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ABSTRACTS

Inside-to-out ultrafiltration membranes for the treatment of wastewater containing powdered activated carbon

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In drinking water treatment, activated carbon under granular or powdered form is commonly used as it adsorbs and thus reduces dissolved organic compounds as well as micropollutants. The addition of activated carbon powder for wastewater applications is a process that has attracted the attention of operators following the publication of promising results and the implementation of more stringent discharge regulations. In fact, fines of powdered activated carbon must be removed before discharge of the treated wastewater into the natural environment. This study presents the results of filtration tests with inside-to-out polyethersulfone ultrafiltration membranes combined with coagulant and powdered activated carbon addition to polish wastewater before discharge. Constant measurement of water quality parameters such as spectral absorption coefficient will show a reduction of organics by powdered activated carbon prior to ultrafiltration by approximately 20%. In order to confirm an added value in terms of lowering concentrations of micropollutants, selected micropollutants have been analyzed in both the raw and filtrate water showing that a reduction of these substances can be reached. Results show that organic content is reduced by approximately 33% for DOC, 54% for COD and that an overall reduction of 80% of the micropollutants can be reached with such hybrid process. Long-term followup of the operation demonstrates that such membranes can be used as a polishing step and that the membranes do not suffer from any performance or integrity loss. On the contrary, it is shown that breakthroughs of powdered activated in elevated concentrations do not negatively impact the performance of the ultrafiltration step. The study finally presents reductions of the operational expenditures which can be achieved by discontinuous coagulant dosing.

Keywords: Micropollutants; Organic compounds; Powdered activated carbon; Ultrafiltration; Wastewater

New technology to treat leachate by low pressure reverse osmosis[#]

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The report presents results of research to develop efficient techniques to treat landfill leachate of the biggest solid wastes storage in Europe located 30 km to the east from Moscow. The leachate constitutes a very complicated chemical solution that contains over 4500 ppm of organics expressed by COD, over 20000 ppm of TDS, over 2500 ppm of ammonia. To purify water with such a complicated chemical composition requires solving of a number of scientific problems, such as: reverse osmosis treatment and reduction of TDS, COD and ammonia to meet discharge regulation values; to reach maximum recovery and utilize RO concentrate ; to ensure pretreatment of wastewater that enters RO; to provide adequate post-treatment of product water prior to discharge.

Conventional solution of this problem involves application of three stages of RO to reduce ammonia concentration to the value of 0.2–1.0 ppm. The first stage of RO requires "direct" treatment of high TDS wastewater with "seawater" membranes under high pressure value of 50–60 bar and further treatment by two stages of RO at low pressure to reduce ammonia concentration.

To expand productivity of wastewater treatment facilities following problems were solved to overcome some disadvantages of existing techniques, such as: very high capital costs of high pressure "seawater" desalination system; high power consumption; high operational costs due chemical consumption to control to fouling and scaling, membrane replacement; low recovery value limited by 30% value due to high feed water salinity and low product flow.

A new approach is described to use low pressure RO and nanofiltration membranes to dramatically decrease operational costs and increase recovery up to 90% and higher using the same total membrane area. The proposed technique is based on results of experimental investigation that evaluated organic fouling and scaling rates in membrane channels and membrane flow and rejection values as functions of recoveries at each stage of membrane treatment. Design of membrane system configuration and calculations of required membrane areas are presented as well as results of optimum recovery evaluation that correspond to minimal values of operational costs. All characteristics of the process are compared with characteristics of conventional high pressure approach. A new ways to further reduce concentrate flow and utilize it involves verification precipitation technology in and to use it in the production of building materials.

Keywords: Landfill leachate; Reverse osmosis; Nanofiltration; Increase of recovery; Concentrate utilization; Organic fouling of RO membranes; Calcium carbonate scaling; antiscalants; RO membrane cleaning; Wastewater sludge handling.

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Modification of the design of the spiral wound membrane element in order to reduce the linear pressure drop and increase its mechanical strength

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When being operated at major facilities the number of spiral wound filtrating elements in one pressure vessel may be up to 7. It should be noted that the element, which is located in that part of the vessel where the concentrate drainage is carried out, is under maximum mechanical load from all the other elements, placed before it. When the requirements for the feed water pre-treatment are complied with, the admissible pressure drop of 3.5 bar on the pressure vessel does not lead to any destruction of the protective shell of the elements. However, the practical application shows that the pre-treatment is not rather frequently paid enough attention at and the admissible drop of pressure on the vessel is considerably exceeded during operation. This leads to failures of elements. The photos demonstrating the abovementioned failures will be submitted. The solution of this problem is possible: 1) to manufacture membrane elements with a better mechanical endurance, and also 2) to decrease hydrodynamic resistance of the spacer.

In order to solve the first task, a new design of the ATD has been developed, the method of joining the filtrate outlet tube with the ATD has been changed; the fiber glass shell has been reinforced. The pictures of the previous and the actual designs are given. As the result, the mechanical endurance has increased 3 times and, as of today, it is the highest one among analog products. The data of comparative loads leading to the destruction of the protective shell are given lengthwise and widthwise, as well as the durability against cyclic loads imitating loads into the pressure vessels under long-term operation.

The change of the spacer geometry has led to a decrease of its resistance at the average rate of 1.5 times. Moreover, this effect was demonstrated on three most frequently used spacer thicknesses used in the production of the spiral wound filtrating elements. The comparative photos of the spacers demonstrate their differences leading to a decrease of the ΔP along the pressure channel of the element. Long-term comparative tests for a duration of more than one year of the elements with standard and new spacers at an industrial site showed not only a considerable decrease of the pressure drop on the installation, but also an increase of rejection by the target components.

At present, the majority of the products by "RM Nanotech" JSC are manufactured with implementation of the achieved results.

Keywords: Spiral wound filtrating elements

Brine recirculation and other high recovery SWRO process innovations utilizing isobaric energy recovery devices

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The recovery rate (recovery) of a reverse osmosis (RO) 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.

Generally speaking, higher recoveries are more CAPEX efficient while lower recoveries reduce OPEX. This relationship implies that a desalination plant design, given a host of other factors, most notably water quality and power cost, will have an optimum recovery which minimizes overall water production costs. Over time the seawater RO industry has standardized the main RO process to that of a single stage operating at recoveries between 40 and 45%.

The purpose of this paper is to show how innovation in SWRO systems configuration using isobaric energy recovery devices (and state of the art RO membranes) will perfectly allow working at high recovery rates, providing 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 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. Finally in the conclusion section, we will present the findings of this study and will open the discussion on the high recovery SWRO and their likeability of implementation by the designers in new plants.

Keywords: High recovery; Energy consumption; SWRO; Isobaric energy recovery devices

Thin film composite polyamide membranes embedded with Acacia gum: performance and antifouling properties

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Membrane desalination by reverse osmosis (RO) is the most-frequently used technology to provide freshwater from saline water in industrial scale. Thin film composite (TFC) polyamide (PA) membranes are the most commonly used RO membranes, which are prepared via interfacial polymerization (IP) technique. The introduction of different additives to the TFC membrane during preparation has been widely reported to adjust the membrane properties and performance [1,2].

In this work novel TFC PA membranes blended with 0.01–0.2 wt.% of Acacia gum (AG) have been prepared by IP technique. It was found that the hydrophilicity of PA/AG membranes increased (by up to 45%) compared with the bare PA membrane due to the amphiphilic nature of AG. In addition, it was shown that PA/AG membranes reduced surface roughness and increased chlorine resistance compared with bare PA membrane. The presence of carboxylic and amino groups in AG macromolecules has been found to increase the negative surface charge of the membrane surface. The membrane flux was also improved with PA/AG membranes as a result of the enhancement in the membrane hydrophilicity and surface charge while maintaining NaCl rejection above 96%. Due to the increase in hydrophilicity and reduction in surface roughness, a significant reduction in the fouling of PA/AG membranes was observed by the increase in the normalized flux (by 44%) when sodium alginate solution was filtered through the membrane. The RO PA/AG membranes were tested with seawater collected from the Arabian Gulf and showed higher salt rejection and lower flux decline during filtration when compared to commercial GE and Dow-Filmtech membranes. These findings indicate that AG incorporation into a PA layer can be used to enhance the properties and performance of TFC PA membranes.

Keywords: Desalination; Reverse osmosis; Thin film composite membrane; Fouling; Salt rejection

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Hybrid ceramic membranes for pretreatment of saline water

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A novel, cheap and high performance hybrid ceramic membrane incorporated with activated carbon (AC) was prepared and tested for oil removal from saline water. The ceramic membrane was prepared by incorporating high surface area powdered AC with alumina matrix. The prepared membrane formed a complex network of micro- in addition to nano-channels, which eventually improved the overall porosity of the membrane by 1.5 folds when compared with pristine ceramic (Al_2O_3) membrane. Moreover, hybrid ceramic membrane has demonstrated super hydrophilicity (contact angle near zero) when compared to pure Al_2O_3 membrane due to the increase in the pore size and porosity. The prepared Al_2O_3/AC membrane has demonstrated excellent oil removal efficiency up to 99%. Hybrid ceramic membranes, which have been tested under harsh operating conditions (such as high oil concentration in a highly saline feed solution), showed no significant change in the rejection over filtration time. The novel membranes can be used in the desalination pre-treatment applications to pretreat oil-containing brackish/sea water.

Keywords: Water; Membrane; Pretreatment; Ceramic; Alumina

A new process for boron removal in desalination plants using deep eutectic solvents

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Boron removal from aqueous streams is conducted for two purposes: either as a preventive measure, such as meeting drinking water regulations in desalination plants and protecting boron-sensitive agricultural crops, or as a productive measure, such as recovering boron as a commodity form industrial effluent streams. Solvent extraction has been studied in the past for boron extraction using different types of alcohols. However, drawbacks due to loss of solvent or solvent toxicity have been a concern.

In this work, four hydrophobic deep eutectic solvents (DES) were prepared from a combination of natural materials, menthol (Men) or thymol (Thy) as hydrogen bond acceptors (HBA) with 1-decanol (Dec) or 2-methyl-2,4-pentanediol (MPD) as hydrogen bond donors (HBD), for the extraction of boric acid from aqueous solutions. The solvents' physical and thermal properties were characterized using TGA, DSC and FTIR. The DES' critical properties were estimated using a group contribution method based on the modified Lydersen-Joback-Reid and Lee-Kesler mixing rules. Extraction

and stripping efficiencies and distribution coefficients of boron between the aqueous and DES phases, were used as performance evaluation criteria. The impact of different parameters was investigated such as pH and ion interferences. The hydrophobic DES made with MPD showed high extraction efficiency of boron (in the boric acid form), up to 90.1% and 83.2% for Thy:MPD and Men:MPD, respectively. Additionally, boron extraction efficiency was high in the 2–7 pH range. The performance was further enhanced by almost 2% and 5% for Thy:MPD and Men:MPD, respectively, when boron was extracted from a synthetic brine solution. The extraction mechanism was better understood when FTIR spectra were recorded before and after extraction of boric acid. The extraction was due to the complexation between MPD in the DES and boric acid. It was possible to stabilize the highly water-soluble diol (MPD) within the organic DES phase, thus enabling its utilization in the extraction of boric acid from an aqueous medium.

The new solvents offer advantages over conventional organic solvents or ionic liquids. These include: high extraction and stripping efficiencies, stabilizing water–soluble components like MPD, enabling its use in water treatment applications, and the incorporation of green and renewable extractant components, such as menthol and thymol.

Keywords: Hydrophobic deep eutectic solvents; Boron; Extraction; Green solvents; Menthol; 2-methyl-2,4-pentanediol; Thymol

Diversifying water supply to increase resilience: The Cape Town experience

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With the impact of climate change on changing weather patterns, the risk of reliance on historic rainfall records for water resource planning has increased exponentially. Regions such as the Western Cape in South Africa reliant solely on rainfed dams are especially vulnerable. While dam levels in the area that serves Cape Town have recovered substantially in the winters of 2018 and 2019, it cannot be concluded with any certainty that the drought has broken, given that rainfall yields have remained far below the long term average. The relatively healthy dam levels are a direct result of reduced demand rather than exceptional rainfall.

The Cape Town municipality runs a professional water utility, which operates as part of the regional water supply system which is overseen by national government. Resource planning matches supply and demand, forecasting 20 years ahead, based on historical supply and demand patterns. At the height of the recent devastating drought which started in 2015, the administration embarked on an aggressive programme to diversify water supply sources. The emergency programme evolved from an unaffordable and impractical programme to a realistic long term augmentation strategy, to provide 300 MLD additional water on the supply side by 2030.

At the height of the drought, international offers of assistance flooded in, but most of these promised unlikely silver bullets at astronomical cost. Many countries cannot afford to be at the bleeding edge of technology, and while unproved tech may in some instances pay off, governments with developing economies will be ill advised to take the risk. It is thus critical to the water security of the most vulnerable, and often, the least prosperous nations to benefit from proven and affordable alternative water resources such as deep aquifer extraction and desalination.

Cost and timing are major influencers in an augmentation programme, together with practical considerations and skill availability. For example, desalination is energy intensive, and apart from structural issues in provision of electricity, South Africa is today still very much reliant on coal, and has a deficit of supply resulting in widespread load-shedding (which has been the norm for nearly a decade). Secure and efficient electricity supply is a pre-requisite for reliable water and sanitation services, and thus adds to the complexity of augmentation.

It is now recognised that water security requires supply sources not solely reliant on rainfall, such as desalination. Responsible implementation of efficient plants require considerable lead times to ensure environmental sustainability.

Through its inclusive water strategy, Cape Town has embarked on an ambitious, and measured programmeto provide increased resilience to future droughts.

Keywords: Diversifying; Augmentation; Desalination; Resilience; Cape Town; Water supply; Demand management

New generation of dissolved air floatation: combination of reliability and boosted performance

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Climate change make water stress more and more significant around the world and leads to consider seawater reverse osmosis desalination as a key market in the next future. With population growth, water demand explodes whereas available spaces are reduced and energy cost increases. To foresee population's needs by producing enough water at an affordable price within an optimized layout, installations are becoming bigger and packed.

Desalination market has been barely so challenging and in SUEZ, we consider this challenge as an opportunity to continuously innovate.

One of our innovation axes is related to the pre-treatment step since a significant part of the capital investment of a SWRO plant lies in these processes. One of them, dissolved air floatation (DAF) has become a must in the region where algae blooms are likely to occur.

To upgrade our DAF technology (dissolved air flotation), different ways are explored:

- Merger of the DAF and filtration to take advantages of both processes at high velocity by guarantying the protection of the RO membranes while saving footprint and offering a robust pre-treatment system with low energy consumption.
- A new generation of DAF. The aim is (1) to improve floated water quality without decreasing the floatation velocity (up to 50 m/h) and (2) to optimize the filtration process in terms of energy consumption and reagents. This new generation of DAF is foreseen to be an efficient 1st step pre-treatment upstream a high rate process (filtration/ultrafiltration).

This paper will present the results obtained on a semi-industrial unit located in the MENA region and able to test both innovations. These results will be compared with a full-scale process line including DAF and filtration.

