salts and/or the concentration is too low for direct reuse, treatment processes are necessary to enable further application.

Of great importance are the separation of the ions or the setting of a defined composition as well as more energy-efficient processes (and combinations thereof) for concentrating the salt solutions to a suitable concentration level. Especially in the area of high salt concentrations (higher than 10 wt. % NaCl), there is a lack of suitable technologies. The state of the art is still thermal evaporation (e. g. MVR, mechanical vapor recompression), which is neither sustainable nor allows in most cases the reuse of produced concentrates. It is not to be expected that all fields of application can be covered with a single technology.

Within the framework of the German Ministry for Education and Research (BMBF) funding measure "Water Technologies: Reuse (WavE II)" in the RIKovery project, the potentials of innovative technologies (osmotic assisted reverse osmosis OARO, high pressure low-salt-rejection reverse osmosis HPLSRRO, high pressure nanofiltration HPNF, forward osmosis FO, flow-electrode capacitive deionization FCDI) are systematically investigated and the promising areas of application are developed.

In order to achieve widely transferable project results, the project consortium has identified industrially relevant applications that cover the main discharges (polymer chemistry, specialty chemicals, mineral industry) but differ significantly in terms of challenges (volume flows, concentration ranges, salt composition, purity requirements for the reuse of salts or water) and thus cover the majority of the industrial salt discharges.

The main goal of the project is to create an economically and technically well-founded basis for decision for the implementation of salt and water recovery processes on a production scale. On the basis of real relevant examples from the practice with modules on a technical scale, it could be shown that innovative technologies significantly expand the possibilities of concentrate processing:

- In particular, the operation of the nanofiltration beyond the usual operating pressure of 41 bar proves to be particularly attractive. Here it could be shown that the separation of sulfates and chlorides is feasible for almost saturated salt solutions.
- The concentration of monovalent neutral salts by means of HPLSRRO succeeds at an application pressure of 120 bar up to 15 wt. % and thus well beyond the limits of high-pressure reverse osmosis.
- It could be shown how clever process concepts can be used to achieve concentration up to the crystallization of monovalent and divalent ions with low energy demand by means of FO.
- FCDI could be used to separate and concentrate chloride ions from sulphate ions in a single step. However, the process is currently at a significantly lower TRL level compared to the pressure-driven membrane processes.

Keywords: Industrial salty waste waters; Concentrate handling; Brine concentration; Ion separation; Brine recycling; Chlorine-alkali electrolysis

SH 129

Overcoming aggregation of some different nanoparticles on thin film composite reverse osmosis membrane

Yousra Kotp*, Mohamed Ali, Amira Sami, Reham Bosela, Shaima Awad, Hosam Shawky

** Desert Research Center, El Matarria, Cairo 11753, Egypt*
yosra.Kotp@drc.gov.eg

The aim of this research is to overcome the aggregation of some different nanoparticles in the casting solution of polysulfone support membrane. A novel method was used to minimize the aggregation by dispersion of three different nanoparticles (TiO_2, ZnO and Al_2O_3) in methacrylic acid then the dispersed nanoparticles were doped into polysulfone casting solution. A polyamide layer was formed on polysulfone support dopped by nanoparticles by interfacial polymerization of m-phenylene diamine and 1,3,5 benzene tricarbonyl trichloride. The membranes surface was characterized by attenuated total reflection Fourier infrared (ATR-FT-IR) spectroscopy, scanning electron microscopy (SEM), contact angle (CA) as well as cross-flow reverse osmosis tests. The results revealed that the membrane doped with ZnO nanoparticles has a good separation performance than others doped with TiO_2 and Al_2O_3.

Keywords: Interfacial polymerization; Thin film composite; Membrane; Nanoparticles; Aggregation

SH 130

High-pressure-driven membrane processes for water-efficient salt concentration from brines in lithium extraction and recycling

Christine Kleffner*, Gerd Braun,
Eric Kadaj, Angel Abajas Errasti

**TH Köln, Cologne – 50679, Germany*
Tel. +49 22182754055, christine.kleffner@th-koeln.de

In the extraction of lithium from salt lakes, significant amounts of groundwater are utilized and lost during evaporation processes, posing a threat to water availability in the affected areas. To sustainably meet the growing demand for the lithium resource, it is imperative to promptly replace current methods with innovative, energy-efficient concepts. These concepts should not compromise water availability in the respective regions by enabling a closed-loop circulation of process water.

Another crucial approach in this context is to enhance the efficiency of lithium recycling from lithium-ion batteries by optimizing existing processes, with a focus on improving both the recycling rate and energy efficiency. In both cases, pressure-driven membrane processes can significantly contribute to increasing energy and resource efficiency.

To replace currently applied highly water- and/or energy-intensive processes, this study focuses on extending the application of membrane-based desalination technologies to higher salinities, coupled with state-of-the-art energy recovery technology. This aims to contribute to the identification of economically and ecologically viable process concepts for brine treatment. Based on experimental results, this study demonstrates the performance and potential of available technolo-

gies. Ultra-high-pressure membrane processes were investigated up to their limits and evaluated for this specific application.

High-pressure reverse osmosis (HPRO) as well as high-pressure low-salt rejection reverse osmosis (HP-LSRRO) are tested in combinations aiming for the highest possible concentration of lithium and, particularly, maximum water recovery. Experiments were conducted on a pilot plant with integrated energy recovery, using commercially available 4" spiral-wound membrane elements specified for 120 bar (HPRO) and 83 bar (HP-LSRRO). Performance tests of HPRO and HP-LSRRO, operated at up to 120 bar, indicate that this process combination offers the potential to concentrate LiCl in an energy-efficient way, while enabling water reuse.

Overall, the results clearly demonstrate that available equipment and technology can be expediently applied under extreme operating conditions to enable an energy-efficient treatment of LiCl solutions. Against this background, the applied energy recovery device (ERD) was demonstrated to have the capacity to reduce the energy demand of a high-pressure membrane process by up to 60%, depending on the process configuration and operating conditions, while achieving efficiencies of over 93%.

Optimizing the linking of the processes through skillful recirculation of liquid flows and appropriate positioning of energy recovery is one of the key challenges that needs thorough attention. Nonetheless, it can be concluded that the investigated innovative process concept offers promising perspectives for a large-scale realization of economically feasible brine treatment and water reuse for this application.

Keywords: Lithium concentration; Water reuse; High-pressure membrane processes; Energy recovery

SH 132

Polymer products for a sustainable energy future — from seawater to hydrogen to the end-users

Markus Ebster*, Daniel Fechtig

agru kunststofftechnik gmbh, Ing.
Pesendorfer Straße 31, Bad Hall 4540, Austria
Tel. +43 676887973320; ebm@agru.at

Hydrogen technology is considered an important building block for climate protection. In principle, hydrogen is available in sufficient quantities, but on earth or in nature it only exists in compounds (e.g.: water, methane, ...). To obtain pure hydrogen, these compounds must first be split. The "green hydrogen" is produced with the help of renewable energy (solar, wind) by splitting water molecules in the electrolysis process and it is a clean alternative to natural gas. However, three main ingredients are crucial for a successful ramp-up of hydrogen projects on a global scale - clean and carbon-free energy, infrastructure and last but not least - water.

To produce (green) hydrogen there are currently two commercial electrolysis processes: PEM ("Proton Exchange Membrane") and Alkaline Electrolysis, which require technical plastic products. The H+ protons move through a system consisting of a negatively charged cathode, a positively charged anode and a membrane (electrolyte). The only byproduct of this process is oxygen, which can then be released back into the atmosphere.

AGRULINE and XXL piping for water transport and water treatment - essential for economic

hydrogen production at scale: In total, approximately 13 kg of water is required to produce 1 kg of hydrogen. Depending on the region and the application, the enormous demand for water is met by groundwater supplies, lake water, chlorinated water or seawater. The AGRULINE and XXL piping system offer application-specific complete solutions for water transport from the source to the desalination plant or water treatment plant.

After treatment - in the electrolysis unit - a distinction is made between process water (e.g., for cooling, ~3–4 L) and the ultrapure water needed for the electrolysis process itself (~8–9 L). Both electrolysis processes require ultrapure water for reliable and durable operation. Compared to alkaline electrolysis, the PEM process requires ultrapure water with ten times lower conductivity (ion concentration) - otherwise the porous PEM - membranes will be blocked due to metallic ions or other (organic) molecules and particles.

PURAD PVDF piping system for transporting and storing ultrapure water: PEM electrolysis uses ultrapure water (60-80°C process temperature at 6–10 bar pressure) with very low ion concentration. The PURAD piping system (PP-pure or PVDF, depending on requirements) in combination with tanks from our semi-finished product range ensures reliable transport and storage of the ultrapure water. Within the ultrapure water plants, but especially after EDI or reverse osmosis, it is important to ensure that the ultrapure water is not contaminated by metal ions, organic compounds, particles or gases on its way to the electrolysis stack. Compared to other plastics, AGRU's PURAD range is characterized by its purity, ease of maintenance, standardized connection technology and sustainability. PURAD pipes and fittings are manufactured in a clean room (class 5) under the strictest cleanliness criteria and are welded in isometric or partial isometric modular design according to customer requirements.

AGRUCHEM and semi-finished product line for the transportation and storage of caustic potash: Alkaline electrolysis uses 20-40% caustic potash solution (KOH) at process temperatures of 70–120°C. For long-term safe operation, these plants require products from AGRUCHEM's product range (PP, ECTFE, FEP and PFA, depending on the process conditions). Typically, in such projects, potash liquor is stored in PFA tanks at the production site, transported from the production site via FEP pipes to the electrolysis plant (100% KOH), mixed with ultrapure water, and transported and stored within the electrolysis plant in PP pipes or tanks (20-40% KOH). In the future, we expect higher process temperatures of up to 120°C due to improved plant efficiency – here too, AGRU offers the proper plastic solutions with outstanding chemical resistance and operational reliability for years to come.