The paper will address the following topics:

- High velocity purpose: What are the limits? Which height of media is really needed?
- Related water quality: Colloidal particles removal? Assimilated organic carbon and biomass removal?
- Savings evaluation: CAPEX, OPEX, Availability, Footprint

Best practices regarding these new generations of DAF will then be shared to provide the most efficient process for the future of the SWRO desalination plants.

Keywords: SWRO; Innovative pre-treatment; Dissolved air floatation; High velocity

Vasilicos Desalination Plant in Cyprus

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The Vasilicos Desalination Plant is situated in the south part of Cyprus 30 km away from the second biggest city of Cyprus Limassol. The plant is designed and built to produce 60,000 m^3/d of potable water supplying 25–30% of the households in Cyprus. The plant consists of the main following steps:

- Pretreatment
- High pressure pumping
- Seawater reverse osmosis in 5 stages
- Energy recovery system
- Boron removal system
- Post treatment (mineralization stage)
- Product pumping station

Additionally there is a cleaning and flushin g system. The desalination plant is part of a power station and therefore seawater is coming from the C. W. pump header consists of 6 pumps feeding also the cooling system for the condenser with sea water.

Keywords: Reverse osmosis; Vasilicos Cyprus; Boron removal

Performance analysis of a full-scale SWRO desalination plant

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The RO technology is the most extended for seawater desalination purposes. The operating data in long-term of full-scale plants is key to analyse its performance under real conditions. This seawater reverse osmosis (SWRO) desalination plant had a production capacity of 5,000 m^3/d for irrigation purposes. The operating data such as conductivities, flows and pressures were collected for around 27,000 h from 2001 to 2004. The plant had sand and cartridge filters without chemical dosing in the pre-treatment stage, a RO system with one stage, 56 pressure vessels, 7 RO membrane elements per pressure vessel and Pelton turbine as energy recovery device. The operating data allowed to calculate the average water and salt permeability coefficients (A and B) of the membrane as well as the specific energy consumption (SEC) along the operating period. The calculation of the average A in long-term operation allowed to fit the parameters of three different models used to predict the mentioned parameter. The results showed a 30% decrease of A, parameter B increase around 70%. The SEC was between 3.75 and 4.25 kWh/m^3. The three models fitted quite well to the experimental data with standard deviations between 0.0011 and 0.0015.

Keywords: Seawater; Reverse osmosis; Desalination; Operating data; Long-term

Water production by RO for paint manufacturing in the automotive industry[#]

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Reverse osmosis is the most extended technology in seawater and brackish water desalination. This technology is used in many applications, one of them the manufacture of automotive paints. In this work, two years of operation of a brackish water reverse osmosis (BWRO) desalination plant are analyzed. The raw water intake was a groundwater well. The desalination plant had a sand and cartridge filters with antiscalant dosing as pre-treatment. The RO system had two stages with 40 pressure vessels (PV) in the first stage and 20 in the second stage with 6 BWRO elements per PV. The feed water conductivity was between 680 and 2,100 μS/cm, the pH in the feed between 6,05 and 7,55. The feed pressure increase from 11 to 28 bars due to membrane fouling along the operating period. The RO system had a recovery around 75% with a production of 7,200 m^3/d approximately. The performance of the plant along these years was evaluated through the calculation of the characteristic parameters of the membrane, such as the average ionic and water permeability coefficients.

Keywords: Brackish water; Reverse osmosis; Desalination plants; Long-term; Operating data

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Low-cost continuous measurement system to learn the relationship between the electrical conductivity "EC" and the temperature "T" in brackish waters[#]

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This work proposes an inexpensive experimental equipment to learn the relationship between the electrical conductivity EC of brackish water and its temperate *T*, in which is used an embedded system (Arduino nano). This design is defined in order to help engineering students and professionals to learn and understand water quality parameters. The design is based on flexible and open-source software and hardware, this is an important features, because they must be capable to modify this design and to obtain experimental results.

Keywords: Electrical conductivity; Reverse osmosis; Water quality; Embedded systems

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Proposal to determine the carbon and ecological footprint of seawater reverse osmosis desalination plants considering the energy mix. Case of study for the Canary Islands[#]

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This study focuses on seawater reverse osmosis desalination plants in the Canary Islands. The objective is to provide proposals to optimize the operation of these plants with impact on energy consumption, water quality, costs and emissions, in order to make this process more efficient and sustainable. Ratios of carbon footprint per m^3 and type of inhabitant or per m^3 and type of productive activity per island are needed for the decision making regarding the energy mix including or not renewable energy. It is not the same to produce water in the different Canary Islands and it depends on the hourly discrimination of the energy costs too. Due to this, it appears the ecological footprint and the necessary territory to satisfy it.

Keywords: Seawater; Reverse osmosis; Desalination plants; Carbon footprint; Ecological footprint; Renewable energy; Energy mix

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Novel spacer designs and spacer surface chemistry modification for reduced scaling in MD

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Membrane distillation (MD), a third-generation desalination technology resistant to increasing feed salt concentration, has potential in niche applications such as brine management. However, low flux and fouling are two major issues that impede the widescale application and commercialization of MD. Feed channel spacers are commonly utilized in different membrane application technologies to abate polarization effects and fouling. However, studies have shown that the use of spacers creates dead zones building a conducive environment for foulant deposition. In this study, we investigated the performance of 3D printed spacer designs in MD based on mathematically modeled triply periodic minimal surfaces (TPMS) to achieve enhanced flux performance and reduced fouling. The TPMS designs are minimal surfaces with an interconnected, maze-like structure that are perfectly curved at every point, with the potential to minimize scaling and enhance flux without a pressure drop trade-off. In this study, five different TPMS feed spacer designs (i.e. CLP, Gyroid, tCLP, P and S shapes) were evaluated in comparison with the conventional mesh spacer (CS) under increasing feed salt concentration. Scaling control and pressure drop performance were specifically evaluated with calcium sulfate as model scalant. When treating synthetic brine over increasing feed concentration between 75,000 ppm to 100,000 ppm, the best performing TPMS spacer, tCLP, not only had higher initial flux (80 LMH) compared to the CS (50 LMH) but also exhibited better flux retention. Under calcium sulfate scaling, the fouled membranes with TPMS spacers had a 46% lower scalant deposition than CS. With CS, the scalant deposition completely masked the membrane surface. However, with TPMS spacers, the scalant deposition was only limited to the spacer contact regions. The reverse trend was observed for the scalant deposition on the spacers wherein the highest deposition was observed on tCLP design while CS had the least deposition. Furthermore, the enhanced flux with the tCLP design was at the expense of increased pressure drop (0.52 bar vs. 0.04 bar) than CS. To abate high-pressure drop with the tCLP design, a hybrid spacer design dubbed Gyr-tCLP combining tCLP and Gyroid was evaluated. It exhibited flux performance on par with tCLP at reduced channel pressure drop. To overcome the increased scalant deposition on the TPMS spacer design surface coatings based on graphene and fluorinated silica (FS) were investigated. The FS coating imparted the highest surface hydrophobicity with an increase in water contact angle measurements from 84.9 to 140.1 degrees. This was accompanied by lowered surface free energy (from 22.1 mJ/m^2 for uncoated sample to 1.1 mJ/m^2 for FS coated sample) with a specific reduction in polar component of surface free energy. The use of FS coated spacer in MD with calcium sulfate as the feed solution not only reduced the scalant deposition on the spacer by 74% but also reduced the scalant deposition on the membrane by 60%. Overall, this study sheds light on possibilities to custom design MD feed spacer based on TPMS architectures with the advantages of enhanced flux, moderate pressure drop and scaling control in comparison with the conventional mesh spacer.

Keywords: Spacers; Membrane distillation; Triply periodic minimal surfaces; Calcium sulfate; Fluorinated silica

The cost of environmental protection in the desalination plants of Alicante

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The Environmental Impact Statement (EIS) of the desalination plants in Alicante establishes a system of seawater by-passing to dilute the brine and to protect *Posidonia oceanica* meadows. The aim of this paper is to quantify the energy consumption that involves the dilution of the brine to meet the environmental requirements from 2012 to 2018. During the research period, the operation of the plant has been variable, depending of supply needs. The results indicate that the energy consumption of the dilution system has fluctuated between 2.135.315 kWh consumed in the year 2012 and 685,988 kwh for the year 2013, with an average consumption for the selected period of 1.205.952 kWh. The energy cost for the year 2012 was € 179.556,43while for 2,013 it was €60.786,91, with an average annual cost of €91.690,33. This variability is due to the fact that MCT has several sources of water supply and optimizes the needs according to the cost of the average price of all available resources. The cost of dilution also has a seasonal component due to the greater need for water in summer but also to the variability of oceanographic conditions throughout the year. Although the dilution

supposes an additional cost of the water produced by the desalination plants, it has allowed fulfilling the requirements established in the EID and protecting the seagrass of *Posidonia oceanica* from the desalination plants discharge.

Keywords: Brine; Dilution; Energy cost

Energy analysis of a seawater reverse osmosis (SWRO) desalination system for small marine vessels[#]

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Desalination in the marine world has always been one of the most used resources for obtaining quality water. Its biggest disadvantage is energy consumption, which has led to a large number of studies to investigate how to reduce it. This work presents the results obtained from analysing the energy consumption of a small-scale SWRO desalination plant and its application in small marine vessels. For this, different parameters have been considered: flow, pressure and quality of water demanded in the vessel. In the experimental study, the optimal pressure points applied in the system are estimated to meet the needs demanded with the lowest possible energy consumption.

Keywords: Desalination; Reverse osmosis; Energy consumption

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Mitigation of climate change through the analysis and reduction of greenhouse gases in desalination plants[#]

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This research aims at estimating the contribution of desalination plants to greenhouse gases (GHG) emissions and, consequently, to climate change. The case study will be in Gran Canaria island. This island has been selected due to the serious imbalance between water resources and water consumption, what makes desalination technology key in the island. Approximately 70% of its water supply comes from desalination plants, mostly reverse osmosis (RO) plants. The specific energy consumption of the existing RO desalination plants in the island is around 4 kWh/m^3 in average, what means that ca. 11% of the energy consumption of the islands is devoted to desaliantion. The Arucas-Moya Desalination plant, with 15,000 m^3/d capacity and 19 GWh of energy consumption per year, has been selected as case study for the analysis. An evaluation of the different methodologies and protocols available to estimate the carbon footprint in water processes was carried out (O_2C, WEST, WEST-Web, Tampa Bay Water and UK Enviroment Agency Tool). Among them, the O_2C tool (developed by SUEZ company) was selected because it includes a section related to reverse osmosis processes. This tool takes into account all the stages included in the life cycle assessment. Results estimate a carbon footprint of 25,468 tonnes of CO_2 equivalent per year. It has to be highlighted that during the construction phase the footprint reaches the

highest values. The study concludes with the identification of different technologies capable of mitigating the GHG emissions, achieving a carbon-neutral model plant and mitigating the climate change in these kind of desalination plants.

Keywords: Desalination; Greenhouse gas emissions; Reverse osmosis; Climate change

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Enzymatic-chemical cleaner formulation for cleaning organic and biological foulants

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In the cases where organic and biological foulants are the main cause for performance loss in membrane systems, high pH chemical cleaners are commonly used to restore system performance. High pH can however cause membrane damage from repeated use, especially if the pH is outside the recommended membrane safe range. This paper looks at a unique near-neutral pH chemical cleaner that uses enzymes to boost its cleaning strength. This universal cleaner can be used on reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF) and microfiltration (MF) membranes. A series of lab, full-scale and pilot tests were performed on membranes from three different sites representing diverse feed waters and foulant types to compare performance recoveries after cleanings with enzyme-chemical blend. A performance recovery comparison between enzyme-chemical cleaner and generic high pH chemical cleaner will be also be reported. Furthermore, this study will show how enzyme-chemical cleaner delayed the onset of fouling and decreased the cleaning frequency requirements.

Keywords: Enzyme cleaners; Neutral pH; Specialty cleaners; Biological fouling; Organic fouling

Proposal for a simple method for calculating biogas production in natural treatment systems for livestock wastewater

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This paper proposes a simple method for estimating the production of biogas (CH_4–CO_2) obtained from the treatment of wastewater from livestock farms in anaerobic digestion chambers of natural treatment systems. For this, the use of a mathematical model based on two biological reactions of anaerobic decomposition is proposed; one for the process of acetogenesis, considering Monod growth, and another for methanogenesis, considering Haldene growth. In addition, temperature *T* and pH are considered as factors affecting biological growth in anaerobic digesters.

Keywords: Wastewater, Biogas production; Anaerobic digestion modeling; Natural treatment systems

Evaluation of the combustion system, in a laboratory scale, for the energy use of the solid from activated sludge treatments of urban wastewater

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The combustion of solid fuel has a complexity different to the liquid and gaseous fuels. It is of interest to know the possibilities of recovery of numerous urban solid waste and the different configurations which affect to the combustion process.

In order to take an advantage of the energy use of the urban solid waste from activated sludge waste water plants in particular, a pilot system has been implemented in a laboratory scale, to evaluate the main variables affecting to the combustion.

The objective of this article is to show the experiences and to define these variables which affect to the correct combustion for a better evaluation of the solid from activated sludge treatments of urban wastewater.

Keywords: Activated sludge; Valorization; Solid; Combustion

Estimation of the combustion potential of the solid from livestock wastewater with natural treatment systems

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The experiences of waste water treatment realized in Gran Canaria have demonstrated their suitability in their application to the size and operation of the common livestock farms on the island. Waste water from these treatments, solid and liquid fraction, have the potential for reuse and evaluation in many ways. One of the most commonly used assessments is the combustion of solid waste and its energy use in the processes and needs of the farm. The variability of the solid from anaerobic processes for a correct accurate assessment of an estimate of the combustion potential of that solid. The objective of this article is the calculation of this potential as well as the effect of the configuration, and disposition of the material in its combustion process.

Keywords: Natural systems; Valorization; Solid; Combustion

Monitoring of membrane fouling by the zeta potential

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The tendency of a membrane towards fouling is influenced by the properties of the membrane, the composition of the feed solution, and the filtration conditions. Among the properties of a membrane, parameters which describe the inter-

action of membranes with their environment are of major importance for studies of membrane fouling. The membrane surface charge gives direct information on electrostatic interactions between the membrane surface and compounds in the feed solution, which is one cause of membrane fouling. The surface charge of a membrane can also be tuned to favor or suppress certain interactions with components in the feed solution, directly influencing membrane fouling [1].

Zeta potential analysis reveals the changes on the membrane surface charge by fouling during the filtration process. In this work, the zeta potential of different new and fouled membranes was determined from streaming potential measurements. For the analysis, the membrane sample was arranged to create a capillary flow channel between two measuring electrodes. An induced flow of electrolyte solution shears off the charge-compensating ions and gives rise to a streaming potential signal, which is transferred into a zeta potential result.

As one example in this work, the zeta potential of thin-film composite (TFC) polyamide membranes for nanofiltration and reverse osmosis was studied at different pH value. Such membranes typically show a highly negative zeta potential at pH 6-8. After the filtration process, the decrease in the negative zeta potential indicates the deposition of a foulant layer on the membrane surface. Upon evaluating the pH dependence of zeta potential, further insights for membrane surface modification, ageing, fouling and cleaning can be gained. The possibility to study the zeta potential at different concentrations of the contaminant in the feed solution allows to systematically analyze the early stages in membrane fouling [2]. Surface charge analysis can also be used to optimize membrane cleaning by evaluating the effects of different cleaning agents on the membrane surface [3]. It thus has the potential to contribute to all efforts to optimize the performance of a membrane.

Keywords: Nanofiltration; Forward osmosis; Zeta potential; Membrane fouling

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The use of natural minerals for the replenishment of magnesium into drinking water following desalination

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In the fourth edition of their Guidelines for Drinking Water Quality, the World Health Organization recommended that where drinking water supplies were being supplemented with, or replaced by demineralized or desalinated water, remineralization processes should be implemented that replenishes the water with both calcium and magnesium salts to levels similar to those found in the original source. Despite these recommendations, the replenishment of magnesium salts is rarely performed, if at all. One of the main obstacles to magnesium replenishment is the relative cost of current methods, which significantly increases the total cost to desalinate and stabilize the water. This tends to position this subject as a question of luxury rather than necessity. Magnesium however is an essential mineral for the human body, being utilized by every organ and its deficiency has been strongly linked to a range of health issues, particularly cardiovascular disease. Furthermore, the World Health organization has recognized the importance of drinking water as a significant source for minerals, whether during its consumption as beverages, or consumed as food (inherent and/or added during preparation). Whilst in some locations desalination is used to augment conventional water supplies to deal with situations of drought or increasing populations, in other locations desalination has become the mainstay for water supply and residents rely on this as the main process to provide potable water. A change therefore in the composition of the water due to supply from desalination as opposed to conventional sources, can have an impact on the overall intake of minerals for human health. Desalination is crucial technology for a sustainable future, to deal with ever increasing populations and global water shortages. As such, it is important to maintain a positive public perception of the process and develop processes that can cost effectively achieve the goals outlined by the World Health Organization. In the last months, an investigation into alternative methods for magnesium replenishment has been performed, with a focus on the application of natural magnesium-based minerals as a method to reduce the operational costs compared to current techniques. To overcome the drawbacks of slow dissolution kinetics of natural minerals, the products are supplied to the process in a micronized form. This results in an increase in the total available surface area available for reaction whilst being dissolved in a proprietary Membrane Calcite Reactor (MCR). To allow the formation of high concentrations of

dissolved magnesium in a side stream, and decrease the required investment, various acids are dosed into the reactor. A range of different combinations of acids and magnesium-based minerals have been tested to quantify their respective advantages and drawbacks, as well as their respective applicability to both Greenfields and Brownfields sites alike.

Keywords: Remineralization; Magnesium; Post-treatment; Desalination; Mineral

A comprehensive methodological approach to develop and compare integrated treatment processes for the valorisation of wastewater effluents

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The industrial production is continuously growing because of the increasing demand and this leads to heavy consumption of raw materials. To achieve a more sustainable development, it is fundamental to decouple these phenomena by introducing circular economy models. These would allow for reducing the consumption of energy and materials and for recycling pre-treated effluents. In this context, we developed a novel multi-step method to devise and analyze integrated processes (chains) for the treatment of specific industrial effluents. The method is given by four steps: (i) implementation of techno-economic models for pre-treatment and concentration technologies; (ii) definition of suitable inputs and parameters and of representative outputs for each model; (iii) development of integrated platforms simulating the treatment chains by interconnecting the models of single technologies; (iv) definition of global outputs informative about the technical, economic and environmental performances of the entire chain.

The design of the treatment chains depends on the main target product that has to be produced. However, in general, these present the same pattern, given by a pre-treatment and a concentration step. The pre-treatment step is designed to remove pollutants through membrane filtration units, as nanofiltration, and to maximize the production of valuable by-products, like $Mg(OH)_2$, in crystallizers. The solution produced by the pre-treatment step is typically a NaCl-rich water solution and it is fed to the concentration step. This is composed by concentration technologies (as multi effect distillation or reverse osmosis) and an end-crystallizer, if the target product is high purity NaCl.

The economic analysis is performed by calculating a global levelized cost of the main product of the chain, for example a target water solution to be recycled or NaCl crystals. Thus, the economic feasibility is assessed by comparing the levelized cost of the product with its current market value. Moreover, the definition of global outputs, such as total energy requirements, levelized cost of the main product and specific CO_2 emissions, allows for comparing different chains and for identifying the most economically feasible and environmentally friendly solution.

The proposed method is flexible and able to simulate treatment chains for different wastewater effluents. In this work, we present the results obtained by applying the method to three case studies: water softening, coal mining and textile industries. In the case of water softening and textile industry, we devised treatment strategies to purify the wastewater and to recover a target NaCl-water solution reusable as a reactant. Conversely, for the coal mine effluent, the proposed treatment chains were designed to produce NaCl crystals competitive with the market. For each case, we identified the most economically feasible and the least energy intensive chain among various alternatives. With the most feasible systems, we found levelized costs 40–50% lower than the corresponding market values and we observed that lower CO_2 emissions were produced for recycling the reactant than for producing fresh one.

Overall, this work shows that the developed method can be used as a decision support tool to select the most suitable circular strategies for different industrial sectors.

Keywords: Industrial wastewater; Circular economy; Treatment chain; CO_2 emissions; Recycling; Membrane processes

Assessing the use of photovoltaic energy at a seawater reverse osmosis desalination plant: a case study of Porto Santo Desalination Plant (Madeira – Portugal)[#]

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Global climate change is a subject that involve, not only energy sector or transport sector, but also water sector due to energy consumption in its process. Therefore, efforts in the reduction of energy consumption based on fossil fuels must be performed in the water sector. In this sense, renewable energy, such as photovoltaic energy, could be associated with seawater reverse osmosis (SWRO) desalination plants in order to reduction of its energy consumption from fossil fuels. On the other hand, photovoltaic generation represents an option that could cause a reduction of production cost of desalinated water from these plants. Besides, battery energy storage system (BESS) can contribute to a more integration of renewable energies for its use.

In this paper a technical and economic assessment of photovoltaic generation is carry out in order to supply energy to a SWRO desalination plant. An associated BESS based on Lithium-ion batteries was also studied. SWRO desalination plant of Porto Santo Island (Madera, Portugal) was considered as a study case in this paper. Desalination capacity of this Porto Santo plant is 6800 m^3/d and its annual energy consumption is about 4833.82 MWh.

Several values of rated power of the photovoltaic plant and BESS capacity were analyzed. Photovoltaic energy generation, BESS energy flow or total energy balance were obtained using HOMER Pro® software. Used energy data is hourly.

Economic evaluation considers a period of 25 year and it takes into account parameters such as internal rate of return (IRR), net present value (NPV), payback or levelized cost of energy (LCoE).

Besides, sensitivity analysis was made including variation of capital expenditure (CAPEX), photovoltaic generation decrease due to photovoltaic modules degradation and variation of electricity cost from utility grid.

Results suggest that photovoltaic generation causes a lower LCoE and a reduction of energy consumption from utility grid based on fossil fuels. Therefore, a reduction of desalinated water cost and lower greenhouse gas emission could be achieved. Result show a range for rated power of the photovoltaic plant for this study case takes into account IRR, NPV and LCoE. This range is from 450 kW to 650 kW and it shows higher values of IRR. Results also indicate higher values of LCoE when lithium-ion BESS is considered. It is due to energy consumption profile of the SWRO desalination plant, contracted electricity supply rate and current cost of lithium-ion BEES.

Keywords: Desalination; Seawater reverse osmosis; Photovoltaic generation; cost; Lithium-ion battery energy storage system

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Membrane cleaning procedures: performance of commodities vs. formulated cleaners

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Over the last two decades there have been important breakthroughs in new technology for the recovery of energy, new materials and different morphologies for reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF) and microfiltration (MF) membranes. These efforts are mainly focused on reducing costs and improving energy efficiency.

The presence of fouling on the surface of a membrane has an irrefutable effect on energy consumption and plant efficiency. Therefore, one of the main goals for water treatment with membranes is to avoid fouling. However, eventually

all membranes suffer from some fouling to the point where cleaning procedures must be applied to restore membrane performance. It is critical this cleaning is effective and does not cause damage to the membranes being cleaned.

Very often, commodities are the initial choice when a cleaning procedure must be applied this choice being price driven rather than performance or research driven. There are a wide range of formulated products available but very little data comparing performance against commodities.

One of the best ways to choose the most effective cleaning product is to have an accurate identification of fouling through autopsy and to make cleaning tests with different cleaners to optimize the protocol.

The results obtained during a significant number of autopsies performed on both reverse osmosis and ultrafiltration membranes, revealed the common composite nature of fouling [1, 2]. Therefore, when considering a cleaning procedure, it is very important to use cleaners that are versatile and effective enough to ensure the greatest removal of all the fouling components from the membrane surface.

This study includes the results obtained from cleaning tests carried out during autopsies of different membranes and different foulants. The performance of both commodities and formulated cleaners are compared and contrasted.

Keywords: Fouling; Cleaner; Commodities; Membrane autopsy

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The role of alternative water resources for agricultural irrigation in the Canary Islands

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Alternative Water Resources (AWR), namely desalinated and reclaimed waters, have emerged as advanced technological developments for agricultural irrigation in regions facing water scarcity. The Canary Islands Archipelago (Spain) is a singular territory with approximately fifty years of desalination experience and more than thirty years with reuse water initiatives for irrigation. These islands, situated in the middle of the Atlantic Ocean, have the highest density of desalination plants per square kilometer in the world. With more than 730.000 m³/d of installed capacity (almost 2% of the global desalination capacity), more than 70% of the water for human consumption in the Islands comes from desalination plants and 35% of the agricultural areas are irrigated with this water resource. There is a great variety of plant sizes with different design conditions and locations, and a wide diversity of technologies is implemented. The analysis of the use of Alternative Water Resources in the Canary Islands is a key worldwide place for testing and experimentation in the field of desalination for irrigation.

Two case studies were developed in two Canarian islands facing completely divergent situations in regards to the use of AWR for agricultural irrigation. The first case study was the area of the Southeast of Gran Canaria, a region with agricultural diversity covering coastal intensive export-based crops with a long trajectory in using a variety of fresh and alternative water resources. The second case study focused on an on-going implementation of reclaimed water for agriculture in the Valle Guerra region (on the island of Tenerife).

The conducted research of both case studies was part of the Horizon 2020 project MAGICâ€"Moving Towards Adaptive Governance in Complexity: Informing Nexus Security coordinated by the University Autonoma de Barcelona (UAB) in which the ITC (Instituto Tecnologico de Canarias) was a partner. The MAGIC Project aimed precisely at integrating qualitative and quantitative styles of analysis to contrast the narratives with a reasoning of the socio-ecosystems. Through an integrated methodology, the following challenges and questions were addressed: what role do these water resources play in the recovery or reduction of pressures on natural sources? Is it plausible and desirable to implement these technologies if we take into account future scenarios of climate change, energy crisis or hardening of export conditions? What role do alternative waters play in agricultural development if we take into account current limitations such as price, quality, emerging pollutants and impacts on the soil and the environment?

While desalination can certainly be an essential option for resource security purposes in isolated and island areas, an effective assessment of the performance of desalination in relation to nexus security required a comprehensive understanding of the nature of the entanglement over water, energy, and food flows.

Following the participatory strategy (promoted by the European Water Framework Directive), farmers were surveyed in both areas to understand how they use AWR to irrigate their crops. Interesting results were obtained, like the strategy of combining desalinated seawater with other water resources, such as groundwater and/or reclaimed water, to guarantee water and food security in the island's territory. These results allowed the team of the ITC (together with the UAB and JRC) to extract different narratives behind AWR, to find out whether water problems are being sorted out or if they are actually worsened with strategies like desalination or industrial/urban treated wastewater reuse.

Keywords: The Canary Islands; Water-Energy-Food nexus; Alternative water resources for agricultural irrigation

SWRO O&M: Partial replacement with TFN membranes in Maspalomas I SWRO

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Seawater reverse osmosis (SWRO) operation and maintenance (O&M) always involves different challenges which determines the successful system performance along the time. Selection of the operational parameters, chemical dosages and cleaning-in-place frequency can drastically affect the resulting permeate quality and operational costs. Membrane partial replacement is also one of the more complicated tasks. Making the decision about which membranes, position and how many elements should be replaced requires a deeper evaluation of the operational data and estimation based normally in the potential specs of the new elements to be installed. This process can be even more challenging in the membranes installed are different models and from different brands.

In 2019, the membranes installed in the SWRO plant Maspalomas I needed to be partially replaced in order to improve permeate water quality before getting involved into the months with warmer feed water. The major issue the site was struggling with was boron concentration in the permeate side. Boron removal with reverse osmosis membranes is typically more challenging than other species due to the lower rejection RO membranes can achieve against it. TFN membranes, which have been proved to perform very successful with boron removal, were selected to perform the partial replacement.

LG Chem Projection Software Q+ has a unique feature which allows the user to create membrane models. This tool can be used to define the specifications of the existing membrane elements installed in an existing train in operation. This would allow predicting and projecting system performance with partial replacement with a satisfactory accuracy. The designer can identify the most suitable new membranes model, minimum number of membranes to be replaced and best positions to be replaced in order to comply with the current plant limitations, such as maximum feed pressure, and permeate water quality requirements.

This case study, based on the field data obtained from Maspalomas I, will guide through the different steps required to undertake this task and it will show the comparison of the field data with the projected values predicted during the process to verify its accuracy.

Keywords: SWRO; Partial replacement; Boron removal

Case study: Reduction in energy consumption with second generation TFN membranes in La Caleta SWRO (Canary Islands, Spain)#

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Nowadays, seawater desalination with reverse osmosis (SWRO) is one the most efficient techniques to provide safe and reliable water to populations around the globe. However, in SWRO, energy consumption is still the main handicap being able to reach above thirty percent of the total cost of the project.

In order to improve energy savings in SWRO, Thin-Film Nanocomposite membranes could allow reaching competitive permeability with very high salt rejection performance. The operation with membrane elements which offer superior permeate water quality allows using higher permeability elements with potential energy savings in SWRO operation.

Canary Islands is a Spanish archipelago located in the Atlantic Ocean just across of the Sahara desert in Morocco. This region has been one of the main references in SWRO in the world with the first SWRO constructed in 1964 and currently with over 300 plants within its 7 islands. La Caleta is a Seawater Reverse Osmosis plant located in Adeje, Tenerife, one of the two major islands in the archipelago. The plant had an initial capacity of 11,000 m^3/d. In 2019, one full train with a total capacity of 5,000 m^3/d was replaced with TFN membranes to improve the operation in both, permeate quality and operational conditions.

In addition, after few months of operation, a pilot study to test a new TFN membrane model with even higher rejection was started at La Caleta SWRO. The aim of this study is to verify membrane performance in order to compare new evolved TFN elements with existing ones installed and assess the potential advantages in terms of energy savings in plant operation.

This study will show current TFN membrane installed performance and it will compare it with the new TFN model installed for the pilot study in terms of permeate quality using collected filed data. In addition, an energy comparison evaluation will be developed to show the potential advantages that the new TFN generation membranes could deliver from an energy consumption and operational cost perspective.