Hydrogen transportation: The produced hydrogen is stored under high pressure either in tanks or underground in caverns. The hydrogen is transported to the various end users (industry, mobility, heating, fuel cells...) via the existing or newly laid gas pipeline network. From the pressure reduction station, the "green gas" can be distributed either as a hydrogen-natural gas mixture or 100% at pressures up to ten bar through the AGRULINE pipe system made of PE 100-RC.

For the transport of hydrogen, the AGRULINE PE 100-RC pipe system offers a complete solution that is cost-effective, reliable and easy to maintain. The AGRULINE product range has been assessed by the DBI (Gas Technological Institute) for suitability for the transport of 100% hydrogen and now not only meets the relevant standards and norms (CEN EN 1555 - 1-3, ÖVGW GB 210 and HE 200) but also the "H2Ready" quality mark (DBI GTI 109).

Keywords: Hydrogen; Polymer pipes; Polymer sheets; fluoropolymers; Electrolysis; Ultrapure water; Desalination; Caustic potash; Hydrogen transport

SH 133

Sustainable desalination practices for green hydrogen production in the Gulf of Cortez: a gateway to European markets

Beatriz Casasola

Boreal Light GmbH, Schichauweg 52, Berlin 12307, Germany
casasola@winture.de

The Gulf of Cortez, situated amidst Mexico's coastal regions and in close proximity to the Atlantic Ocean, emerges as a focal point in this study on sustainable desalination practices and green hydrogen production. With a unique geographical advantage, this research assesses the environmental, economic, and logistical aspects of leveraging the Gulf of Cortez as a potential hub for exporting green hydrogen to European markets.

Desalination, a vital process for harnessing seawater resources, intersects with the ambitious goal of green hydrogen production, offering a pathway towards water sustainability and clean energy generation. Focusing on the Gulf of Cortez, we are analysing optimal desalination conditions, specifically targeting 2 water salinity levels: Brackish water up to 6000 ppm and seawater up to 43000 ppm with a production of 1000 m^3/h. Five solutions were analized (deep well injection, evaporation ponds lagoons and biotreatment lagoons, vacuum evaporation, brine elctrolysis, re-use of brine).

Results indicate that the Gulf of Cortez presents an opportune location for sustainable desalination practices, ensuring responsible water resource management while fostering the production of clean energy for export. The analysis considers the logistical advantages of this region in the context of hydrogen transportation to European markets, providing valuable insights for future energy trade.

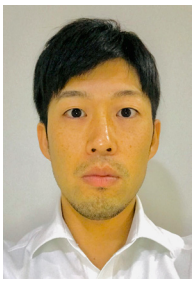
The best technichal-economichal analysis shows that the use of Brackish water and the lagoons are the best option for such a low medium salinity, meanwhile with the use of sea water it is necessary to use electrodyalsis to reduce the volume and then post treatment of the waste.

This research project seeks to illuminate the linkages between desalination, green hydrogen production and global energy markets, with a specific focus on the Gulf of Cortez. By strategically positioning Mexico as a key participant in the global green hydrogen supply chain, this research charts a course for sustainable development, economic growth and environmental stewardship, with particular emphasis on the treatment and environmental impacts associated with brine disposal.

Keywords: Reverse osmosis; Brine treatment; Green hydrogen; EDI; ED

SH 134

Successful pilot test result by CTA hollow-fiber 8-inch SWRO membrane with CO_2 utilization



Nobuyuki Masumoto*, Thomas Altmann, Ratul Das,
Ruben Gomez, Mohammad Saeed,
Ahmed Radwan, Yuuki Miura

** Arabian Japanese Membrane Company,*
P.O.Box 295313, Riyadh 11351, Saudi Arabia
Tel. +966 545490347; nobuyuki_masumoto@ajmc.com.sa

The cellulose tri-acetate (CTA) hollow fiber (HF) reverse osmosis (RO) membrane has excellent characteristics such as large membrane surface area, anti-biofouling, high fouling tolerance with superior chlorine tolerance and high salt rejection. CTA HF RO membrane has more than 30 years experiences in the Middle East (ME) region and applied wider range of Seawater RO (SWRO) desalination plants.

CTA HF RO membrane made by TOYOBO MC was particularly designed 10-inch diameter for the conventional SWRO plants. In order to apply with the current SWRO plant design and serve CTA HF RO membrane benefit to more wider plants/clients, 8-inch diameter type CTA HF RO membrane (model: HS8155EI) was developed. This developed CTA HF 8-inch RO membrane has followed the same characteristics with the conventional CTA RO membrane, and, as a new remarkable characteristic, interchangeable with other polyamide spiral wound type membrane which directly replaceable.

In cooperation with ACWA Power, TOYOBO MC and AJMC have been jointly carrying out a demonstration test of HS8155EI using containerized RO demonstration unit at the seawater desalination RO (SWRO) plant stationed in Dubai UAE in the Arabian Gulf region since 2023 Mar, and the test has been continued as of the end of 2023 Dec.

This demonstration test is aimed the following subject;

1. To verify TOYOBO MC developed CTA HF 8-inch RO membrane HS8155EI performance,
2. To verify effective acidification for feed water pH control by carbon dioxide (CO_2) assuming CO_2 capturing system utilization, and
3. To seek potentiality of 2nd pass RO process volume reduction by high purity of RO permeate water quality.

During the demonstration period, it is observed the TOYOBO MC CTA HF 8" RO membrane (HS8155EI) has been performing following higher efficiency with potential economic aspects;

1. Less pressure drop resulting less power consumption under high recovery operation,
2. less chemical cleaning requirement,
3. effective & stable pH control by CO2, and
4. higher RO permeate water quality resulting less 2nd pass RO process volume requirement.

This paper summarized the results of the joint demonstration test verified the possibility of an enhanced RO desalination system utilizing a TOYOBO MC CTA HF 8-inch RO membrane with the utilization of CO_2 capture system as an alternative acidification and minimization of 2nd pass RO system.

Keywords: Cellulose tri-acetate (CTA); Hollow fiber (HF); Reverse osmosis (RO) membrane; Large membrane surface area; Anti-biofouling; Fouling tolerance; Superior chlorine tolerance; Energy consumption; 8inch RO membrane; CO_2 capturing; Acidification

SH 135

Design of a high-recovery zero-liquid discharge solar desalination pilot: aiming a beyond state-of-the-art concept

Frederico Felizardo[1*], Pedro Horta[1], Andrea Cipollina[2], Nunzio Cancilla[2], Guillermo Zaragoza[3], Isabel Requena[3], Juan Antonio de la Fuente[4], Ángel Rivero-Falcón[4]

[1] University of Évora – Renewable Energies Chair, Polo da Mitra da Universidade de Évora, Edifício Ário Lobo de Azevedo 7000-083 Nossa Senhora da Tourega, Portugal
[2] Università degli Studi di Palermo, Dipartimento di Ingegneria, viale delle Scienze Ed.6, 90128 Palermo, Italy
[3]CIEMAT-Plataforma Solar de Almería, Spain
[4] Instituto Tecnológico de Canarias, Departamento de Agua - Water Department, Spain

**Tel. +351 969 348 041; facf@uevora.pt*

Whereas the need for additional water resources becomes ever more pressing in a framework of combined population and specific water consumption increase with climatological impacts of climate change, the increased reliability and efficiency of desalination technologies renders marine or brackish water resources a viable solution, especially in coastal areas where, in turn, the largest population conglomerates occur.

In view of the coincidence of water scarcity regions with high solar irradiation potentials, the use of solar energy as energy input for the higher specific energy consumption pertained by desalination technologies emerges as a technological solution for the reduction of its energy related environmental impacts, ever closer to economic competitiveness in a wider range of applications and contexts.

A thorough approach to the potential impacts of desalination, though, implies due consideration of its effluent - brine - which has led to the development, along the most recent years, of so-called "zero liquid discharge" concepts, aiming at an increased recovery ratio and/or at the economic valorization of this effluent - some of its components extracted over consecutive processes and/or, ideally, fully eliminating liquid discharges from the desalination/effluent valorization plant.

In the scope of project Sol2H2O - European Twinning for research in solar energy to (2) water (H_2O) production and treatment technologies, funded by the European Commission through Horizon Europe GA Nr. 101079305, a pilot of a zero-liquid discharge solar desalination plant

is being designed and engineered, for ensuing experimental testing and demonstration: an innovative hybrid solar-driven water production and water treatment pilot powered by solar energy is proposed to ensure the sustainability of the overall process, leading to the maximization of freshwater production, and approaching the ZLD.

The pilot aims at demonstrating a "beyond state of the art" technological combination, surpassing the existing produced water recovery rate in current systems situated at around 50%, to levels close to 80%. The treatment chain system will be able to treat 1 m^3 of water per day and consists of the following equipment: photovoltaics panels with reverse osmosis (PV/RO) system, a multiple feed plug flow reactor (MF-PFR), a membrane distillation (MD) plant and at the final treatment stage two solar evaporation ponds. Seawater is sent to the RO unit powered by the electrical energy produced by PV panels with a capacity to operate with water salinity up to 45 g/l and providing a brine recovery rate of 30%: It produces two streams: a permeate with high-grade quality water for industrial and drinkable purpose and a brine retentate, enriched in all ions present in seawater.

The brine is sent to the MF-PFR unit for selective recovery of magnesium and for removal of calcium in the form of hydroxides. The recovery/removal is carried out by a fractionated reactive crystallization adding an alkaline reactant, such as sodium hydroxide water solution. After solids separation, the clarified effluent will be sent to solar powered vacuum-enhanced air-gap membrane distillation unit, with a capacity to treat water with high salinity. Operating in batch conditions, it can produce two different streams, one is a pure distillate and the other one is a retentate, whose concentration can reach about 250,000 ppm.

The high concentrate brine is sent to a first solar evaporation pond (Solar Pond 1) to produce NaCl with high purity to be used at food grade and a remaining brine depleted in NaCl is sent to solar evaporation pond 2, for complete evaporation and precipitation of a mixture of chloride and sulfate salts, which can be used for de-icing purposes. At this point the whole treatment chain meets the zero liquid discharge concept because no effluents are produced and then released into the environment. The pilot installation and commissioning are programmed to be performed during the last quarter of 2024.