Keywords: SWRO; Energy; TFN

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In situ microstructural analysis of biofilm developed in filtration systems

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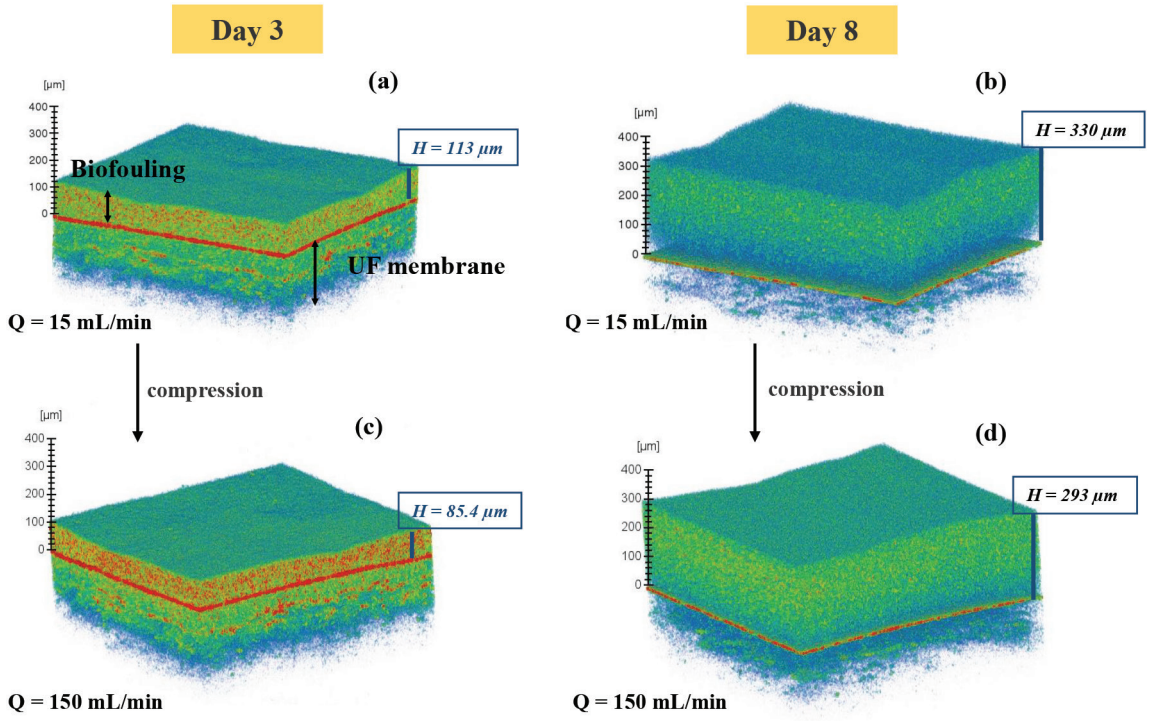
Biofouling is recognized as one of the major cause of membrane performance decline in filtration modules. As the biofilm evolved on membrane surface, its intrinsic structure significantly undergoes alterations depending on the fluid hydrodynamic conditions and feed quality. In the present study, Optical Coherence Tomography scans (OCT) were utilized with an advanced mathematical tool to characterize the structural and mechanical properties of biofilm evolving on UF membrane surface in a dead-end mode. At various stages of biofilm growth (3–8 d), compression and decompression processes were carried out by increasing or decreasing the feed flow rates (Q) over the biofilm in a range of 15–150 mL/min. The modification of biocake morphology against the compression/decompression processes was in-situ monitored by high resolution 3-dimensional OCT scans taken at various stages of the filtration (Fig. 1). A mathematical framework was developed to measure structural and mechanical parameters of the growing biofilm which include biomass thickness, microporosity, micropermeability and strain rates. The internal biomass porosity tends to increase with the maturation of the biofilm. The calculated values were raised from 0.214 at day 3 to 0.482 day 8 of biofilm development at the same flow rate (Q = 15 mL/min). However, the total permeability of biofilm/membrane (initially calculated of 4.540×10^{-14} m^2 at day 3) showed a dramatic decrease to reach 5.190×10^{-15} m^2 at day 8 for the same feed flow rate. This decrease of perme-

ability with the growth of biofilm results in hampering the diffusion of feed solution thereby decreasing the permeate flux production over the course of filtration (from 33.6 LMH at day 3 to 8.2 LMH at day 8). Furthermore, biomass thickness and stress/strain behaviors against compression/decompression processes revealed the deviation of biomaterial nature from elastic to viscoelastic material as the biofilm matures from day 3 to day 8.

Keywords: Filtration processes; Biofouling; Mechanical and structural analysis; OCT



3D-visualization of biomass cake developed on UF membrane surface at Q = 15 mL/min (a, b) and under compression at Q = 150 mL/min (c, d) at various stages of biofilm growth (days 3 and 8).

Influence of polyamide-layer surface morphology on reverse osmosis membrane scaling – A visualization case study on $CaCO_3$ scaling

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Irreversible membrane fouling is a significant problem in reverse osmosis (RO) plants operating at high calcium concentrations. The polyamide (PA) layer microstructure on RO membranes is thought of as one of the substantial factors promoting this irreversibility. These convoluted microstructures might trap salt crystals, which would be difficult to rinse during cleaning cycles. So, understanding the scaling dynamics on the RO membrane PA-layer is crucial for improved membrane performance and operation cost. This work seeks to understand the influence of PA-layer microstructures on $CaCO_3$ scaling using state-of-the-art visualization techniques from millimeter to nanometer scales. High flux brackish water RO membrane coupons were fouled in a custom-built RO crossflow system with a 250 ppm $CaCO_3$ feedwater. To capture the onset of scaling, the filtration experiments were performed at 0.05 m/s crossflow velocity and 200 psi transmembrane pressure for 2 h. The evolution of the scale deposition was monitored using an in-situ imaging system at mm-scale (Fig. 1). Samples were collected from the scaled regions of the membrane and analyzed under electron microscopy at μm and nm scales. The scanning electron microscopy (SEM) images confirmed the presence of $CaCO_3$ and NaCl crystals on the membrane surface (Fig. 2). The transmission electron microscopy (TEM) images confirmed

presence of simple and complex folds of the compressed PA-layer nodules, similar to previous studies. These folds are possibly the outcome of the swelling and stretching of the crosslinked PA-layer during the membrane wetting and pre-compaction period and create large and small voids within the PA-layer (see Figs. 3 and 4). Salt ion crystallizations were seen on the directly accessible ridges and valleys of the PA-layer. However, no signs of scale accumulation within the PA-layer void spaces were noticed (Fig. 3). To achieve better contrast, some samples were stained using RuO4. Although this process improved the visibility of the ridges and valleys in the PA-layer, no noticeable difference in identifying the accumulated scales was seen (Fig. 4).

In conclusion, the results confirm that the onset of foulant accumulation on RO membranes can be examined through controlled, short-duration crossflow filtration followed by TEM imaging. To our knowledge, this is the first investigation of evaluating the influence of convoluted microstructures of PA-layer on membrane scaling. In future, more detailed TEM analysis will be performed to evaluate the kinetics of membrane scaling and its influence on membrane performance. The research outcome would provide valuable insights for membrane cleaning strategies as well as designing novel anti-scaling membranes.

Keywords: Reverse osmosis; Polyamide layer; Inorganic scaling; TEM Imaging

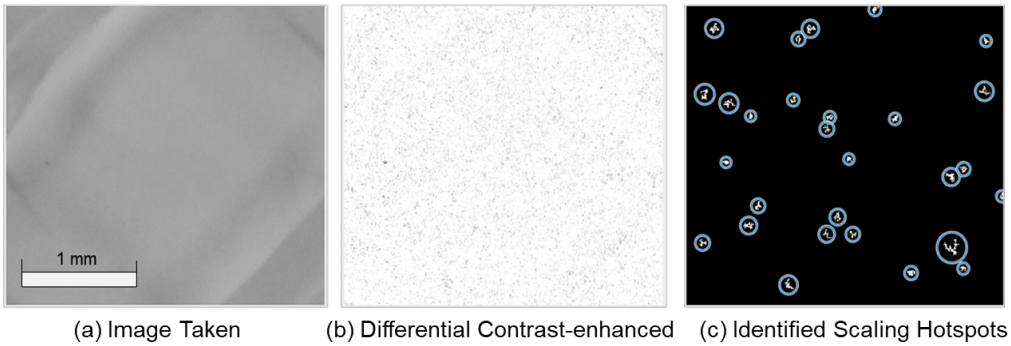

Fig. 1. Real-time monitoring of membrane scaling in mm-scale. Images taken were subtracted from a reference image, contrast-enhanced, and then, filtered to identify the scaling hotspots.

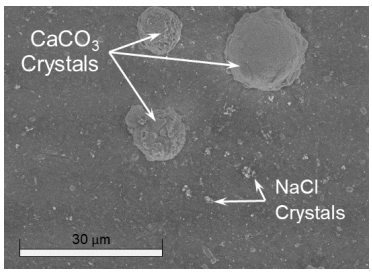

Fig. 2. SEM showed the $CaCO_3$ and NaCl crystals growth on the membrane; the identities of these crystals were verified by SEM-EDX.

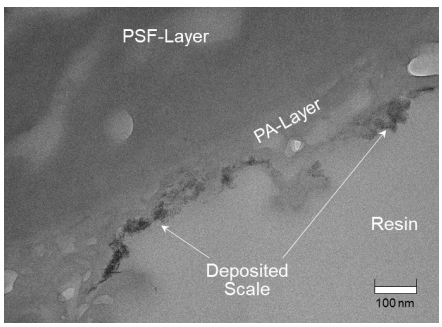

Fig. 3. TEM image of a non-stained BW30 RO membrane cross-section embedded in resin. The image shows the polyamide (PA)-layer folds on the porous polysulfone (PSF) layer. The crystallized salt ions are deposited on the top of PA-layer.

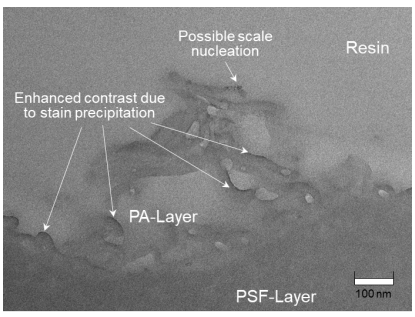

Fig. 4. TEM image of a RuO4-stained BW30 membrane cross-section. It shows a complex fold of the polyamide (PA)-layer nodules with dense stain precipitations present on the edges of the ridge-valley structures of the PA-layer as well as within the void spaces in the PA-layer.

Theoretical and experimental investigation on vacuum assisted AGMD (V-AGMD): Effect of design and operation parameters

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Air gap membrane distillation (AGMD) is one of the common configurations of applying the membrane distillation (MD) process for water desalination and other applications (Al-Zoubia et al., 2018). Although AGMD has many advantages, it results in relatively low flux and productivity compared with other MD configurations (Zihyu Liu et al., 2017). Accordingly, vacuum assisted AGMD (V-AGMD) was applied in this study to overcome the limitation associated with low flux in conventional AGMD. Together with the experiments in a bench-scale system, a model was developed to predict the experimental results. The flux and energy efficiency in conventional AGMD and V-AGMD were compared under various conditions. The effects of design and operation parameters such as the temperature difference, the air gap width, and the magnitude of the vacuum pressure on V-AGMD performance were investigated and predicted by the theoretical model.

Keywords: Membrane distillation (MD); Air gap MD (AGMD); Vacuum assisted AGMD (V-AGMD); Flux; Model

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Characterization of biofouling in spacer filled membrane filtration channels using optical coherence tomography

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Reverse osmosis for seawater desalination is hampered by the growth of biofilms causing biofouling on the membrane and feed spacer surface. Biofouling can lead to intolerable loss of system performance and increasing operational costs. The development of biofilms is strongly affected by process conditions such as feed water substrate concentration and flow rate. Understanding how process conditions affect biofilm accumulation, spatial distribution, and composition is key for improved system performance. For in-situ and non-destructive characterization of biofilm structure at the membrane surface, optical coherence tomography (OCT) is increasingly used. OCT uses near-infrared light to capture 2D and 3D images from within optical scattering media. For spacer filled channels, image analysis is complicated by (i) scattering from the spacer surface which hinders isolation of scattering from the biofilm on the spacer surface, and (ii) shifting of the apparent location of the membrane below feed spacer filaments due to the increased optical path length.

In this study, biofilms are grown in membrane fouling simulators at different nutrient concentrations and flow rates. System performance (pressure drop, transmembrane pressure, rejection) is monitored and biofouling on the feed spacer and on the membrane is characterized with OCT. Image analysis is improved by (i) positioning feed spacer geometry obtained from x-ray computed tomography in 3D OCT images to visualize the feed spacer and to mask scattering from the spacer surface, and by (ii) adjusting for the shift in apparent location of the membrane. Biofilm structure and spatial distribution will be related to process conditions and system performance. Understanding the impact of feed water quality and flow rate on biofilm growth can lead to the development of a strategy for biofouling control.

Keywords: Biofouling; Reverse osmosis; Feed spacer; Biofilm structure; Optical coherence tomography

Optimization of membrane distillation modules configuration through CFD calculations, validated experimentally for brine treatment

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After a full decade of intensive scientific investigation, membrane distillation (MD) did not yet reach the expected level of industrialization. Despite its unique ability to handle highly concentrated solutions with relatively simple design, it still suffers from low levels of water recovery, excess thermal energy consumption and severe polarization phenomena. Moreover, within the scope of hybridization with other processes such as forward osmosis (FO) and reverse osmosis (RO), MD often represents the limiting step, operating with low flow rates to avoid membrane wetting and requiring relatively elevated temperatures conflicting with other processes efficiency [1]. In this study, various configurations of MD modules are investigated using advanced CFD modeling, validated experimentally, with full coupling of momentum, heat and multicomponent transport of full brine salt composition. The conjugate approach that integrates membrane, feed and permeate channels is used [2]. The approach differs from previous multi-stage [3] or parallel analyses as it enables to predict pressure along the membrane surface of each module to help analyze wetting limitations, as well as species concentration evolution along the channels to bring insight into potential crystallization phenomena. Parallel versus series layouts are compared for different number of stacking and different modules lengths and channel heights. A detailed analysis is drawn in terms of energy consumption and water recovery that will be used to determine an optimum MD layout.

Keywords: Membrane distillation; Modules configuration; Brine treatment; CFD calculations

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Sewage sludge and the ignition of an experimental combustor: state of the art in biomass approach

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In 2015, 77% of energy resources were obtained through the combustion of fossil fuels such as oil and coal. Searching for alternative fuels has meant the birth of new techniques for the recovery of waste as a source of energy. Alternative fuels, such as urban solid waste or sewage sludge, have been used in recent years as complementary fuels in increasingly advanced combustors. The combustors must comply with the proper mixture of fuel and oxygen to begin the oxidation reaction or ignition stage (Start-up). At present, the most commonly used combustion chambers are the fluidized bed chambers, where the bed is formed by biomass and the oxidizing gas by a mixture of oxygen and fossil fuel. The present research shows the ignition stage of an experimental laboratory scale combustor with an electrical resistance for heating and where the main fuel is sewage sludge that is exposed to an oxygen atmosphere.

Keywords: Combustor; Sewage sludge; Experimental design; Start-up

Method for stable operation for an integrated stand-alone downsized diesel engine and solar PV generator system for powering a reverse osmosis plant

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For the production of a quantity of water from a reverse osmosis plant, an amount of electrical energy must be consumed, and for the generation of this energy, in a conventional electrical network, a quantity of emissions is emitted in the form of gases of greenhouse effect. The magnitude of these emissions depends on the set of technologies that make up the power generation system of the power grid to which the water production plant is connected. The energy produced by this set is often called the energy mix, which tends to depend heavily on the territory and energy policy. In relation to territorial dependence, electricity networks usually have energy mixes that cause higher greenhouse gas emissions, since they usually have systems based on lower yield technologies. These electric power production technologies can be classified, mainly, into two types: conventional and renewable. Within the conventional technologies, several can be considered: diesel engines, gas turbines, combined cycles, steam turbines, which usually have different yields and quantity of emissions, and on the other hand there are technologies based on renewable energies, such as : solar PV, wind, waves, etc ... On the other hand, to reduce greenhouse gas emissions, it is possible to propose the generation of electrical energy necessary for the production of water in the same installation, through hybrid energy systems. These hybrid energy systems can be composed of several types of technologies, in which the greatest amount of energy from renewable sources tends to be integrated, with the support of an energy storage system or a conventional technology, such as a diesel engine. Therefore, this article proposes a methodology to achieve the stable operation of a high-efficiency diesel engine in an integrated stand-alone downsized diesel engine and solar PV generator system for powering a reverse osmosis plant, thereby reducing gas emissions from greenhouse effect associated with the water production.

Keywords: Energy mix; Reverse osmosis; PV source; Energy hybrid system.

Innovative membrane process with microfiltration and reverse osmosis treating the effluent (wastewater) produced in a cheese industry (cheese whey) to get "waste 0" and sub-products

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The cheese whey (95% composed of water), is an effluent produced in the cheese industry, of which more than 1.5 million tons are generated in Spain, constituting a serious environmental problem. The process starts by the total conversion of whey using a new technology (fermentative / enzymatic) in different compounds such as lactic acid, proteins, salts and water, all products with commercial utility.

This fermented product is processed by a two-stage membrane system, a totally innovative process in this type of fermented products:

1. Microfiltration. Separate all suspended solids, mainly lactic bacteria.
2. Reverse Osmosis. The microfiltrated permeate obtained is concentrated leading in a microbiologically stable product and reduce transport costs.

The final products of the entire process are: biomass concentrate (lactic bacteria), which agronomic utility in biocontrol and biofertilization processes; concentrate from reverse osmosis rejection, mainly composed of proteins in the form of peptides and calcium lactate, both with uses in agriculture as biostimulants / biofertilizers and in animal feed; and the permeate from reverse osmosis, reusable in other industrial processes.

This work demonstrates the technical feasibility of this valorization process in order to achieve the objective of "Waste 0" from a problematic by-product, while obtaining products with commercial utility.

Keywords: Innovative membrane process; Microfiltration; Reverse osmosis; Wastewater; Cheese whey; "Waste 0".

The importance of fouling-resistant membrane elements – the FilmTec™ SW30XFR-400/34

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Biofouling in reverse osmosis (RO) occurs when bacteria settles in the elements and start building a biofilm. This paper highlights the performance of a new generation of fouling resistant RO element, the newly developed FILMTEC™ SW30XFR-400/34 seawater fouling resistant membrane element in terms of its biofouling resistance. Additionally, this paper presents a validation of the product at a realistic scenario: the Middle East Red Sea. The validation trials proved the robust performance that this new membrane element shows under harsh biofouling conditions. This membrane element is able to offer 34% lower pressure drop than previous generations with a stable performance in terms of normalized permeate flow and salt rejection. In the validation trials this feature led to a significant reduction of the chemical cleanings (i.e. CIP) caused by biofouling; more than 33% reduction of the annual CIP frequency. Additionally, thanks to the membrane chemistry robustness, one of the FILMTEC™ brand essence attributes, the product is able to offer advantaged chemical resistance when chemical cleanings (CIPs) are performed. Under the same conditions, where an element from another membrane manufacturer is experiencing 85% increase in salt passage, FILMTEC™ SW30XFR-400/34 shows stable performance.

Keywords: Seawater; Reverse osmosis; Fouling resistant; Membrane; Pressure drop; Biofouling

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The importance of long-term stable performance of reserve osmosis elements#

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Water scarcity is being recognized as one of the main threats that mankind is facing globally. Reverse osmosis (RO) membrane technology has developed as a promising technology to address this problem. This increase has been driven as materials are improved and costs dropped. This is especially relevant for Middle East countries (ME), where population is located in arid and semi-arid regions with limited rainfalls and a high degree of evaporation due to the high

temperatures the region is exposed to. Therefore, getting a robust element that is able to offer a stable salt rejection even after multiple cleanings is of utmost importance to sustain the population and economic growth of the region. This paper aims at demonstrating the superior durability of FILMTEC™ membranes compared to other manufacturers. This superior durability has been reported in a number of desalination plants where FILMTEC™ membranes lifetime has exceeded more than 10 years but a quantification and a reliable comparison of such superior durability compared to other manufacturers in a controlled environment has not been completed to date. In this paper, FILMTEC™ SW30XLE elements are exposed together with equivalent commercially available membranes from other suppliers to a durability study to simulate long term operation and to determine the evolution of the membrane specifications with time. Particular focus is paid to the changes in salt rejection. Membrane durability plays a determining role in membrane replacement, which ultimately has a critical impact in the economics of any desalination plant. In this study it was determined that after a number of cleanings, the salt passage increase of the membranes from other suppliers was close to 3.5 times larger than the value experienced by FILMTEC™ membranes. More specifically, the salt passage increased experienced by FILMTEC™ in the first study was 22% while the membrane from another supplier showed a 73% increase and in the second study, FILMTEC™ had a salt passage increase of 43% while the membrane from the other manufacturer has a 140% salt passage increase. In a 100,000 m³/d desalination plant, this enhanced durability showed by FILMTEC™ elements might represent a 5.5% cost of water decrease in the reverse osmosis stage, and total savings of 1.34 US ¢/m³ in the whole plant, which can be translated into savings of 488,000 USD per year.

Keywords: Reverse osmosis; Seawater; Robustness; Cleaning in place; Desalination

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Wave to energy and water — desalination via Wavepiston wave energy converter

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The Wavepiston Wave Energy Converter (WEC) is an apparatus that produces pressurised sea water (up to 60 bar) using the longitudinal motion and force of waves as power source. The converter is placed further from the shoreline and the pressurised water is conducted to ashore via a pipeline. On land the water is fed to a reverse osmosis system for desalination.

Key technical areas in making this system succesful are developing cost-effective solutions for pre-treatment of high-pressure sea water and creating methods that ensure constant pressure and flow feed to the reverse osmosis membrane. The operational principle of the desalination set-up allows supplementing it with a sub-system for generation of electricity.

The system will be demonstrated in the Horizon 2020 Fast Track to Innovation project "Wave to Energy and Water" (W2EW), where a full-scale Wavepiston WEC will be installed converting the wave energy to both potable water via desalination and electricity.

Given a successful demonstration the W2EW solution offers potable water powered by renewable energy at a competitive price along a major part of the coastlines across the world.

Keywords: Wave power; Wave energy; Desalination; Reverse osmosis; Wavepiston

Influence of temperature in the performance of a non-stirred anaerobic bioreactors for the wastewater treatment

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Anaerobic digestion is a recognized biotechnology system for the treatment of high-strength wastewater. This kind of technology has been increasingly implemented worldwide due to its capacity for both, reducing wastewater plants operating cost and, producing heat and electricity through the use of biogas recovered from the anaerobic processes. Temperature is a critical factor affecting anaerobic digestion, as it influences the system heating requirements and methane production. Despite the fact that, for the production of methane from animal manure a standard temperature of 35ºC is generally recommended, in small farms, due to their inaccessibility to waste heat from an electrical generator, digester systems can efficiently operate at a temperature of 22ºC both to produce methane, and reduce greenhouse gas emissions and odors. In this work, a numerical model based on the finite elements method, in a two-dimensional space, is proposed to calculate the internal and external temperature performance of non-stirred anaerobic bioreactors, according to a set of boundary values subjected to them. This model allows the simulation of the anaerobic reactors' complex functioning, for heterogeneous fluids with different physical-chemical properties. It provides a useful tool for improving the knowledge acquisition for digesters' internal dynamic, making it possible to determine the influence of temperature in anaerobic digesters' treatment under different scenarios efficiency. The results are relevant to decide the optimal operational conditions for the digester, as well as for optimizing anaerobic processes through the establishment of the boundary values.

Keywords: Temperature; Wastewater treatment; Bioreactor; Efficiency

Analysis of brine management from the perspective of the sustainable development goals

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In the coming years the desalination industry is expected to grow in response to an increased water demand. In addition, due to climate change, drought periods will be more severe in some regions of the world and desalination will be an effective measure to ensure water supply.

However, the desalination process produces brine, a hypersaline by-product that has a potential damage the environment and the marine ecosystems, if appropriate measures are not taken during brine discharge.

The growth of desalination leads to an increase in brine production; hence, it is crucial to seek new techniques and strategies to manage its discharge in a sustainable way.

In 2015, the United Nations announced the Sustainable Development Goals (SDGs) to eradicate poverty, protect the planet and ensure prosperity for all people worldwide. Composed of 17 goals and 169 targets, these measures are presented as an opportunity to critically evaluate our society and its current development and production models and apply sustainable models that guarantee a better world.

With the growing concern for brine production globally, it is key to face the challenge of brine management.

This work aims to provide an analysis of brine management from the perspective of the SDGs. To this end, the link between the different brine management solutions and the goals & targets of the 17 SDGs has been analysed.

The congress paper provides, first of all, a comprehensive overview of the main regulations for brine discharge at European level. In addition, it analyses techniques and technologies currently used for brine management. Building on this framework, eventually the work assesses the relationship and degree of compliance of such approaches in relation to the SDG targets.

The results of this work highlight how effective brine management measures can contribute to the achievement of the SDGs, especially for the protection of the marine environment, CO_2 emissions' reduction and innovation promotion.

Because of the growth and development scenarios we are experiencing, the society and the industry must embrace new innovative solutions from the perspective of the Sustainable Development Goals to guarantee a more sustainable and competitive world. The paper aims to contribute this change, providing guidelines to align brine management with the Sustainable Development Goals.

Keywords: Sustainable development goal; Brine management; Environment

A fouling comparison study of algal, bacterial, and humic organic matters in seawater desalination pretreatment using UF ceramic membranes

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This paper investigates three types of organic matters, algal organic matter (AOM), bacterial organic matter (BOM), and humic organic matter (HOM) in terms of organic fouling behavior and removal efficiency with the use of ceramic ultrafiltration (UF) membranes. UF experiments have been conducted at constant flux mode using (5 kDa) and (50 kDa) ceramic membranes. Six filtration cycles of 30 min each followed by hydraulic backwashing for one minute were tested in duplicates. AOM and BOM were extracted from marine algae and marine bacteria, while (Suwannee River) humic acid was used as HOM. These organics were spiked separately into synthetic seawater feed with a total TOC of (0.5 mg/L).

Results showed that 5 kDa membranes removed more TEP/organics and showed lower fouling formation than 50 kDa membrane. SEM analysis showed that fouling was dominated by cake layer formation for the 5 kDa membrane while pore blockage followed by cake layer formation is apparent for the 50 kDa membrane. SEM revealed that a cake layer is formed for all tested organics; the flux was stable over the filtration periods for AOM and BOM. For 50 kDa membranes, AOM and BOM presented a similar fouling behavior. However, AOM was quite higher compared to BOM concerning of TEP concentrations and gel-like formation; which attributed to high polysaccharides concentration in AOM.

For 5 kDa membranes, TEP particles derived from AOM and BOM caused the formation of a compact thinner cake layer of low porosity which enhances fouling resistance. HOM cake layer was thicker than those for AOM and BOM and it was more porous and less compact. This occurred more likely when HOM particles bind with Ca molecules offering large aggregates and leading to the high porosity of the HOM cake layer on the membrane surface.

Keywords: SWRO pretreatment; UF Ceramic membranes; Fouling; AOM; TEP

Nutrient limitation strategy for biofouling control in seawater reverse osmosis membranes

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One of the main drawbacks to become reverse osmosis desalination a more sustainable process is the environmental and economic costs involved in strategies to control the biofouling of reverse osmosis membranes. These strategies currently require the frequent use of chemicals [1], such as reducing agents, which represent a potential damage to the polymeric membranes, as well as to the environment. This situation forces to look for new strategies that allow a more sustainable biofouling control in all senses.

With this objective, this study proposes an alternative pre-treatment specifically aimed at microbial development through the limitation of nutrients in seawater. This alternative is based on the use of a high phosphorus affinity adsorbent

(essential element for bacterial growth [2]) and low cost. This, through a system similar to activated carbon biologics, allows us to limit this nutrient to concentrations that affect cell viability. Furthermore, in this study, the phosphorous concentration at which microbial growth begins to be affected has been determined by microbial kinetic assays.

In this way, an environmentally friendly strategy is proposed with the added advantage of being able to generate by-products of interest in the fertilizer sector from the regeneration solution of the adsorbent material. These by-products would be obtained after mixing the regeneration solution with a certain volume of reverse osmosis brine allowing the precipitation of phosphate compounds of calcium and magnesium in addition to allowing the reduction of brine returned to the sea. All these factors make this study a strategy that contributes to increasing the sustainability of the desalination process.

Keywords: Biofouling; Adsorption; Nutrient; Phosphorus; Reverse osmosis

Acknowledgements

The *LIFE Dreamer* project has been funded by the European Commission under the framework of the LIFE Programme (LIFE 16 ENV/ES/000223).

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Innovative high recovery seawater reverse osmosis desalination scheme

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Seawater desalination by reverse osmosis (RO) has gain its consideration due to its feasibility and cost-efficiency. It produces a significant part of the total potable water worldwide (39,4 million m^3/d [1]), especially in the Middle East and North Africa (MENA) countries with major water scarcity problems. Despite its widespread, the total conversion of these plants commonly reaches the 50%, returning the half of the intake flow back into the sea doubly concentrated. Reducing the volume of RO brine by increasing the process recovery is one of the main challenges for today's water companies. Seawater brine, with twice the salts as the natural seawater has a high scaling potential as well as a high osmotic pressure, which makes it difficult to be treated by osmotic force driven technologies.

Thermal technologies performance are not highly dependent on salt concentration, but during the evaporation, salt concentration increases and scaling eventually occurs. The process begins with the CO2 evaporation, displacing the carbonate equilibrium forming CaCO3 and increasing the pH which can also entail a precipitation of $Mg(OH)_2$. Calcium sulfate can also take part on the scaling process.

In order to avoid the precipitation of these divalent ions, a brine softening stage can increase this brine recovery in about a 20% [2]. A common softener procedure is based on chemical precipitation, which entails a high reagents consumption and a difficult performance.

Nanofiltration as a second stage reverse osmosis has shown a great brine softener water pre- treatment method, by decreasing the scaling formation in a considerable rate. Furthermore, as brine comes pressurized from the RO system, no additional pumping is needed and concentrate pressure can be recovered, similarly to a common RO system.