Keywords: Solar desalination; Zero-liquid discharge; High recovery rate; Demonstration pilot; Case study

SH 136

Enabling membrane distillation crystallisation for brine management through the mitigation of scaling

Aphiwe Jikazana, Pablo Campo-Moreno, Ewan McAdam*

Cranfield University, College Road, Cranfield MK43 0AL, UK
Tel. +44 1234754546; e.mcadam@cranfield.ac.uk

Membrane distillation crystallisation (MDC) can facilitate process intensification for brine management through uniquely enabling both concentration and crystallisation within a single unit process. However, to facilitate this transformative step, scaling must be mitigated and crystallisation controlled to enable sustainable operation. This study introduces non-invasive techniques to provide amongst the first measurements of induction time within two discrete domains of MDC

(boundary layer and bulk solution) which are complemented with the characterisation of supersaturation, to collectively provide an accurate description of scaling and crystallisation mechanisms founded on classical nucleation theory (CNT). Direct evidence is presented for how boundary layer supersaturation sets the nucleation kinetics for crystals formed in the bulk solution. While crystal size was evidenced to be controlled through T or ?T, modifications do not consistently align to CNT and were explained by relating morphological differences to complex mass and heat transfer processes set within membrane distillation by T. Scaling was only evidenced when the boundary layer was extensively supersaturated. The mechanism for scaling was shown to be distinct from that for the formation of crystals recovered in the bulk solution, which contradicts hypotheses within the current literature, and was readily explainable through CNT. A modified power law relation between supersaturation and induction time establishes for the first time a basis with which to mitigate scaling and control the morphological characteristics of the produced crystal phase. The broad range of operational characteristics that can be controlled within MDC, offer considerably greater control over crystallisation than with existing unit processes, and can be fully described by the unique analytical framework set out within this study.

Keywords: Brine management; Desalination; Membrane distillation; Crystallisation; Zero liquid discharge

SH 138

Air gap membrane distillation: optimal use of residual heat from green hydrogen production

Paul Buijs*, Radjes Nidhansing

* *1st:water, Compass Building, Al Hamra FZ, Ras Al Khaimah, UAE*
Tel. +971 509767302; paul.buijs@1stwater.org

Membrane distillation (MD) has been described and patented already in 1963 (Bodell, 1963), only shortly after the first reverse osmosis (RO) desalination membrane was patented (Loeb, 1960). In contrast to reverse osmosis (RO), MD is not widely applied for desalination, despite that there has been 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. However, scale up of an MD module to a commercial size has proven to be challenging, temperature polarization is limiting the maximum usable membrane surface area in the module.

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 spacers can be adapted to the applications. Lab scale (1–2 m^2) and full-size modules (15–30 m^2) are available. Several applications, including desalination for green hydrogen productions have been demonstrated or ar under investigation. In the presentation, a few of these cases will be discussed.

References

Bodell BR. Silicone rubber vapor diffusion in saline water distillation, United States Patent Serial No. 285,032; 1963
Loeb S, Sourirajan S. US Patent 3,133,132. High flow porous membranes for separating water from saline solutions, United States Patent 3,133,132; 1960
Nidhansing R, Lo-A-Njoe Stuart I, Verbunt J. Method of producing a fluid-flowable unit with the function of a heat exchanger, a filter, or a combination of both; basic module that is planar and suitable for the method, Netherlands Patent NL2017501B1; 2018

Keywords: Membrane distillation; Green hydrogen; Desalination; MD module

SH 139

Desalination in Egypt from EPC to PPP: planning and implementation

Amr Seoudy*

Water Treatment Consulting Office (WTCO), Cairo 11762, Egypt
Tel. +20112867000; a.seoudy@wtco-eng.com

In the last decade Egypt consider desalination as one of the main resources to secure water supplies especially for new urban communities and remote areas.

In this time period Egypt fund the desalination projects relied on government financial support or loons from international finance entities to implement the projects based on EPC contracts model, this model is used to plants with capacity around 1 M cubic meter per day.

A review which has been done by the government of what the advantages and disadvantages of the applied contracting and management system, shows that there is some issues regarding this model especially the sustainability of the plants performance, which indicates that EPC contracting model is not the optimum financially and economically in most of the cases.

About five years ago the government after some studies decided to change the contracting model for desalination to PPP model.

The road towards a successful and effective Public-Private Partnership (PPP) project is not rosy nor easy. It's requires active and effective involvement and collaboration between the government entities and the private sector organizations.

A plan has been developed to ensure overcoming all stakeholders needs from legal, financial, social, and educational points of view.

The study shows the positive and actual executive steps taken by the government, whether issuing laws regulating cooperation between private sector in infrastructure projects, securing the lands area for projects implementation and the feasibility studies, the study also evaluate

The study also evaluate the extent of the government's seriousness in implementing practical procedures for PPP projects and providing proposals to improve implementation steps and reassure stakeholders

Keywords: Desalination PPP; Desalination economics

SH 140

Renewable energy in irrigation of reclamation land in Egypt and the world — review

Nadia Eshra

National Water Research Center,
Naser City, Cairo, El_Qanater Elkhairia,
Qalubia, Cairo 13621, Egypt
nadiaeshra@gmail.com

The agriculture in Egypt faces big challenges represents in; corrosion of farmlands in Delta and the lack of fresh water. On other hand there are a technological revolution in the field of agricultural mechanization and land reclamation while its backbone is the energy, which gave hope to overcome these challenges. Egyptian Strategy 2030, renewable energy from the main pillars for the sustainable development. Agriculture especially the irrigation, requires energy as an important input to production. Adoption of renewable energy technologies in agricultural activities offers promising prospects in addressing trade-offs and leverage on interactions between improving water, energy, food security and climate change for sustainable agriculture in agriculture field. Renewable energy dealt with the paper are; solar (two types; PV and thermal), wind, biomass and biogas in irrigation water pump in general, presented the different pumping water systems, performance, economic aspects and environmental impacts. This paper introduces an international review of the application of renewable energy in irrigation for different cases study in world such as Africa (Sudan and Nigeria), Asia (India, Indonesia, Taiwan, Pakistan, Saudi Arabia, and Iraq), Europe (Turkey, and Greece), and some cases in Egypt. Also, the paper presents the reviews of previous researchers of the data. The paper concluded of some international experimental can be more useful and suitable to be applied in Egypt.

Keywords: Energy and agriculture; Renewable energy and reclamation; Reclamation and different expertise

SH 142

Synergizing solar-driven desalination with the green hydrogen economy

Norhan Nady Mohamed*, Nourhan Rashad,
Marwa Showman, Noha Salem, Sherif Kandil

**City of Scientific Research and Technological Applications*
(SRTA-City), Borg El-Arab City, Alexandria, Egypt
Tel. +20 1090918521; norhan.nady77@yahoo.com

The integration of desalination with renewable energy sources like solar or wind power is a key aspect of the Green Hydrogen Economy, as it addresses both water scarcity and clean energy requirements. Solar water evaporation presents a promising alternative for desalination, as it solely relies on renewable and eco-friendly solar energy, eliminating concerns about brine disposal. However, conventional solar evaporation suffers from low efficiency due to the placement of the solar absorber at the bottom of the water body.

A noteworthy advancement in solar-driven desalination systems is the development of novel photothermal magnetic (Janus) membranes, which will be highlighted during the presentation. These membranes represent a significant breakthrough as they enable solar-thermal energy conversion at the air/liquid interface. By utilizing photothermal membranes/foam, this approach offers benefits over conventional bulk heating-based evaporation, including reduced thermal losses and improved energy conversion efficiency. The use of photothermal magnetic Janus membranes in solar-driven desalination systems holds great promise for achieving higher energy efficiency, increased freshwater production, and improved sustainability. This development represents an important step forward in advancing solar-driven desalination technologies, bringing us closer to realizing the goals of the Green Hydrogen Economy.

During the presentation, an overview of this novel photothermal magnetic (Janus) membrane will be presented and discussed in detail.

Keywords: Photothermal magnetic membranes; Solar-driven desalination; Solar absorber; Air/liquid interface

SH 143

Innovative online monitoring of calcium and magnesium in an RO brine recovery process using NF technology

Luis Navarro

Hach, Cubelles 08880, Spain
Tel. +34 637494417; luis.navarro@hach.com

The recovery of valuable compounds present in RO brines is gaining momentum globally. Magnesium and calcium, among other compounds like sodium chloride, boron, rubidium, or scandium, are concentrated through the RO process, converting RO brines into an alternative sustainable source to obtain these valuable materials.

Presently, there are different initiatives and projects working on different substances recovery through the brine mining set of technologies (membrane concentration, evaporation, crystallization, etc.). However, these new processes and technologies face a challenging concentrated matrix management that can expose equipment and instrumentation to a high risk of failure.

Approaching the right online instrumentation for process control in concentrated brine environments is not an easy matter due to the high interference matrix scenario and instrument corrosion as well.

The work presented is particularly focused on a novel solution for online monitoring of calcium (Ca) and magnesium (Mg) in an RO brine concentration and purification system using special nanofiltration (NF) membranes. Fast, reliable, and robust data is crucial to understand better, develop, and improve the membrane-based systems applied to brine recovery.

The work has been deployed in three phases. (1) In the first one, different synthetic brines have been produced using sodium chloride (NaCl) and magnesium chloride (MgCl2) to choose and validate the analysis solution; (2) Real brine tests and (3) validation ion a real pilot plant (with a technology partner)

Phases 1 and 2 have been performed and with excellent results, while phase 3 will be deployed during February and March 2024.

The technology tested has been the colorimetric titration that exhibited very robust results and reproducibility while keeping excellent limit of detection (LOD).