In the pilot system designed for the Life-dreamer project, four 8" membrane have been installed and fed with 4.5 m^3/h of RO brine continuously. This brine, as a product of a 50% recovery RO system has a total dissolved solids (TDS) content of 71 g/L with a calcium concentration of 850 (±50) mg/L; a magnesium concentration of 2500 (±100) mg /L and a sulfate concentration of 5500 (200±) mg /L, in average. Nanofiltration, working at recoveries of the 50%, has been able to reduce calcium in a 70%; magnesium in 85% and sulfates in a 98%.

A comparison on membrane distillation (MD) performance fed by this pre-treated brine versus a raw brine has reveal an improvement increasing brine recovery in a 25%.

Further insights of the experimental results obtained both at the NF and MD pilot plants from an hydraulic and quality perspective will be presented in the manuscript.

Keywords: Seawater desalination; Reverse osmosis; Nanofiltration; Brine; Membrane distillation; Divalent ions

Acknowledgements

The *LIFE Dreamer* project has been funded by the European Commission under the framework of the LIFE Programme (LIFE 16 ENV/ES/000223).

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Environmentally friendly liquid cleaner for cost-effective reverse osmosis membrane cleaning

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Membrane fouling is a persistent problem throughout reverse osmosis systems that reduces plant efficiency and increases operating costs. Membrane cleaning depends on the type of deposit affecting membrane performance. Knowing the nature of membrane foulants will allow selecting the best cleaners and the most effective cleaning procedures.

Both, cleaners and cleaning procedures, play a key role in restoring the membrane performance. Standard cleaning procedures using generic chemicals often prove to be ineffective in foulants removal. If the cleaning agents are not the appropriate ones, the desired cleaning effectiveness may not be achieved, or the membrane could be damaged. The use of formulated cleaning chemicals ensures high performance and compatibility with membranes, and extends membrane life. Formulated cleaners consist of a blend of mixed ingredients that act synergistically, including components that target specific foulants. Reverse osmosis cleaners containing Ethylenediaminetetraacetic acid (EDTA) and phosphorous in their formulation are widely used for membrane cleaning.

However, their biodegradability and phosphorus contained are some of the reasons for the growing concern of environmental impact that represents the discharge of these compounds into the environment. The fact that EDTA is not biodegradable leads to the presence of considerable amounts of it in aquatic systems, with serious environmental consequences. When cleaners containing phosphorus are discharged into the environment, they can act as a nutrient source for algae and bacteria leading to eutrophication.

In this context, an innovative and environmentally friendly liquid cleaner was developed. It is an EDTA-free and phosphate-free high pH liquid cleaner formulated to remove organics, biofouling, colloidal fouling, clay deposits, alumino-silicates and other particles deposits. It is a highly formulated cleaner that contains environmentally friendly active agents with excellent chelating performance that replace the non-biodegradable chelating agents.

The aims of this study were to evaluate and validate the effectiveness of the EDTA-free and phosphate-free liquid cleaner in removing biofilm and clay deposits (alumino- silicates) from reverse osmosis membranes; and to compare its efficacy with a proprietary high pH powdered cleaner.

Cleaning tests were performed with flat sheet cells in the laboratory in order to evaluate and compare the effectiveness of the environmentally friendly liquid cleaner with a powdered cleaner. Cleaning tests were carried out on membrane samples mainly fouled by organic fouling, biofouling and colloidal fouling. The composition of foulants on the membrane surface was firstly identified and characterized using a combination of several techniques: confocal laser scanning microscopy (CLSM), attenuated total reflectance Fourier transform infrared spectroscopy (ATR-FTIR), ATP analysis, bacterial counts, and scanning electron microscopy and energy dispersive X-ray spectroscopy analysis (SEM-EDX). The membrane surface was covered by a thick gelatinous deposit layer. The deposit layer had a dense and compact structure. Fully developed biofilm was found. This biofilm was the predominant form of membrane fouling and it was composed of bacteria and extracellular polymeric substances (EPS).

Analysis of the deposits also showed the presence of alumino-silicates (clay deposits). After determining the fouling behavior and mechanisms involved in membrane fouling, our study focused on selecting the best cleaning procedure and the most successful cleaners for restoring the membranes performance. Environmental and economic criteria were taken into consideration to design the cleaning membrane strategies. Cleaning processes to remove biofilm and alumino-silicates required a combined sanitization using non-oxidizing biocide and high pH cleaning. The high pH cleaning chemical used were the environmentally friendly liquid cleaner and the powdered cleaner. The effectiveness of both cleaners were evaluated in terms of normalized permeate flow and normalized salt rejection before and after the cleaning procedure. Comparative analyses of membranes before and after cleaning procedures also were conducted using CLMS, ATR-FTIR and SEM-EDX techniques. The results demonstrated that environmentally friendly liquid cleaner in combination with non-oxidizing biocide restored membrane performance to design specifications provided by membrane element manufacturer; and removed bacteria, biofilm and clay deposits from membranes surface. It fully penetrated, reached and destroyed internal biofilm layers. Environmentally friendly liquid cleaner provided the same cleaning effectiveness as powdered cleaner in terms of normalized permeate flow and foulants removal.

The environmentally friendly liquid cleaner was tested in a real reverse osmosis plant with biofouling and colloidal fouling problems. The plant showed symptoms of severe biofouling that included low permeate flow and high differential pressure. The cleaning procedure restored the membrane performance to initial start-up situation. Clay based deposit and biofilm were removed and biological slime was eliminated.

The results demonstrate that formulated EDTA-free and phosphate-free liquid cleaner is an environmentally friendly, cost-effective, and economically viable membrane cleaner. Furthermore, it is readily biodegradable and does not contribute to eutrophication. Lastly, also it is effective at low doses so it reduces operating costs and minimizes chemicals discharge to the environment.

Keywords: Reverse osmosis; Membrane cleaning; Formulated liquid cleaner; EDTA-free and phosphate-free cleaner; Biofouling; Colloidal fouling

Breakthrough dry seawater reverse osmosis elements[#]

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Water scarcity is one key challenge mankind is facing. Seawater reverse osmosis desalination is a promising technology to solve it. However, further innovation which needs to go beyond product specifications is needed to decrease the total cost of water while at the same time, improving sustainability footprint. This paper describes a breakthrough step-change in innovation within the desalination industry: transitioning from Wet-test Sea Water Reverse Osmosis (SWRO) elements to Dry-test SWRO elements. This new concept has been achieved by DuPont thanks to a significant breakthrough in RO technology: continuous advancements in membrane chemistry, automated precision manufacturing, single source manufacturing, a robust quality control, and enhancements in testing methods and procedures and Dry-test SWRO elements offer significant advantages over wet-test elements, given the requirement to monitor and eventually replace preservation solutions for wet membranes. Since dry-tested membranes do not need to be stored with the solution, they help enable longer storage times, lower labor costs and easier long-term warehouse planning. Dry-test SWRO membranes also are safer to install due to a 4 kg reduction in weight and are easier to handle. From the sustainability point of view, the dry-test SW concept also brings plenty of benefits:

1. Reduces fresh-water consumption as no wet testing is required;
2. Eliminates wastewater generated during wet testing;
3. Significantly reduces energy consumption by skipping wet testing which can be translated in a decrease in carbon dioxide generation per element of up to 20%; and
4. the lower weight for shipping will also significantly decrease the environmental footprint of these elements. In a large desalination installation supplied with Dry-test SWRO elements, the greenhouse gas emissions reduction equals those generated by a passenger vehicle driving around 7 million miles[1].

Additionally, dry-test SWRO elements offer the same water productivity and permeate quality as wet-test elements, once stabilized. New RO elements require a short time to fully stabilize, experimental results indicate that wet elements take up to 48 h whereas dry elements up to 72 h.

Keywords: Innovation; Reverse osmosis; Water treatment; Desalination

[1] Source: Global Water Intelligence (GWI) – Nov 2019 Update. United States Environmental Protection Agency Greenhouse Gas Equivalencies Calculator

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MITIMAC. Climate change mitigation through innovation in water cycle using low carbon technologies

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The water industry in Spain accounts for 2–3% of annual energy consumption, which represents a significant amount of energy use. Reverse osmosis desalination plants consume around 4 kWh/m^3, with an estimated annual consumption in Spain of 2,460 GWh, whilst the wastewater treatment plants consume approximate values of 30 kWh per person per year, estimating an annual consumption nationwide at 2,672 GWh. Therefore, a sustainable management of water resources is of great importance, which becomes especially significant in insular environments. The Canary Islands have specific problems concerning the water supply, and as a consequence of the isolation and remoteness of the continent, sustainable management of water resources is essential. MITIMAC is a cooperation project which main objective is to enhance research, technological development and innovation through the creation of a technological cluster, through collaboration and joint work of the Macaronesian region, in order to mitigate climate change in the water cycle, through clean and innovative technologies internal and external to the cycle. For that purpose, knowledge of characteristics and difficulties existing within each region is necessary (Canary Islands, Madeira, Cape Verde, Azores, Mauritania and Senegal) and the analysis of greenhouse gas emissions, in the water cycle, for a further development of governance solutions and guidelines from a technical perspective in order to mitigate climate change in the water sector. The participating entities in the Project are: Instituto Nacional de Investigación y Desarollo Agrario, Universidad de Cabo Verde, Direction de la Gestion et de la Planification des Ressources en Eau, Instituto Tecnológico de Canarias, Universidades dos Açores, Secretaria Regional do Ambiente e Recursos Naturais, Ecole Superiere Polytechnique de Noakchott, Office National des Services d'Eau en milieu Rural, Secretaria Regional da Energia, Ambiente e Turismo - SREAT, AREAM - Agência Regional da Energia e Ambiente da Região Autónoma da Madeira, Université Gaston Berger du Sénégal, Fundaçao Gaspar Frutuoso y Universidad de Las Palmas de Gran Canaria.

Keywords: Technological cluster; Climate change; Water cycle; Clean technologies; Greenhouse gases

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Microbial desalination cell for low energy drinking water production in Canary Island

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Nowadays, desalination has become a very affordable solution to cope with fresh water shortage in off-shore areas. However, current desalination technologies require significant electrical or thermal energy. In this respect, MIDES project aims to develop the World's largest demonstrator of an innovative and low-energy technology for drinking water production, using Microbial Desalination Cell (MDC) technology as pre-treatment step for RO, decreasing the energy consumption from 3 kWh/m^3 to 0.5 kWh/m^3.

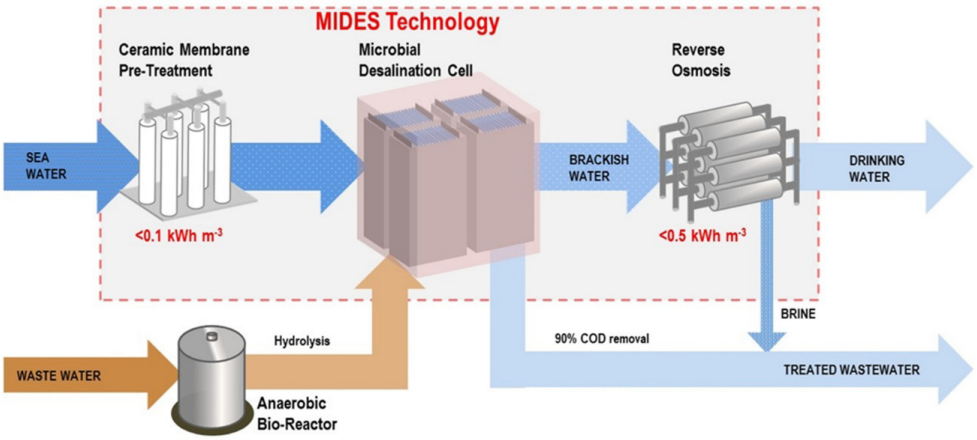

Fig. 1

The roadmap of the lab-MDC up scaling (100 cm^2 electrode area) goes through the assembly of a pre-pilot MDC comprising 15 units of 600 cm^2 electrode area, towards the development of the world's largest MDC technology (15 units of 4000 cm^2). The results obtained with a lab-scale MDC have led to a significant improvement of water production compared to values reported in literature [2], reaching desalination rates of 0.5-3 L/m^{2}h.

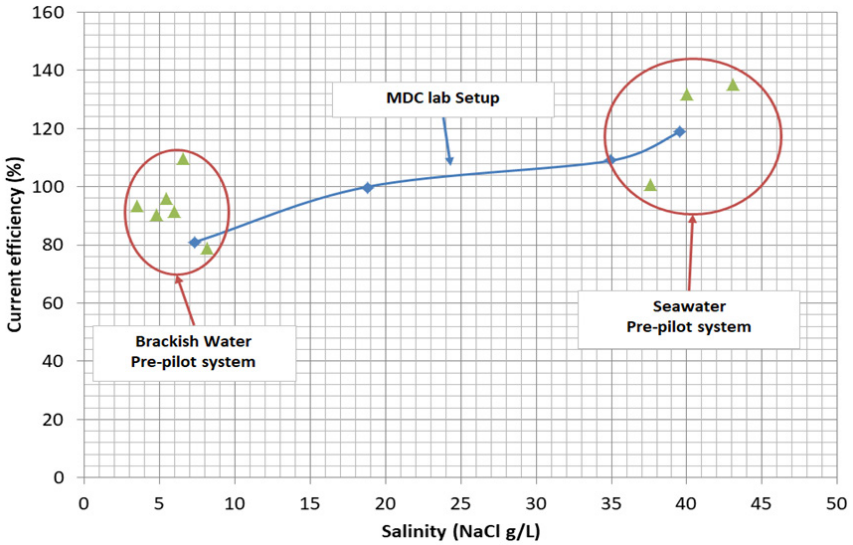

Fig. 2. Desalination efficiency: MDC lab setup and pre-pilot system comparison.

Subsequently, desalination rates of 0.4-12 L/m²h were obtained using MDC pre-pilot system, indicating a good scalability of the system. Industrial wastewater (brewery) has been identified as the optimal feed to enhance the activity of the bacteria in the MDC. This technology will be validated at pilot scale in three demo sites: Denia (Spain), Canary Islands (Spain) and Egypt. Three pilot plants of 150 L/h were constructed and operated under real environments in desalination plants operated by Aqualia.

SWDP Oeste, in the Canary Island of Tenerife, has been selected as Demo site for the validation of this technology. The overall process includes a pre-treatment of the seawater stream by ultrafiltration membraneas prior to enter the MDC unit, where it is partially desalinated (70-90%) before the RO post-treatment.

SWDP Oeste was selected as demo site due to the characteristics present in the water and the environmental conditions of the island of Tenerife. The south and west of the Tenerife island presents a notable water scarcity with high water stress index. Seawater desalination it is a major source of freshwater in this area, to supply it for agriculture uses (mainly banana crops), recreational, urban and touristic uses. The rely of the region on desalinated water, a long tradition of research and development application to solve problems and notable support from local authorities (Consejo Insular de Aguas de Tenerife, CIATF) make it a strategic place for the development of new desalination technologies.

The MDC pilot plant shows the capability of desalinate seawater using renewable energy by biio-electrochemical process. The energy contained in the organic matter it is degraded by electroactive bacteria growing in the anode, transfer this energy and it is used to split ions by electrodialysis membranes, obtaining a desalinated stream using only the energy contained in the organic matter. To make the system more efficient the desalination process in the Microbial Desalination Cell was stopped when a selected desalination rate was achieved, in this case when the seawater salt concentration gets below 5 g/L of TDS and the desalination rate reach the curve asymptote. The final polishing it is provided by a reverse osmosis membrane but working at low pressure with lower energy consumption.

Fig. 3. SWDP Oeste, in Guía de Isora (Tenerife, Canary Island). Demo Site MIDES Project.

The results obtained shows a sustained seawater desalinated stream obtained from the bio-electrochemical process inside the Microbial Desalination Cell, and the good scalability of the technology from the lessons learned from lab and pre-pilot scale, applied to the pilot scale.

Keywords: MDC; Bio-electrochemistry; Desalination; Upscaling

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Exploring novel filter media as pretreatment of reverse osmosis

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There is a fundamental challenge involving the fouling mitigation in reverse osmosis (RO) in desalination plants. Pre-treatment it is a basic step in water desalination, and more efficient pretreatment system have to be explored to retain polluting agents in order to prevent them from arriving the RO membrane modules, increasing the plant efficiency and reducing the costs associated to membrane fouling (cleaning regents, membrane replacement, off-line time). In this context, the MIDES Project (EU H2020 grant agreement No 685793, www.midesh2020.eu) aims to explore and optimize a series of materials and technologies for both brackish and seawater pretreatment to protect the membranes of RO and microbial desalination cell from pollutants.

Between the pretreatment technologies explored in the project, a series of novel filter media have been studied in order to compare them with conventional media (sand and anthracite). For this purpose, a filter media pilot plant was designed and constructed for treating high foulant brackish water from the Racons River in the EDAS Racons (Denia, Spain) operated by Aqualia.

Fig. 1. Novel media filtration pilot plant.

This pilot plant consist in a multicolumn pilot plant with a capacity of 8 m^3/h divided in four identical streams of 2 m^3/h per column. Several novel media filtration have been selected for testing. In one of the columns, a traditional material configuration based on sand and anthracite were installed, to be used as a baseline to compare the performance of the rest of the filtration materials. In a first stage, other materials were selected, such as filtration glass, calcined atapulgite, activated clay, zeolites, garnet, etc. with different mixes and configurations.

Filtration rates of 8, 11, 13, 15 and 19 m/h, as well as the filters washing process or the coagulant influence have been explored. Different parameters such as the permeate turbidity, the fouling kinetics, run length times, head loss were studied in order to analyse the novel media suitability for further use as a pretreatment of reverse osmosis desalination plants.

In Figs. 2 and 3 can be observed the pressure increase vs time and fouling kinetics for the four different filter media: sand-anthracite, calcined atapulgite-anthracite, activated clay and filtration glass. Results indicate that all the materials tested can produce good quality permeate, being the best of them the activated clay. On the other hand, the presence of biofouling was not observed in filtration glass material, which causes important cost saving deriving from media filtration process.

The evaluation of novel media filtration, as alternatives to the classic configuration sand or sand-anthracite can improve the desalination plants in many ways, depending on the facility needs. Water quality can be increased by selecting the adequate media filtration if higher permeate quality it is required to avoid membrane fouling, or select media filtrations with higher production capacity in under dimensioned plants, higher mechanical resistance or low fouling potential, depending on the needs.

The media filtration market it is developing new and very interesting materials and test many of them on real environment working on parallel for comparative purposes can provide lot of information to designers, constructors and operators of those facilities, selecting the best alternative for each situation.

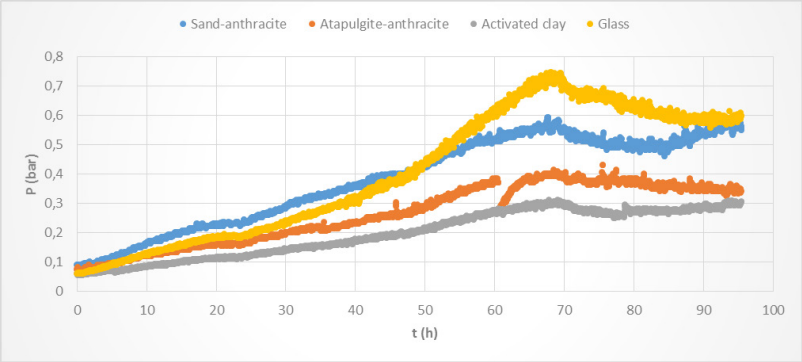

Fig. 2. Trans filter pressure vs time.

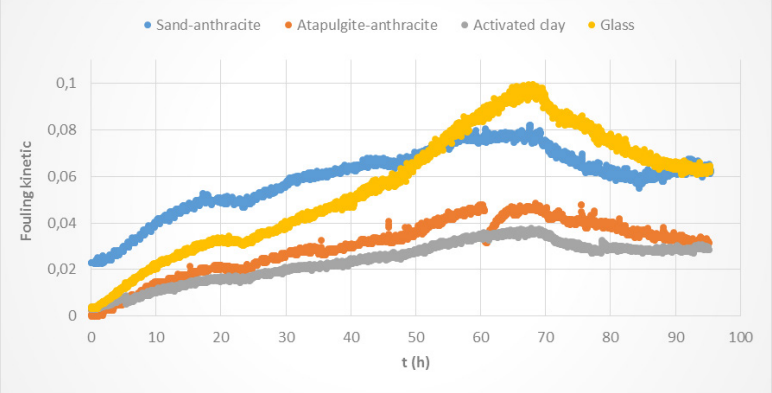

Fig. 3. Fouling kinetics in the filtration media vs time.

Keywords: Novel media filter; Sand filter; Pretreatment; Brackish water

Electrodialysis processes for minimizing waste production in phosphoric acid plants

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Application of chemical fertilizers in agriculture is essential for meeting the increased global food demand by the growing population. Phosphorus is one of the main macronutrient that inorganic fertilizers are based on. It is provided through the production of phosphoric acid in the 'wet process' – dissolution of mined and beneficiated phosphate ores by concentrated sulfuric acid. This process generates solid, liquid and gaseous waste byproducts. The solid waste comprised of phoshphogypsum ($CaSO_4.nH_2O$) with residual P, as well as trace amount of heavy metals, rare-earth elements and radionuclides. The liquid wastewater is acidic and has the potential to precipitate sparingly soluble salts such as fluorite (CaF_2) and gypsum. Both solid and liquid waste byproducts are currently accumulated piles or ponds respectively, posing environmental and health risks. Cost-effective solutions are therefore needed for increasing the sustainability of phosphoric acid production worldwide. We study the integration of advanced electrodialysis processes as part of a physicochemical process designed to treat the phosphoric acid waste, while recovering valuable resources. To tackle the solid waste challenge, we build on a previously suggested process in which phosphogypsum is dissolved by an alkaline solution (caustic or ammonia), producing lime or calcite (with sequestered CO_2) and a concentrated sulfate salt solution. We demonstrate the technical feasibility of using electrodialysis with bipolar membranes (EDBM) to convert the sulfate salt to the original alkali solution and to sulfuric acid. To tackle the acidic liquid waste, we explore the use

of electrodialysis incorporating monovalent selective cation exchange membranes (MVS-CEM). We study the effect of different operational parameters and quantitatively assess the feasibility of the processes in terms of efficiency, energy consumption and operating costs. Revealing the trends, trade-offs and interrelations between the key process parameters will allow expanding both scientific and applicative knowledge of electrodialysis processes. Although more research is required prior to large-scale implementation, our results indicate that novel electrodialysis processes are potentially cost-effective routes for minimizing the environmental risks posed by the phosphoric acid industry.

Keywords: Waste valorization; Cleaner production; Fertilizer industry; In-place chemical production

Redox potential effect of bisulfite in brackish water with the presence of chlorine dioxide, chlorite, chlorate and metals[#]

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In desalination plants, disinfection is necessary to control biofouling, one of the main problems in the long-term performance of reverse osmosis membranes. Addition of both chlorine and the dechlorination reagents affects oxidation and reduction potential (ORP). The present investigation evaluates the evolution with time between bisulfite dose and ORP values, to assess the impact of chlorine dioxide, chlorite, chlorate and dissolved metals in the redox potential. Results showed that using chlorine dioxide as an oxidant (1 mg/L), it was needed at least 45.8 mg/L of bisulfite to reduce ORP values below 300 mV. In the presence of chlorite ion (0.65 mg/L) and adding 100 μg/L of different dissolved metals, the redox potential values did not increase higher than 300 mV except for cobalt (Co^{2+}); at 3 mg/L of chlorite it was needed at least 46.9 mg/L of bisulfite to reduce the ORP below 300 mV. The influence of bisulfite without chlorination species in brackish water, but with dissolved metals showed redox values always below 300 mV, except for 15 mg/L of bisulfite with 250 and 500 μg/L of dissolved Co^{2+}. Overall, the presence of chlorine dioxide, chlorite and dissolved metals, particularly Co^{2+}, has a strong influence in the behaviour of the redox potential after addition of bisulfite.

Keywords: Bisulfite; Desalination; Chlorine dioxide; Chlorate; Chlorite; Metals; Redox potentia

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Design, development and demonstration of a large-scale MD plant (400 m^3/d)

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Membrane distillation (MD) is a separation process using a vapor pressure, which results from the temperature difference between feed and permeate water. MD has several advantages compared to RO and other desalination processes for the treatment of saline water and wastewater. Because water is transported through the membrane only in a vapor phase, MD can offer complete rejection of all non-volatile constituents in the feed solution; thus, almost 100% rejection of ions, dissolved non-volatile organics, colloids, and pathogenic micro-organisms can be achieved via the MD process. But more importantly, due to the discontinuity of the liquid phase across the membrane, water flux in MD is not influenced by the osmotic pressure gradient across the membrane. Consequently, the greatest potential of MD can be realized through the treatment of highly saline solutions. Nevertheless, MD is still in its early stage in terms of commercial applications. Little information is available on implementation and scale-up of MD processes, which is essential for its widespread application in industry. In this context, this study intended to develop technologies for design of practical MD systems. Special focus was on the optimization of MD in terms of productivity (flux) and economics (energy efficiency). Theo-

retical models were developed to quantify the effect of design parameters on MD process performance. Hollow fiber MD modules were applied under vacuum MD configurations with thermal vapor compressor. A pilot-scale MD system with the capacity of 1 and 10 m^3/d were developed and operated to obtain scale-up parameters. Based on these results, 400 m^3/d MD plant was demonstrated using large-scale MD modules (10 m^2 per module). The results presented in this study offer general and practical guidance to design and demonstrate industrial-scale MD systems.

Keywords: Membrane distillation (MD); Scale-up; MD pilot plant; Model; Design; Energy efficiency; Desalination

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Ultrafiltration as a pretreatment in a seawater reverse osmosis desalination plant

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Surface seawater reverse osmosis (RO) desalination plants require a high quality of the feed water in terms of suspended solids and turbidity of water. Sometimes, the content of suspended solids to remove is excessive for a conventional pretreatment and, if the temperature of the feed water increases, it can develop a high microbiological content. In many cases, these characteristics are not contemplated in the design of all desalination plant. Therefore, the pretreatment is greatly affected causing problems of operation in the facilities.

The aim of this work was to design and evaluate the potential of ultrafiltration (UF) pretreatment prior to RO for desalting surface seawater. The UF system was directly operated in a convectional full-scale desalination plant. The competitiveness of UF pre-treatment concerning conventional pre-treatment was assessed by examination systematically the SDI (Silt Density Index). Results shows that UF provided better quality of permeate water and performance than conventional pre-treatment helping fouling control.

Keywords: Reverse osmosis; Desalination; Pretreatment; Seawater; Ultrafiltration; Fouling

Simulation of bipolar membrane electrodialysis (BMED) units by a validated process model

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The BMED technology can be used for the production or the regeneration of acid and base solutions by water dissociation. BMED has practical applications in several fields including in chemical and biochemical industry, environmental protection and, recently, even for brine valorisation. Many are the irreversibility sources involved in the BMED process. Some of them are related to the non-ideal transport properties of the ion exchange membranes causing undesired co-ion leakages and water flux. Furthermore, the presence of shunt currents through the manifolds (i.e. distributors and collectors of the solutions) decrease the current efficiency.

The aim of this work is to give a quantitative description of the main phenomena involved in BMED processes by a multi-scale model. Four different dimensional scales were effectively combined within the gPROMS platform. The lowest scale simulates the channels and includes two sub-models. CFD simulations are devoted to the estimation of concentration polarization phenomena and pressure losses while the other channel sub-model evaluates the physical properties

of the solutions. The middle-low level simulates the triplets, combining mass balance equations and fluxes through the membranes. Moreover, this model scale calculates electrical variables as the cell resistance and the electromotive force. Channel and triplet scales were implemented with 1-D discretization of the variables. The middle-high level is the stack model. It includes two sub-models: one predicts the shunt currents through the manifolds and the other one calculates the pressure losses in the whole stack. The highest level is the external circuit one, which computes the external pressure losses and the transient behaviour of closed-loop layouts. This multi-scale model was validated both by experiments with a laboratory test-rig unit and data already presented in literature. A sensitivity analysis was performed to gather useful information about the system performance by comparing current efficiency and net power density in different configurations. Simulation results show the effect of the operating variables (e.g. current density and mean flow velocity) and system geometry, highlighting the importance of the manifolds characteristics for the process efficiency. The thoroughness of this mathematical model provides a powerful tool for the design of BMED units.

Keywords: Electrodialysis; Bipolar membrane; Ion-exchange membrane; Water dissociation; Acid; Base; Modelling

Desalinated seawater for crop production in closed soilless systems with drainage treatment

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Agriculture in southeastern Spain region uses more than 80% of water resources. Desalted water is essential to ensure crop water demands, and actually 7.3% of the water consumed by agriculture in the region is obtained from desalination (both seawater and brackish water).

Within the current techniques of agricultural production, the closed soilless growing systems stands out, which have experienced an important boom in the whole world linked to the development and cheapening of plastics, and the advantages of this cultivation system. Greenhouse production stands out for its high efficiency in the use of water and nutrients. The favorable environmental conditions of the greenhouse contribute to reduce the consumption of water of the plants, increasing the yield of the crops and, therefore, the water productivity. It is estimated that in the south and southeast of Spain, 15% of the irrigated land under-greenhouse are under soilless system.

The present study presents the LIFE16 ENV/ES/000341 DESEACROP European project, which aims to demonstrate the sustainable management of desalinated seawater for crop production in closed soilless systems with the final goal of to strengthen resilience of these systems as a key productive, economic, social and environmentally friendly sector in the water-stressed Mediterranean region. For this, an experimental study is being carried out in which the crop response is being studied, both in soil and in soiless, using 3 types of water for irrigation: seawater desalinated water, well water and a mixture of these two at 50%. Another important activity and one of the main innovations of the project is the treatment of the drainage from the soilless crop, in order to minimize its impact on the environment and reduce water consumption. The study is being carried out in an experimental greenhouse and the drainage of the soilless crop is treated by reverse osmosis powered by photovoltaic solar energy to later reuse them in the irrigation of the crop.