Two analyzers are needed to monitor calcium and magnesium hardness (total hardness-calcium hardness) achieving excellent results in the ranges of 500 to 1500 ppm of both hardness

Keywords: RO brine mining; Online monitoring; Calcium and magnesium

SH 144

Development of novel water-energy-food-ecosystem (WEFE) mini-complex based on a standalone renewable energy aquaponic agriculture

Hassan Fath, Abdalla Zaineldin*, Ahmed Shamim, Abdelwahab Shalaby, Tein Chieh, Ahmed Torky

*Alexandria University, Alexandria 21526, Egypt
Abdalla.zaineldin@alexu.edu.eg

Besides global warming, the lack of water and food security is essential for many countries worldwide. It is of concern in Egypt and the MENA-GCC region. The lack of irrigating water resources, hot climate, and high solar radiation pose an obstacle in raising farmland and making growing crops an expensive resource-intensive endeavor. California faces a similar problem of freshwater shortage that affects conventional agricultural food production. In cold climates, controlled environment agriculture (CEA) facilities like greenhouses (GHs) have been introduced to trap solar energy to increase indoor air temperature and maximize crop productivity and quality. CEA agriculture has also become popular in hot regions as global warming poses serious threats for the agricultural system in those regions. However, CEA is very energy-intensive, and the existing practices for heating and cooling GHs have different drawbacks. These include water-intensive evaporative coolers and energy-intensive mechanical cooling systems, lack of suitable shading, and less focus on utilizing available renewable (solar/wind) energy. These all add to the capital cost (CAPEX) and operational costs (OPEX), which could e about 20-40% of total operating expenses.

California (US) and Egypt enjoy a relatively high renewable (solar/wind) energy (RE), utilizing these resources have great potential to overcome these drawbacks of GHs as well as producing water and generating power. Therefore, this project focuses on the techno-economic modeling, detailed design, and pilot test of an innovative RE-driven aquaponic system integrated with a desalination technique. The study will also focus on optimizing the proposed system using machine learning-based algorithms. The study will also focus on integrating artificial intelligence for efficient control of the indoor environment. The ultimate goal is to achieve the water-energy-food-ecosystem (WEFE) nexus for the small remote coastal communities in Egypt and California as well as the MENA-GCC region and worldwide. The design of micro-complex sub-systems/components outputs will be an input to other sub-systems/components for the green environment in a sustainable green and ecosystem way. Dissemination of the project outcomes to SMI/SME targeting commercialization pathways.

This paper presents an overall presentation of the proposed WEFE project Co-Funded by both Egyptian and US Funding Institutes. The overall proposed standalone green min-complex consists of the following sub-systems:

1. GH cavity, for primary plants growth
2. Transparent roof with a set of PVT for electricity generation and partial shading
3. An additional set of land PVs panels for more electricity generation

4. Thermal chimney for natural ventilation assistant,
5. Set of wind turbines for electricity generation,
6. A set of fish tanks for fish growth and plants nutrient generation,
7. Service room (Containing RO plant, Batteries & rectifiers, Fertilizer Preparation, etc.)
8. An additional set of roofs PVs (for additional Electricity generation)
9. Set of Solar Stills (SS) for additional distilled water and salts Production
10. Areas for outside agriculture of high salinity plants (Animal feed, biofuel production)
11. Areas for possible animal/chicken farming

Keywords: Solar energy; Aquaponic

SH 145

NF pilot study: performance comparison of different commercial NF elements in GCC conditions under different operational parameters

Ruben Gomez*, Ratul Das, Thomas Altmann, Roman Boda

** ACWA POWER, The One Tower,*
Barsha Heights, 42nd Floor, Dubai 30582, UAE
Tel. +971 529296816; rgomez@acwapower.com

The need of more SWRO desalination plants is unstoppable across all the GCC countries in order to cover their freshwater availability. This phenomenon is growing along with sustainability and circularity concepts for each new plant which makes new innovative technologies more relevant to ensure these two concepts are affordable and feasible. Nano-filtration (NF) technology is swiftly becoming a new intermediate desalination step as it can reduce energy consumption of conventional RO process by rejection of multi-valent ions, hence reducing average salinity feed RO units will tackle but it is, also, becoming a benchmark step for specific brine mining procedures.

Our pilot study mainly focuses on the evaluation of different NF (nano-filtration) commercially available membranes to determine their multi-valent ions rejection selectivity under different and specific operational conditions. We have conducted several pilot run with more than six (06) different NF OEMs. This was carried out in a small NF pilot fed by filtered GCC seawater where parameters like recoveries, pH, fluxes, etc. were gradually modified meanwhile different samples (feed, permeate and brine) were analyzed to determine each stream composition and subsequent NF element performance.

Keywords: Specific energy consumption; Nanofiltration; Seawater desalination; Pretreatment; Rejection

SH 146

Modification of photovoltaic driven single stage reverse osmosis system to a closed loop RO: design and experiments

Vinay Narayan Hegde*, Joachim Went,
Mohammadhassan Abbasigevarand, Joachim Koschikowski,
Werner Platzer

** Fraunhofer Institute for Solar Energy Systems,
Heidenhofstr. 2, Freiburg 79110, Germany
Tel. +49 761 45885884; vinay.narayan.hegde@ise.fraunhofer.de*

Climate change is creating challenges for reliable water supply and management. The highly populated areas in the world either live in the water scarcity or approaching the water scarcity. The ground water in many of the arid regions has high salinity and not suitable for drinking or agriculture. The season also influences the salinity and the level of brackish ground water. The inland desalination can be a solution for potable water supply from the saline ground water resources.

The main desalination technology used in these cases is reverse osmosis (RO). But the standard RO has its own limitations such as high energy demand, limited recovery rate in a single stage, sensitive to seasonal fluctuations of raw water quality, etc. Due to limitations in the recovery rate, large amount of brine is produced. The brine disposal is a big challenge especially for inland areas. If the brine is disposed untreated to the existing water bodies or to the environment it may worsen the situation and increase salinity of the water resources significantly in the long term. Also, if the energy source is fossil fuel, it increases the CO_2 footprint of the system. The renewable energy driven RO can address this issue of carbon footprint, but not the issue of fluctuating raw water conditions. RO systems are not usually designed for transient operation. The closed loop reverse osmosis (CLRO), commercially known as CCRO, can address some of the disadvantages of standard RO, such as fluctuating feed concentration and limited recovery rate.

The project 'Enhancement of the recovery ratio in brackish water desalination systems for agricultural irrigation project – HighRec' aims to develop technologically, environmentally and economically comprehensive concepts for high recovery brackish water desalination system with compliance to the irrigation water requirement. The focus in this project is on the CLRO desalination system driven by photovoltaics, as it can adapt to the energy supply and feed concentration. The CLRO process is a semi batch process and operates in two modes: plug flow and closed loop. The time of operation of closed loop and plug flow decides the overall recovery from the system. The project also includes building a small-scale demonstration system. in Qatar for water supply to hydroponic green houses.

A small scale CLRO plant is modelled/sized in a CLRO tool developed at Fraunhofer ISE. The modelling or sizing tool is written in Python language. The tool is developed to overcome the limitations of commercially existing semi-batch sizing tool. The program allows the user to select from a vast range of membrane elements existing in the market and gives suggestions to choose a proper membrane based on the characteristics of feed water. While sizing the system, the program is set to consider the design guidelines from the membrane manufacturer without surpassing these limitations. The tool is modularized for simplification and for versatile use. The individual modules include Water and salt permeability coefficient, Osmotic pressure calculator, Membrane selection and design guidelines based on silt density index (SDI), System sizing for CLRO, Plug flow mode and Closed loop mode. The final output from the program contains element by element performance

data and overall cycle performance data and the results are exported to an excel file.

A commercially available, containerized, small RO system including pretreatment, dosing and cleaning units is selected as a pilot plant. The key parameters for the pilot system are 1.5 m^3/h capacity, seawater as feed, 30% recovery rate, feed flow rate up to 5 m^3/h. The containerized system offered by Boreal Light GmbH was selected as a base system as it fulfilled all the key parameters and was cost effective. The retrofitted system based on the data from the modelling tool is equipped with a feed and recirculation pump to realize closed loop and variable flow rates and pressures during the operation. The system is equipped with 21 kWp PV panels without battery backup and a grid connection for continuous operation. The system is currently under operation in Qatar and supplying water to the horticulture farm. The data access and monitoring of the system can be done remotely.

In this contribution, the designed values obtained from the modelling tool and measurement data from the pilot plant are compared. In addition to that the comparison between the standard single stage RO system and retrofitted CLRO system in terms of energy consumption, water recovery and permeate production are given. The lessons learnt from this simple method of retrofitting are low effort in construction, reduction in cost intensive parts compared to systems with side conduit or energy recovery devices. On the other hand, it comes with its own disadvantages, such as frequent variation in the operating points of the pumps, realization with low automation, variable permeate flow rate and recovery.

Keywords: Closed loop RO (CLRO); Retrofit; HighRec

SH 147

Membrane deformation in reverse osmosis units: impact on the fluid flow in permeate channels

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

** Università degli Studi di Palermo, Viale delle Scienze, Ed 6, Palermo 90128, Italy*
Tel. +39-327171521 1, giuseppe.battaglia03@unipa.it

Reverse osmosis (RO) is a well-established desalination technology that produces tens of millions m^3/d of clean water from seawater or brackish water. The spiral wound module is the most popular and economic membrane packaging configuration typically employed in RO units. In the modules, meshes of plastic fibres, called spacers, keep membranes separated and define the channels where solutions flow. However, spacers cause hydraulic pressure drops across the module, leading to a decline in the overall process performance. Numerous studies have thoroughly investigated the impact of feed spacers on the performance of RO units. Conversely, the permeate side has been mainly neglected. De Roever et al. [1] observed evidence of membrane deformation into permeate channels during seawater RO applications. Kleffner et al. [2] identified membrane deformation and membrane compaction phenomena during high-pressure RO operations (120 bar). These phenomena were argued to cause a water flux reduction higher than ~15% [2]. The present study introduces the first fluid-structure interaction modelling tool aiming at assessing the impact of permeate side features on RO unit performance. The model considers membrane deformation into permeate channels into account. One-way coupled 3-D mechanical and fluid dynamics simulations were conducted using Finite Element and Finite Volume methods. Membrane deformation experimental data were exploited to tune the mechanical characteristics of the membrane and the permeate spacer.

Specifically, an innovative experimental set-up was adopted to measure pressure losses in permeate channels and, at the same time, to optically record pressure-induced membrane deformations. A very good agreement was found between numerical and experimental data. Permeate channel porosity decreased from ~0.8 (undeformed case) to ~0.4 under an applied pressure of ~60 bar, causing pressure losses through the permeate channel to increase up to 20 times. The developed model paves the road toward a comprehensive understanding of the influence of membrane deformation and membrane compaction phenomena on the performance of RO units, phenomena that have been neglected so far.

Keywords: Membrane intrusion; Structural mechanics; Computational fluid dynamics; Darcy flow

SH 148

Refining SWRO designs for the lowest total cost-of-water analysis: technical and economic analysis of multi-stage SWRO options for

Eli Oklejas*, Rory Weaver, Lester Burton

FEDCO, 800 Ternes Drive, Monroe, MI 48162, USA
Tel. +1 7342413935, rweaver@fedco-usa.com

This presentation outlines a novel seawater reverse osmosis (SWRO) approach designed to diminish the capital and operational expenditures, minimize the physical footprint, and lower the environmental impact of large-scale desalination plants. By integrating well-established technologies from current industrial and SWRO practices into a novel configuration, our approach offers a risk-averse strategy conducive to immediate implementation in upcoming SWRO projects.

Anticipated benefits of this innovative mega-scale SWRO system include substantial reductions in energy demands, biofouling incidents, and clean-in-place (CIP) frequencies, alongside extended membrane lifespan and improved permeate output. The presentation will focus on several key technological innovations that contribute to these outcomes:

Brine-staged SWRO membrane arrays reduce biofouling potential by balancing system flux and reducing concentration polarization, allowing for higher recovery and reduced membrane replacement frequency.

A centralizedVFD system removes the need for a medium-voltage variable frequency drive (VFD) on each RO train, which reduces energy consumption by up to 3.5%, significantly lower capital expenses, and bolsters overall system dependability. Feed pressure variation is instead provided by a motorized feed turbocharger on each train.

Implementation of turbo-generators for energy recovery from the second pass of the RO system, capitalizing on hydraulic energy in the second-pass RO system brine.

After a brief summary of the technical advancements described above, this paper will demonstrate the life-cycle cost benefits associated with this design. Considering direct CAPEX, cost of financing, energy costs and other operating costs (membrane replacements, chemicals, consumables and so on), this paper will demonstrate the potential for reductions to the cost of desalinated water beyond those achieved in recent decades in mega-scale SWRO. The table below summarizes the projected impact of such a design:

The above design delivers the following benefits to reduce the total cost of desalination water:

- Reduction in total CAPEX by 17% due to higher recovery, which reductions in equipment requirements and scope of both onshore and offshore civil works.
- Reduction in energy consumption by 14% due to optimized configuration of hydraulic and electrical equipment
- Reduction in chemical and consumable use by 16% due to higher recovery, which reduces the total feed flow
- Reduction in CIP frequency from once every 6 months to once every 10.5 months. This can also be expected to increase the useful life of RO membranes.

In conclusion, contrary to the widely held belief that reducing the total cost of desalinated water is now primarily a matter of incremental design changes and financial engineering, there remains significant potential to reduce the cost of large-scale SWRO by using novel arrangements of commercially proven technologies.

Keywords: SWRO; Desalination; CAPEX; Seawater reverse osmosis

SH 149

Design guidelines for small- and mid-scale desalination for optimal Capex, Opex and membrane performance

Haytham Ahmed, Eli Oklejas,
Rory Weaver*, Casey Bly

FEDCO, 800 Ternes Drive, Monroe, MI 48162, USA
Tel. +1 7342413935, rweaver@fedco-usa.com

The main goal for small and medium size water desalination plants is get a reliable plant with lowest possible CAPEX may this goal be different in MEGA plants as OPEX is more important. one from way to lower the COPEX is by increasing the recovery for that we sow recovery increasing in last few years from 30% to 45% but also there are a drop in the membrane life time.

This paper presents a guideline to design energy efficient high recovery reverse osmosis (RO) systems. Different feed water salinities, ranging from 8,000 to 45,000 ppm were studied. The use of inter-stage turbochargers, turbine-assisted pumps and multistage multi turbo configurations is presented. The proposed arrays enable achieving high recoveries along with a safe membrane operation. In all designs, the flux and recovery per membrane module was obtained using the hydraulic energy of the brine. For all the studied cases feed water temperatures of 25 and 35 °C were used at zero- and three-years membrane age. A commonly used membrane projection software was used to model the system. The turbocharger performance was calculated using manufacturer proprietary software. The results revealed that using a multistage design approach along with turbochargers yielded the expected process benefits plus a significant reduction in the feed flow due to higher recoveries without jeopardizing the membranes performance. The reduction in feed flow yields CAPEX and OPEX reductions for the intake, pretreatment, brine discharge, pipe diameter, footprint, decrease in chemical consumption and other parts of the plant whose cost is directly tied to the feed flow.

High recovery not only drops the plant CAPEX but also its critical factor in some cases. In some

areas, especially tourism location feed water availability is limited so the only solution to increase your recovery, so you get more fresh water from same amount of feed water.

This paper will present the fundamentals of brine-staged membrane arrays, and demonstrate the application of brine-staged RO with different case studies for BWRO and SWRO cases.

Keywords: Small-scale desalination; Mid-scale desalination; SWRO; Biofouling

SH 152

Marine transportation of fresh water using the salinity gradients energy

Valeriy Knyazhev*, Vladimir Loshchenkov

Institute of Marine Technology Problems FEB RAS, Sukhanova str., 5a, Vladivostok 690091, Russia
**Tel. +7 9241315804; kvv@marine.febras.ru*

In many regions of the world, there is an acute shortage of fresh water. Consumers on the coasts of the seas and oceans also have this problem. The delivery of fresh water there by tankers from places rich in water resources is currently not cost-effective, and can be used in exceptional cases. The authors set the task to increase the profitability of transportation of natural drainage of clean fresh water by sea transport with minimal construction and maintenance costs. A modular automatic sea transport with a propulsion system powered by the difference in salinity of the transported fresh water and the surrounding sea water is considered.

The transport contains a cylindrical container made of elastic elastic material for fresh water, a water intake and supply system, an engine, a power plant, a navigation and communication control unit with dispatch control and management. Transport has surface and underwater design options. In the case of only the surface version, the fresh water tank takes the shape of a cylinder when filled; when empty, it folds compactly like an accordion in diameter by internal cable winches attached to the front diametrical stiffness of the tank. The surface version is optimal for transportation over distances of more than 1500 km with the return to the loading point of several empty transports in a compact form by a cargo ship. In the case of the underwater version, instead of cable winches, the tank contains transverse elastic ties and a buoyancy device with ballast. The underwater option works at depth and surface, but returns for loading on its own. Ice conditions for the underwater option are not a hindrance.

Energy for transportation can be obtained by reversibly mixing in the power plant the transported fresh water and the surrounding seawater. For energy supply of transport, osmotic and reverse dialysis units can be used, both separately and in combination, together. The advantage of an osmotic unit is that the mechanical energy to drive the propellers is obtained directly on the turbine unit. And in a reverse electrodialysis unit, the electricity required to power the automation is directly obtained.

Keywords: Salinity gradients energy; Osmosis; Reverse electrodialysis; Automatic transport; Fresh water.

SH 154

Water quality aspects for PEM electrolysers

David De Vos*, Bart Ghysels

ENGIE Laborelec, Augustin Delportestraat 106, Brussels 1050, Belgium
**Tel. +32 491222026; david.devos@engie.com*

Proton exchange membrane water electrolyser (PEMWE) lifetime is highly dependent on water quality requirements. The recommendation is to always use ultra-pure water (UPW, <0,1 µS/cm), but return of experience shows that failures in the water treatment train, corrosion of system elements, or degradation of stack components can occur, affecting water quality. Small amounts of unwanted ions and molecules can cause irreversible damage to electrolyser stacks, which have very high CAPEX costs. In this study, a first step will be taken towards developing water quality requirements and operational guidelines in case of contaminant intrusion in PEMWE.

A small bench-scale PEMWE (~50W) at the ENGIE Laborelec site was used to assess the effect of typically encountered water contaminants on the operation and efficiency of the stack. To this end, a first set (e.g., sodium, iron,…) was tested at three different levels of concentration (low (1 ppm), medium (10 ppm), and high (100 ppm)). Degradation was assessed by obtaining EIS spectra and polarization curves after performing a use case on the different impurity levels, compared to the UPW baseline. Cations were introduced in sulphate salt form and anions in acid form, and screening effects by counterions were investigated by performing tests with H_2SO_4. Testing conditions were compliant with JRC standards .

Detailed results and conclusions will be shared at the International Conference on Desalination for the Green Hydrogen Economy in Sharm-el-Sheikh. At Engie Laborelec, we are in a prime position to gain information on the impurities present at the industrial scale, due to large-scale H2 projects, and close collaboration with OEMs, supplier, and operators. Their input will be used to finetune and expand the list of impurities to be tested.

Keywords: Water quality; PEM; Electrolysis; Polarization curves; EIS

SH 155

Innovative PSF membrane composite for antifouling resistance and rejection properties

Farah Abuhatab[1,2]*, Thanigaivelan Arumugham, Shadi W. Hasan

**[1]Department of Chemical Engineering.*
[2]Center of Membranes and Advanced Water Technology (CMAT)
Khalifa University of Science and Technology,
Abu Dhabi, P.O. Box 127788, UAE
farah.abuhatab@ku.ac.ae

The widespread application of ultrafiltration membranes for the removal of various water pollutants is firmly established. Yet, their hydrophobicity presents a significant challenge, leading to an increased susceptibility to membrane fouling and endangering both durability and operational performance. To address these issues, a frequent technique is to regulate membrane hydrophobicity

through the incorporation of surface-modifying agents into the membrane aiding in the development of antifouling capabilities. This study proposes an innovative membrane modifier, namely, silver phosphate (Ag_3PO_4) nanoparticles incorporated into a modified metal-organic framework (Cu-MOF) structure to form Cu-MOF/Ag_3PO_4 composite. This modifier was integrated into a polysulfone (PSF) membrane to fabricate a series of novel ultrafiltration membranes (0.025, 0.05, 0.1, 0.5, and 2 wt%) via the phase inversion method. This novel membrane composite has been characterized, optimized, and evaluated for the development of efficient antifouling ultrafiltration membranes. The resultant membrane possessed a highly hydrophilic surface that not only showed improved water permeation but also enhanced the resistance to fouling. Moreover, in dynamic three-cycle filtration tests using bovine serum albumin protein (BSA), the PSF membrane modified with 0.1 wt% modifiers achieved a maximum flux recovery ratio of 82% (cycle-1), 79% (cycle-2), and 77.8% (cycle-3). The results demonstrate the high potential of these modified membranes as an effective technique for improving antifouling properties.

Keywords: Nanomaterial; Metal-organic framework; Membrane; Wastewater treatment; Antifouling

SH 156

The role of water desalination in the Green Hydrogen Challenge

Guillem Gilabert-Oriol*, Jordi Bacardit,
Marc Slagt, Matt Roth, Martin Deetz

**DuPont Water Solutions, Tarragona 43110, Spain*
Tel. +34 682 015 166; guillem.gilabertoriol@dupont.com

The global pursuit of more sustainable sources of energy and mobility is transforming our economy. Hydrogen has emerged as a promising vector due to its versatility as a fuel or feedstock. Hydrogen can play several major roles in energy transformation, contributing to the decarbonization of transportation, heat, and energy sources, both industrial and domestic, and as a greener feedstock in the production of ammonia or methanol, for example.

The Green Hydrogen Challenge

Hydrogen can be produced by several methods from different feedstocks, but the most sustainable technology is termed Green Hydrogen, in which hydrogen is produced from water by renewable energy powered electrolysis. From the perspective of water-related challenges, a similar technical landscape is found when the source of electricity is nuclear power, which is the so-called Pink Hydrogen.

Water for the Green Hydrogen ecosystem

Electrolysis is the process of electrically splitting the water molecules into hydrogen and oxygen gas. There are various types of electrolyzers, and they all rely on high purity water as the feedstock to produce hydrogen. The water quality and dynamic water chemistry have a direct impact on the lifetime of the key components of the electrolyzers: membrane, electrodes, and catalysts. As a result, the overall efficiency and economy of the operations. It is critical that water quality is well under-

stood and managed to ensure efficient operation and maximize the lifetime of the components.

The net supply of demineralized water required for electrolysis is estimated in the range of 10 L/kg of H_2. According to the International Energy Agency, by the end of 2023 the global electrolyzer installed capacity was estimated to be in the range of 2 GW; in 2030, 175 GW of installed capacity is expected. The final number could be even higher if projects in early evaluation stages can be implemented at that time. Translated into water supply requirements, while at the beginning of 2024 only 6,000 m^3/d are required, in 2030 that market would need more than 750,000 m^3/d, and further increase will be necessary to achieve the 2050 net zero emissions targets.

Additionally, water may be required for other purposes beyond the net requirements of hydrogen production. To maintain temperature in the electrolyzer loops, electrolyzer plants require cooling. While at this moment, most of the installations rely on air-based cooling or hybrid cooling with very low water consumption, when projects scale up, water-based cooling may come into consideration. In that case, total water volume needs for an electrolyzer installation could more than double. On the other hand, hydrogen is expected to be used as feedstock to produce other goods, such as ammonia, and fertilizers, or to be combined with hydrocarbons to make them lighter. In these production processes, utility water will be required, for example, for boiler feed to produce steam or for cooling needs too.

Water treatment technology for Green Hydrogen Production

Whether sourced from tap water, surface water, reclaimed wastewater or seawater, feed water requires treatment to reach the quality necessary for electrolysis; the selection of technologies for the water treatment line will not only determine the water quality but also the overall recovery rate (water efficiency) and energy consumption, among other features. Additionally, to prevent the accumulation of critical impurities in the electrolyzer loops, dedicated polishing is required, and its design must be in accordance with the electrolyzer type.

Where can innovation play a role in the green hydrogen ecosystem?

As an emerging space, the green hydrogen ecosystem has recognized unresolved needs from the perspective of water treatment. From one side, to offer cost-competitive hydrogen, the water treatment industry must play a role in the expected overall efficiency gains. On the other hand, as projects scale up, significant amounts of water will be required to produce hydrogen and the resulting hydrogen-sourcing production processes will compete with existing uses and other emerging uses of water. The hydrogen industry will soon face the following question: "What if water needs to be sourced from…?" Durable and reliable water quality is critical to achieving an efficient operation, each source may require a dedicated technology scheme to achieve the required quality, and innovation will be required to deliver robust, reliable, and efficient water treatment solutions to the hydrogen industry.

This work will provide:

- From water to hydrogen basics: principles, flows and technology outlook.
- An estimation of overall water consumption.
- A critical view on the water quality specifications vs production costs; water contaminants and their role in the process.
- A holistic view on the design of water treatment solutions: potential treatment schemes, technoeconomic aspects, and innovation needs.

Keywords: Green hydrogen; Decarbonization; Water treatment; Water reuse; Desalination

SH 157

Practical application of NF-OARO technologies as pretreatment and concentration stages for desalination brine valorisation

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

Canary Islands Institute of Technology (ITC),
Santa Lucía de Tirajana 35119, Spain
**Tel. +34 644741668; ariverof@itccanarias.org*

Commonly, a global desalination brine valorisation scheme is composed of a pre-treatment stage, followed by a concentration stage and a final conversion stage. In the pre-treatment stage, the main objective is to remove the multivalent ions (especially those that can cause scaling) from the main stream. At the concentration stage, the aim is to concentrate as much as possible the brine at the lowest energy consumption besides producing more fresh water.

The Canary Islands Institute of Technology (ITC) has constituted an open testbed platform for desalination brine valorisation, within the framework of the existing DESAL+ LIVING LAB platform, in Pozo Izquierdo (Gran Canaria). A Nanofiltration (NF) pilot plant as a brine pre-treatment stage and an Osmotically Assisted Reverse Osmosis (OARO) pilot plant as a brine concentration stage have been tested and evaluated with real desalination brine at ITC's brine valorisation open testbed.

This real application shows the integration of the above technologies, the preliminary results obtained, in terms of chemical composition of the different streams, total recovery and specific energy consumption. These results and future tests open the possibility of integrating conversion technologies to the ITC open testbed facilities, where startups, research centers and companies could test and validate their innovative solutions regarding brine valorisation.

This work and facilities has been done with the support of the E5DES project (85% ERFD - INTERREG MAC 2014-2020), SOL2H20 project (WIDENING HORIZON CSA and the Cabildo de Gran Canaria – SPEGC).

Keywords: Brine; Seawater reverse osmosis; Brine characterization; Brine mining; Industrial valorisation; Open testbed; Nanofiltration; OARO

SH 158

Brine valorisation via extensive operation of a pilot-scale electrodialysis with bipolar membranes (EDBM)

Calogero Cassaro*, Giovanni Virruso, Antonia Filingeri,
Fabrizio Vassallo, Andrea Cipollina,
Alessandro Tamburini, Giorgio Micale

** University of Palermo, Via Spagna, 16, Favara 92026, Italy*
calogero.cassaro01@unipa.it

Nowadays, human activity tackling fresh-water scarcity by desalination plants leads to the production of waste hypersaline streams which are discharged directly into the sea. According to EU policy, conventional disposal strategies are environmentally unsustainable and new stricter discharge

regulations are needed. With this respect, extracting value from these hypersaline wastes can make the process even more sustainable. For instance, the recovery from desalination brine of valuable minerals (including critical raw materials) and chemicals which can be reused inside the industrial process is well known to be beneficial and of interest.

To this aim, electrodialysis with bipolar membrane (EDBM) has been recently proposed as a promising method for the efficient removal of salt ions from concentrated saline solutions through the beneficial production of alkaline and acid streams. Furthermore, acids and bases derived from EDBM are often of sufficient purity for utilization in various industrial processes such as pH adjustment and neutralization reactions. Surprisingly, EDBM unit has never been investigated in industrial-relevant scenarios using a real brine coming from desalination plants as a feed.

In the present work, the influence of saline stream composition and the implementation of different operating strategies were investigated in a pilot-scale EDBM unit installed in an industrial site.

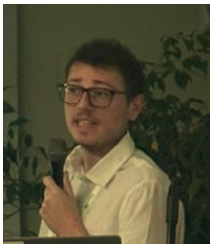
In particular, a long-run experimental campaign was conducted to assess the performance of the unit when fed with both artificial and real brines. During the tests, the effect of two different control strategies (flow-rate and pressure control) was also studied, evaluating the impact of the internal leakage at a fixed concentration of the alkaline product. At the same time, different steady-state conditions were analysed, varying the outlet flow-rates and the supplied power, demonstrating the flexibility and stability of the process in providing several product targets. Results showed how the behaviour of the unit strongly depends more on the control strategy adopted rather than the feed employed. Indeed, for the same feed, a wide range of current efficiency (CE), between 20–90%, and specific energy consumption (SEC), between 1.5-7 kWh kg^{-1}, were found for both products (acid and base solution).

This study revealed that EDBM is a very suitable technology in an industrial context where acid and base streams can be re-used, aiming to ensure waste valorisation and increasing the circularity of the whole process.

Keywords: BMED; Brine mining; Ion-exchange membranes; Scale-up; Desalination; MLD; Chemicals production; Circular economy

SH 159

An improved electrodialysis system for the simultaneous production of fresh water and hydrogen: a preliminary assessment



Giovanni Campisi*, Alessandra Pellegrino,
Federica Proietto, Alessandro Galia,
Alessandro Tamburini, Onofrio Scialdone, Giorgio Micale

**Università degli Studi di Palermo,*
Viale delle scienze, Ed 6, Palermo 90128, Italy
Tel. +39 3806369361; giovanni.campisi02@unipa.it

Latest years are characterized by an increasing interest on finding new global strategies to substitute fossil fuels with more sustainable energy vectors.

Green hydrogen has became the bet of many countries in the world, and the European community is strongly promoting research in order to reduce its production price [1], which is still expensive and not fully competitive with the one obtained from current fossil fuel technologies

(e.g. steam reforming). Scientific community is mainly looking for ways to reduce costs, which are mainly related to materials and electric consumption. However, an underestimated problem of the future large-scale production of hydrogen from water electrolysis is the huge volume of desalinated water required as feed. The main desalination process currently used is reverse osmosis (RO), but other desalination technique include thermal technologies (e.g. multi-effect distillation, MED) or electro-membrane processes such as the electrodialysis (ED) in which an electric field is applied to separate the ions present in the water.

A classical ED unit [2] is constituted by a cell package, a repetition of ionic exchange membranes and spacers, enclosed by 2 electrodes. Normally, an aqueous solution of Na_2SO_4 as supporting electrolyte is fed to the electrodic compartment, in which the electrolysis of water takes place. Thus, the external electrical circuit is closed by a power supply and the ED technology desalinates the feed by consuming energy and producing a concentrated brine.

In this work, an ED unit is studied and improved for the simultaneous production of fresh water and hydrogen. Alshebli et al. [3] have already studied an experimental ED system for the desalination of an Na_2SO_4 solution, and investigated the simultaneous production of hydrogen at the electrodes. Recently, Fonseca et al. [4] experimentally studied an ED system for the desalination of a saline NaCl feed in the range of 10–30 g L^{-1} with a maximum hydrogen production up to 21.6 mL h^{-1} cm^{-2} at a current density of 469 A m^{-2}, further demonstrating the feasibility of the new proposal. Moreover, independently of the current density adopted, in typical ED stacks, where one cathode only is present, the amount of hydrogen produced is too low for being considered as a real product and does not modify the process economics. The idea of the present work is that to assemble a unit where the whole cell package is split up in smaller ones, spaced out by new electrodes. Thus, the larger number of cathodes increases the hydrogen production while the feed water entering the system is simply divided up into the smaller cell packages without changing the fresh water yield. This work aims to evaluate the profitability and the remunerability of such a plant, and calculate the corresponding Levelized Cost of Hydrogen (LCOH) when the water is sold at the same production price of an equivalent ED unit. Preliminary analysis shows how the LCOH can be maintained below the price of 5 € $kg^{-1}H_2$, if brackish water (5 g L^{-1}) is used as feed, demonstrating how the new proposal could be a valid possibility for new desalination plants. Furthermore, the technology can also be profitable for existing plants that could be revamped and improved with green hydrogen production.

Keywords: Electrodialysis; Green hydrogen; Economic analysis; Brackish water; Desalination

[1] European Commission et al., The role of renewable H_2 import & storage to scale up the EU deployment of renewable H_2?: report. Publications Office of the European Union, 2022. doi: 10.2833/727785.
[2] S. Al-Amshawee, M. Y. B. M. Yunus, A. A. M. Azoddein, D. G. Hassell, I. H. Dakhil, e H. A. Hasan, «Electrodialysis desalination for water and wastewater: A review», Chem. Eng. J., vol. 380, p. 122231, gen. 2020, doi: 10.1016/j.cej.2019.122231.
[3] R. F. Alshebli, B. Yuzer, e Y. Bicer, «Experimental investigation of simultaneous hydrogen production and desalination via electrodialysis process», Int. J. Hydrog. Energy, p. S0360319922058207, gen. 2023, doi: 10.1016/j.ijhydene.2022.12.104.
[4] M. J. D. C. Fonseca, F. V. D. Fonseca, e C. P. Borges, «Electrodialysis feasibility for simultaneous generation of desalinated water and hydrogen as by-product», Int. J. Hydrog. Energy, vol. 53, pp. 1396–1403, gen. 2024, doi: 10.1016/j.ijhydene.2023.12.058.

SH 160

$Mg(OH)_2$ production from salt solutions: a novel optimized pilot-scale crystallizer

Giuseppe Battaglia*, Daniele Milia, Damiano Costanzino, Giuseppe Scelfo, Fabrizio Vassallo, Fabrizio Vicari, Alessandro Tamburini, Andrea Cipollina, Giorgio Micale

** Università degli Studi di Palermo, Viale delle Scienze, Ed 6, Palermo 90128, Italy*
Tel. +39-3271715211; giuseppe.battaglia03@unipa.it

Water scarcity and mineral security are two crucial issues that human beings are facing nowadays. Desalination provides fresh water from salt-aqueous solutions. On the other hand, desalination technologies generate concentrated salt streams as a by-product, whose disposal has raised concerns. Seawater contains a lot of the chemical elements reported in the periodic table. Thus, concentrated seawater waste streams can be considered a sustainable source of minerals. Since 2020, the European-funded SEArcularMINE project has been focused on the recovery of critical raw materials from seawater waste bitterns [1]. Bitterns are the by-products of sea salt production in saltworks. Bitterns are highly concentrated solutions. As an example, magnesium ions (Mg^{2+}) concentration can reach values up to 60 g/L in bitterns. Notably, Mg^{2+} concentration in seawater is 1.3 g/L and it doubles (2.6 g/L) in waste solutions of reverse osmosis desalination plants.

The present work introduces a novel pilot-scale crystallizer for the recovery of Mg^{2+}, in the form of magnesium hydroxide, $Mg(OH)_2$, from saltworks bitterns. The design of the crystallizer was aimed at minimizing the local supersaturation level all over the reactor volume. The novel design allowed the well-known issues of scarce thickening and filtration characteristics of $Mg(OH)_2$ suspensions [2] to be tackled. A ~12 g/L $Mg(OH)_2$ suspension was produced by adopting a 0.5 M synthetic sodium hydroxide solution and a ~48 g/L Mg-containing bittern, collected from Margi saltworks (Trapani, Italy). A thickening rate (in a 500 mL cylinder) and a filtration time (filtering 100 mL) of ~500 mm/h and ~30 s were measured. A 100% Mg^{2+} recovery was achieved. In addition, $Mg(OH)_2$ powder mass purity was higher than 98 %.

The novel pilot scale crystallizer represents a promising technology able to produce $Mg(OH)_2$ suspensions characterized by excellent thickening and filtration characteristics from salt solutions such as saltworks bittern or seawater desalination brines.

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] G. Battaglia et al., "Evaluation of the Purity of Magnesium Hydroxide Recovered from Saltwork Bitterns," Water (Switzerland), vol. 15, no. 1, Jan. 2023, doi: 10.3390/w15010029.

[2] M. Turek and W. Gnot, "Precipitation of Magnesium Hydroxide from Brine," Ind. Eng. Chem. Res., vol. 34, no. 1, pp. 244–250, 1995, doi: 10.1021/ie00040a025.

Keywords: Magnesium hydroxide; Mineral recovery; Brine valorization; Pilot scale; Critical raw material

SH 162

Predicting particulate fouling in full scale reverse osmosis plants

Mohanad Abunada[a,b], Nirajan Dhakal[a], Raffay Gulrez[a], Pamela Ajok[a], Yuke Li[a], Almotasembellah Abushaban[c], Herman Smit[d], David Moed[e], Noreddine Ghaffour[f], Jan C. Schippers[a], Maria D. Kennedy[a,b*]

[a]*IHE-Delft Institute for Water Education, Water Supply, Sanitation and Environmental Engineering Department, Westvest 7, 2611 AX Delft, the Netherlands*
[b]*Delft University of Technology, Faculty of Civil Engineering, Stevinweg 1, 2628 CN Delft, the Netherlands*
[c]*Mohammed VI Polytechnic University, International Water Research Institute, Lot 660, Hay Moulay Rachid, Ben Guerir 43150, Morocco*
[d]*PWN, Rijksweg 501, 1991 AS Velserbroek, the Netherlands*
[e]*Evides Industriewater, 3006 AL Rotterdam, the Netherlands*
[f]*Water Desalination and Reuse Center (WDRC), Biological and Environmental Science and Engineering (BESE) Division, King Abdullah University of Science and Technology (KAUST), Thuwal 23955-6900, Saudi Arabia*
**Tel. +31 15 215 1774; m.kennedy@un-ihe.org*

Since particulate fouling due to the deposition of particles/colloids is persistently a problem in RO systems, there is a need to be able to reliably predict particulate fouling in order to effectively assess, monitor and control the performance of RO systems. The ASTM methods, i.e. silt density index (SDI) and modified fouling index (MFI), are commonly used to assess the particulate fouling. One of the main drawbacks is that both SDI and MFI simulate particulate fouling of RO using a 0.45 um membrane, and thus neither method assesses the effect of small colloids (< 0.45 um) which are more likely to be responsible for RO membrane fouling. Consequently, a more promising method the modified fouling index – ultrafiltration (MFI-UF) was developed (to operate at constant flux) whereby a UF membrane is used in order to capture and assess smaller colloids.

The main objective of this research was to apply the MFI-UF method (at constant flux) to verify its accuracy, reproducibility and applicability to predict particulate fouling in RO systems. In this research the MFI-UF method is applied to predict particulate fouling rates in two full-scale RO plants. The MFI-UF was measured using 5, 10 and 100 kDa membranes at same flux as was applied in the full-scale RO plants (20-26 L/m^2.h). The particle disposition factor (Ω) was calculated to simulate particle deposition in RO cross-flow filtration, and subsequently the particulate fouling rates in RO plants were predicted using the MFI-UF fouling prediction model.

Other types of fouling (i.e. scaling, organic and biological fouling) were also evaluated based on threshold reference values. However, in all cases it was concluded that particulate fouling was likely to be the most dominant fouling in the two RO plants studied. For the first RO plant, the results showed that the fouling rates predicted based on the MFI-UF measured with the 100 kDa membrane had the best agreement with the actual fouling observed in the RO plant (with 3–15% deviation). However, the fouling rates predicted based on the MFI-UF measured with the 5 kDa membrane were apparently overestimated for both RO plants. The reason was attributed to the correction factor used in the prediction model to correct the effect of surface porosity of MF-UF membranes, which was overestimated in the case of 5 kDa membrane. Accordingly, the results could indicate that 10-100 kDa is mostly the suitable range of MWCO of MFI-UF membranes for predicting particulate fouling in RO plants.

Future research will focus on applying the MFI-UF method to predict particulate fouling rates in more RO plants treating different types of water and operating under different conditions. In addition, further work is needed to develop an automated MFI-UF system which can be used inline in RO plants to provide real-time prediction of particulate fouling rates.

Keywords: Membrane; Fouling: Reverse osmosis

SH 163

Desalination for green hydrogen

Dionisio Visintin

Veolia Water Technologies, Via Prà di Risi, 3 33080 Zoppola, PN, Italy
Tel. +39 335 213275; dionisio.visintin@veolia.com

Water and energy optimization is at the core of Veolia's mission. We strive to provide solutions that optimize their use, cost, and sustainability. This optimization is a complex process that involves multiple technologies and resources available in our Group. We propose a thermal desalination solution that can be the optimal solution to reduce production costs per ton of hydrogen. This solution can be carried out both in small offshore containerized plants and large plants on land near the sea. By exploiting the heat to be disposed of from the electrolyser, we can reduce the cost of producing deionized water.

Keywords: Desalination; Renewable energy

SH 164

Preparation and characterization of PTFE-based pore-filled ion exchange membranes for desalinating electrodialysis and energy conversion process

Ho-Cheol Kang, Jeong-Hoon Kim*

H2 & C1 Research Center, Chemical & Process Technology Division,
Korea Research Institute of Chemical Technology,
Gajeong-ro 141, Yuseong-gu, Daejeon 34114, Republic of Korea,
**Tel.: +82-42-860-7513: jhoonkim@krict.re.kr, hckang@krict.re.kr*

Ion-exchange membranes(IEMs) have been widely used for desalinating electrodialysis and energy conversion processes. Since the IEMs determine the efficiency of the above process, it is necessary to develop them with improved separation performance and durability. Novel composite-type anion- or cation- exchange membranes were prepared as follows; first, pore-filling of monomer mixtures (styrene/ divinylbenzene (DVB), vinylbenzylchloride(VBC/DVB)) and an initiator was done in commercial thin polytetrafluoroethylene(PTFE) porous films, respectively. Thermal polymerization was followed in high temperature oven for the formation of precursor membranes. Post-sulfonation was done with chlorosulfonic acid in methylene chloride to give $-SO_3H$ for the preparation of cation exchange membranes. Post-amination was performed in trimethylamine (TMA) in acetone to give $-N^+(CH_3)_3-$ for the preparation of anion exchange membranes. SEM analysis confirmed these membranes were successfully prepared. The electrochemical properties of the resulting

membranes - ion exchange capacity, electric resistance and water content - were studied in terms of the ratio of dope compositions of monomers (Styrene/DVB, VBC/DVB). The composite membranes showed excellent electrochemical properties – electric resistance, water content and IEC value - depending on the monomer dope compositions (Styrene/DVB ratio and VBC/DVB ratio). These membranes showed lower electric resistances, lower water contents and higher IECs than commercial membranes thanks to thin porous PTFE supports. These results showed our composite membranes could be applied to the desalinating electrodialysis process.

Acknowledgements

This research was supported by and performed as a project named "Lithium Recovery by membrane technology for recycling secondary battery" granted from Sebitchem company, Republic of Korea.

Keywords: Ion exchange membranes; Pore-filled; PTFE; Cation; Anion; Electrodialysis; Desalination

References

1. Maria K. Vera, Walter R. Torres, Claudia I. Galli, Alexandre Chagnes & Victorial Flexer, Environmental impact of direct lithium extraction from brines, nature reviews earth & environment. 23, Feb. 2023

SH 165

A novel tool for modelling the near field and far field dispersion of brine effluents from desalination plants

Silvano Porto Pereira*, Melissa Fontenelle Rodrigues, Paulo Cesar Colonna Rosman, Patrícia Rosman, Tobias Bleninger, Iran Eduardo Lima Neto, Iván Sola, José Luís Sánchez Lizaso

** CAGECE, Rua Tomás Lopes, 85, Fortaleza 60060260, Brazil*
e-mail: silvanopereira@terra.com.br

Regardless of the technology adopted, freshwater production from seawater by desalination always results in a stream concentrated in salts and desalination by products that must have the appropriate destination. For this purpose, the disposal of this concentrate (or brine) to the sea by submarine outfall has been the most common option. To have a minimal impact on the marine environment, computational tools are used to simulate the behavior of these brine discharges. Environmental assessment of desalination plants can be made considering different concentrate and flow productions, diffuser configurations, marine conditions and proximity of environmentally interesting area. Another useful application of these computational tools involves assisting in the design of plans and programs for monitoring the surroundings of the brine disposal points. In this work we develop and present a new tool to model brine discharges from submarine outfall, based on the adaptation of a near-field mathematical model, and its coupling with a Lagrangian model, for specific cases of negatively buoyant effluent discharges. The near-field dilution results were compared with a reference tool (Visual Plumes), at different current marine velocity and vertical angles of diffusers, obtaining excellent correlations and a good reproducibility with a mean absolute percentage error of 9%. With this tool it was possible to evaluate the performance of the diffuser

line as a function of a different configuration. The saline plume generated by the Lagrangian model coupled to this near-field model clearly demonstrates the realistic behavior of a brine submarine outfall release, allowing the application of this tool for other cases, including studies of outfall location and diffuser optimization for a minimal environmental impact.

Keywords: Desalination discharge; Brine dilution; Negative buoyancy; Near-field; Lagrangian model; Outfall modelling

SH 166

Photothermal-catalytic CdS/MXene hydrogel membrane for concurrent freshwater and solar hydrogen production via vacuum membrane distillation

Jiawei Sun, Muhammad Usman Farid, Alicia Kyoungjin An*

School of Energy and Environment, City University of Hong Kong,
Tat Chee Avenue Kowloon,
Hong Kong Special Administrative Region
** Corresponding author: Alicia Kyoungjin An*
Tel. +852-3442-9626, Fax +852-3442-0688, E-mail: alicia.kjan@cityu.edu.hk (A.K. An)

Innovations in solar-driven techniques, such as photovoltaic, photothermal evaporation, and photocatalysis, provide sustainable solutions to the water-energy crisis. For example, photothermal membrane distillation (PMD) harnesses solar energy for desalination, while photocatalytic water splitting offers renewable hydrogen generation. The merging of these approaches shows enormous potential for concurrently generation of fresh water and hydrogen in a carbon-neutral manner. However, developing such integrated system and photothermal-catalytic (PTC) membranes poses challenges. It necessitates not just solar-absorbing materials with high efficiency but also careful management of mass and heat transfer. Despite the potential of PTC co-generation systems, issues with membrane durability, scalability, and collection of products persist. Hence, we designed a novel CdS/MXene hydrogel membrane (HM) which is applied to a customized PMD setup for concurrent production of water and hydrogen. Benefiting from the efficient spectral management and the protection of hydrogel layer, the CdS/MXene HM achieved a high freshwater flux of 1.63 kg m^{-2} h^{-1} with 3.1 mmol m^{-2} h^{-1} hydrogen production rate, and maintained stable performance over 60 h. This study showcases an innovative integration of photothermal membrane distillation with photocatalysis for the sustainable generation of both water and energy.

Keywords: Photothermal; Photocatalytic; Hydrogel membrane; Hydrogen; Membrane distillation

SH 167

Monitoring particulate fouling in RO pretreatment

Y. Liu[a*], M. Qatae[a], A. Yameen[a], N. Dhakal[a], S. Salinas[a], P. Vollard[a], J. Schippers[a], R. Schurer[b], M. Kennedy[a]

[a] *IHE Delft, Institute for Water Education, PO Box 3015, 2601 DA Delft, The Netherlands*
[b] *Evides Water Company, PO Box 4472, 3006 AL, Rotterdam, The Netherlands*
yi.liu@un-ihe.org

Reverse osmosis (RO) membrane filtration is an environmentally friendly technology that is increasingly used in desalination treatment, effectively addressing the human survival challenges arising from the global shortage of freshwater resources. While this technology has successfully achieved high efficiency and environmental sustainability in the treatment process, fouling has emerged as a significant technical challenge, impeding the further efficient production of the technology. Fouling adversely affects the service life of the membranes, increases the operating cost of the plant, and compromises the quality of the permeate.

This study was conducted at an NF/RO pilot plant operated by Evides Water company in Baanhoek, the Netherlands. The pilot plant integrates an advanced treatment system with a conventional pre-treatment system. The pre-treatment system utilizes conventional technologies, while NF/RO membrane filtration and disinfection are used to comply with Dutch drinking water standards. To accurately determine the residual particulate fouling after each treatment unit and assess the risk of particulate fouling in RO system, the modified fouling index-ultrafiltration (MFI-UF) was employed. This assessment was crucial to ensure that the NF/RO feed met the required influent quality standard.

Experiments were conducted to assess the particle fouling potential in the treatment process using the MFI-UF_{10kDa} at a flux of 100 L/m^2h. The experiments were carried out during two periods: November 2022 to February 2023 and May to July 2023. The results revealed seasonal variations in the raw water quality, with lower temperatures (November to February) exhibiting higher levels of fouling compared to warmer temperatures (May to July). This pattern closely aligns with observations from other full-scale water treatment plants, indicating that the treated water from the pilot plant accurately simulates the influent conditions of real plant.

Specifically, the MFI-UF_{10kDa} values were reduced by more than 85% from raw water to NF/RO feed. The microsieve achieved a reduction of ca. 45% compared with the raw water. Subsequently, the permeate from the microsieves (30 µm) was fed to the h coagulation + dissolved air flotation (DAF) + double media filtration (DMF)/triple media filtration (TMF), which contributed to 65% of the removal, resulting in MFI-UF values after rapid sand filtration (RSF) of ca. 3,100 s/L^2, which were within the range for RO feedwater achieved in other scientific literature.

Keywords: Particulate fouling; RO pretreatment

Author Index to Abstracts

Numbers denote the abstract number **(bold)** and page.