Keywords: Desalination; Agriculture; Drainage; Reuse

Recycled NF and UF membranes: pılot plant results

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Reverse osmosis (RO) desalination process is a strongly consolidated technology, representing >65% of the currently installed desalination capacity worldwide. However, membrane technology still presents today an environmental challenge that must be faced to improve their sustainability: the management of end-of-life membranes modules. Currently the disposed membranes that have already exhausted their useful life are disposed mainly in landfills (i.e >800.000 end-of-life modules annually at worldwide scale). As an alternative to the current management (landfill disposal), SACYR AGUA and IMDEA AGUA have developed, the framework of the European project LIFE-TRANSFOMEM, a recycling protocol to transform the end-of-life RO performance into nanofiltration (NF) and ultrafiltration (UF) performance. The main scope of this work is to investigate the performance of the recycled membranes at pilot scale in 4 different applications: pretreatment of RO process, tertiary wastewater treatment, brackish water treatment and agricultural drainage treatment.

Keywords: Reverse osmosis; End-of-life membranes; Recycled membranes; Nanofiltration; Ultrafiltration

Design and construction of a high energy-efficient BWRO desalination plant in the south east of Spain

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The use of desalination technics has been shown to be essential for the water availability in different regions of the south of Spain for several uses such as drinking water, industrial and irrigation. Despite de use of modern technical crops, the continuous increasing demand combined with the lower availability from conventional resources, has given an advantage to the use of desalination to produce the needed water, in most of the cases, this is the only possible alternative to continue with the farming activities in the area. The BWRO plant described in this paper is a good example of it. It´s under operation since 2003, may and till now it has produced more than 120 Hm^3 of desalinated water for crops irrigation. Evidences of its success are the continuous expansions that has been done in these 15 years till reach the production flow of 25,000 m^3/d.

Inside this competitive frame, and with the concern and target of reducing the environmental impact of all the production process, it was requested by the owner of the BWRO plant to the operator a new expansion of a range that vary from 6,000 to 10,000 m^3/d production capacity. The designed for this new expansion include some solution to minimize the energy consumption such as the use of geometrical level between the wells and the BWRO plant, the use of high permeability membranes in a configuration with reduced specific flux and the use of a centrifugal energy recovery system (turbocharger)

The combined effect of all these energetic high efficiency strategies will let the operator to complete the desalination process with almost null additional energy consumption, therefore it will reduce drastically it´s cost.

The current paper shows theoretical calculation of energy savings as well as an evaluation of greenhouse gas reduction associated to the energy savings.

Keywords: Desalination; Brackish water; Energy savings; Energy consumption; Environmental impact.

Treatment of electroplating wastewater by combined membrane technologies and reactive precipitation process at a pilot scale

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A pilot plant composed of a diffusion dialysis (DD) module, a reactive precipitation unit and a membrane distillation (MD) module has been installed in Electroníquel S.A Company, an electroplating industry located in the north of Spain (Gijón, Asturias), to treat the liquid waste obtained from the copper electroplating process. The industrial effluent contains mainly H_2SO_4 and $Cu^{2+,}$ though also organic compounds used to improve the deposition of the heavy metal on the surface of the steel piece. The integrated process consists of firstly the treatment of the copper depleted bath (waste acid solution) as retentate solution with the DD module formed by anionic exchange membranes (AEMs). In this step, the acid is mainly recovered on the diffusate side of the AEM (recovered acid solution) while the Cu^{2+} is highly rejected (metal rich brine) by the nature of the membrane. While the recovered acid solution is recirculated to be reused on the electroplating bath, the metal rich brine is conducted to a continuously stirred-tank reactor (CSTR), in which the precipitation of Cu^{2+} as $Cu(OH)_2$ occurs using NaOH as fresh reactant. The slurry obtained is separated into solid and liquid phases using an industrial filter press. The liquid, composed mainly by Na_2SO_4 solution, is finally treated in a MD module to produce freshwater that can be used later on the electroplating process or as diffusate solution on the DD process.

This work studies the performance of the DD on the separation of the acid and the metal compounds, of the MD on the production of high purity permeate and also the maximum recovery of copper through reactive precipitation. Initially, the DD module was tested using a solution of H_2SO_4 as feed stream. Later, the Cu^{2+} was added to the retentate solution as $CuSO_4{\cdot}5H_2O$. The effect of different flow rates at retentate and diffusate sides on the performance was studied keeping constant the concentration of the compounds. The MD module was tested with an artificial solution of Na_2SO_4 at different thermostatic flow rates, feed flow rates and temperatures of hot and cold sides, studying the effect of these variations on the permeate production and on the specific thermal energy consumption (STEC). Moreover, the reactive precipitation system was tested with an artificial metal rich brine solution, studying the effect of the pH on the recovery of Cu^{2+}. Finally, real liquid waste from the copper bath was treated with the DD module in series with the precipitator system. The slurry obtained was filtered and when a high volume was collected, this was introduced in the MD module. The possible variation of the performance of the total process due to the use of the real solution was evaluated under optimal operating conditions obtained previously.

Fig. 1. Pilot plant installed at Electroníquel S.A. company. Front side (left) and back side (right).

Keywords: Industrial wastewater treatment; Sulphuric acid recovery; Brine valorization; Advances membranes technologies; Diffusion dialysis; Membrane distillation

The use of natural hydrostatic pressure for seawater desalination: theory, practical applications, and considerations

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As the global demand for freshwater skyrockets we increasingly turn to seawater desalination to slake our collective thirst. Desalination itself is a troublesome proposition as salt dissolves very easily in water forming strong chemical bonds that are difficult to break. But, as other water sources are depleted, and considering that oceans cover 71% of the Earth, desalination seems to be the only logical solution.

The most common seawater desalination technology today is membrane-based reverse osmosis (RO). This method is well established, but also has significant shortcomings, including the high cost of pre and post treatment, high energy consumption (though less than thermal distillation), expensive land acquisition, as well as environmental concerns. In an effort to mitigate these economic and ecological obstacles, researchers have considered a myriad of possibilities. The idea of ocean-based systems using the hydrostatic pressure at depth for osmosis has long been discussed and the concept/technique has been proven. However, while this eliminates many traditional cons of RO desalination, primarily energy consumption and environmental issues, it also introduces new concerns, such as transportation of the treated water to shore.

A United States-based company has now patented a technique that allows for the benefits of sea based hydrostatic systems on shore. It is accomplished by 'a well within a well' technique that is both economically and environmentally friendly. This presentation will review the science as well as the practicality of 'free hydrostatic pressure' techniques and offer scalable solutions for both small communities and large cities.

Keywords: Desalination; Reverse osmosis; RO; EconoPure; Hydrostatic; Green solutions; Environmentally-friendly; Ecological; Deep well; Membranes

New aspects of concentration-polarization in reverse osmosis and nanofiltration: theory and practice

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Concentration polarization (CP) is a well-known phenomenon, which adversely affect the efficiency of membrane-based separation processes. Here we studied features of CP that were largely overlooked thus far, revealing interesting theoretical aspects with industrial implications.

First, we address *the peak in the observed rejection* of *neutral solute*, and its subsequent decline, appearing with the increase in permeate flux. Although this phenomenon was previously reported (however scarcely), a theoretical analysis was not performed thus far, nor the practical implications were discussed. Here we investigated the equation describing the observed rejection as a function of flux, based on the solution-diffusion-film model. Surprisingly, this simple analysis revealed a new criterion governing the behavior of the observed rejection, in the form of a non-dimensional Péclet type number. Although fundamental, we could not find this criterion in the published literature. We applied this criterion in evaluating the practical implications of CP induced peak rejection for the case of organic micropollutants removal by nanofiltration membranes. The results indicated that a decline in micropollutants rejection could occur even when operating at typical operating conditions, especially when CP is enhanced by particulate fouling. We tested our analysis by performing numerical simulations of pressure-driven filtration in COMSOL Multiphysics, which couples fluid-flow and solute transport physics. We simulated cake-enhanced-concentration-polarization in COMSOL by integrating porous-media flow physics. The elaborated numerical simulations agreed with the simple theoretical model and confirmed the appearance of a peak solute rejection, which we also observed empirically.

Second, we addressed the concentration-polarization of charged solutes for the case of a feed solution containing trace ions and one dominant salt, a relevant case in many desalination applications. CP of trace-ions is affected not only by diffusion and advection, but also by electromigration. Although a theory for-trace ion transport including CP was previously presented by others, most of the later work on NF/RO modelling did not include CP, although it may have a profound effect on process performance. This may be attributed to the current lack of a closed-form analytical

solution. Here we revisited the solution-diffusion-electromigration-film model, deriving a fully analytical solution for the CP of trace-ions in a dominant salt solution. This resulted in a single closed-form expression, from which the solute concentration at the membrane surface can be directly computed. Together with the analytical expression for trace-ion permeation that we previously derived, a closed-form analytical solution for trace-ion transport is obtained. We further showed that for a limiting case relevant to RO, a compact and elegant CP expression appears as a natural extension of the film model. We used this theory to quantify the effect of electro-migration on the CP of scale-forming trace-ions, and the resulting effect on membrane scaling propensity. For different ionic mixtures, we found that the precipitation potential could increase by up to 60% or decrease by up to 42% when accounting for electromigration.

This work shed new light on the effect of CP on both solute rejection and mineral scaling. We introduce simple theories and accessible implementations which can improve modeling predictions of membrane process performances.

Keywords: Modeling; Transport; Desalination; Scaling; Film model; Electromigration; Micropollutants

Effect of intermittent and variable flux operation on fouling of reverse osmosis (RO) membrane in seawater desalination

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The potential effects of global climate change include longer periods of drought in some regions and an increase in the number of heavy rain events, resulting in imbalances between water demands and water supply all over the world. Seawater desalination using reverse osmosis (RO) has the potential to mitigate it, but it should have the capability to produced fresh water in a resilient manner depending on the level of the water shortage. Nevertheless, the intermittent and variable flux operation of the RO process generally leads to critical problems such as membrane fouling, scaling, and deterioration, increasing the maintenance. Accordingly, the objective of this study was to investigate the effect of intermittent and variable flux operation on the RO fouling. Experiments were carried out in a laboratory-scale RO system that could run multiple membrane modules in parallel. Model foulants that can simulate scale formation and biofouling were spiked in the feed solutions. The response surface methodology (RSM) analysis based on a composite design (CCD) approach was applied to specify the effect of important process variables statistically. This led to the development of the quadratic models for the prediction of fouling propensity in the RO system under intermittent and variable flux operation. Different fouling mechanisms under the different operating conditions were also investigated by examining the fouled RO membranes by scanning electron microscopy (SEM) and atomic force microscope (AFM). The methylene blue test was also carried out to confirm the integrity of the membrane.

Keywords: Reverse osmosis; Variable flux operation; Intermittent operation; Response surface methodology (RSM); Operation type

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GIS-based graphical user interface tools for analyzing solar thermal desalination systems and high-potential implementation regions

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Columbia university has been designated by the US-DOE to develop a user-friendly and open-access software in a 3-year project (2019-2021) that will enable a comparative evaluation of solar thermal desalination technology options and

will use geospatial data layers to identify regions of high-potential for solar thermal desalination. This is accomplished by integrating solar models with desalination models and enhancing their utility by providing GIS-based data inputs. It is envisioned that the software will simplify the planning, design, and valuation of solar thermal and solar hybrid desalination systems in the U.S. and worldwide. Individual experts on solar thermal desalination from Plataforma de Almeria, Spain, are consultants to this project. This project is also advised by several desalination industry partners.

We propose to present highlights and an alpha-version of this software at the EDS 2020 conference.

The software integrates a suite of geospatial data sources and techno-economic input parameters for simulating integrated power systems and desalination technologies all in one interface, with the analysis of solar thermal desalination systems set as the main objective. A desktop application is being developed for detailed analyses, and a web interface will be developed exclusively for quick visualization. For the desktop application, NREL's SAM software integrated to provide techno-economic functions for solar thermal and other power systems. Techno-economic modules for desalination systems are used in combination with SAM's functionality to deliver an analytical workflow for planning and designing solar thermal desalination systems in optimal locations via a user-friendly graphical user interface (GUI). This interface will provide user-defined inputs for technical design and cost parameters to allow for comparative analyses between solar thermal desalination and competing options.

Furthermore, options will be provided for designing integrated systems that would combine solar thermal desalination with grid providing services and/or desalination technology combinations.

The geospatial data layers include, but are not limited to, the following: Solar irradiance (NREL, NASA); irradiation conversions for tracking planes (isotropic and Perez models); seawater salinity (NOAA), topography (USGS); brackish water sources and depths (USGS); sectoral water consumption of domestic, agriculture, and industry (USGS); desalination and water treatment regulatory and permitting requirements (federal, state, local); wastewater treatment plants (EPA); thermoelectric power plants (EPA; current and future population estimates (Census Bureau). Cost data for the modeling framework will be extracted from desalination industry data via the Global Water Intelligence (GWI) database, utility rates (OpenEI), and fuel prices. Furthermore, we will account for waste heat recovery and geothermal resources to supplement solar thermal desalination. Users will also have the option to enter geospatial, economic, or technical data as needed.

The desalination techno-economic models will include: multi-stage flash, multi-effect distillation, membrane distillation, reverse osmosis, forward osmosis, thermal crystallization for zero liquid discharge, and some promising technology hybridizations with solar input.

The software will be made available through a desktop application for detailed analysis and a web interface for quick visualization. The desktop application can be used in three different modes:

Quick Analysis: the user can enter generalized techno-economic parameters such as total system capex, opex, energy conversion efficiency, and other high-level parameters. Once these top-down figures are supplied and the user chooses to run the analysis, map visualization within the GUI displays a rasterized layer showing feasible geographical regions with estimated levelized cost of heat (LCOH) and levelized cost of water (LCOW), as one example. Thus, the user will obtain a quick assessment of areas with high- potential for siting solar thermal desalination plants. This Quick Analysis mode is what would also be available via web interface.

Location-Driven: the user has the option to click on any location within the map embedded in the GUI or specify the coordinates of the point, select a region-of-interest polygon, or upload a GIS vector file with points and polygons of interest. The user can then select from different options the type of solar thermal technology, other power systems, and desalination systems to integrate and simulate. The output will display location-specific results containing ranked optimal design scenarios by minimum LCOH, net-present-value, and LCOW.

Design-Driven: the user enters the techno-economical parameters of a desalination system without specifying a location. Running the analysis would then display a map result for each simulated system to identify high-potential areas for implementation. This mode will also enable the user to add desalination technologies to the library as advances in innovation occur. Furthermore, this mode will allow the user to implement and test technology hybridizations, for example: Forward osmosis (FO) with reverse osmosis (RO); membrane distillation (MD) and RO. A hybridization of MD with RO can take advantage of MD's insensitivity to the salt concentration of the feed stream, so it can be employed after RO to achieve greater recovery of product water and further concentrate the brine. Also MD is driven by low- temperature thermal energy. Successful integrations of FO and MD with conventional desalination technologies (e.g., RO, MED) have the potential to significantly reduce the energy requirement of seawater desalination and bring down the LCOW. In addition to individual system analysis, providing options for hybridization that enhance the value of solar energy will enable balanced comparative assessments between solar thermal desalination and competing technologies.

Investigation of membrane distillation affected by scale formation during concentration of seawater brines

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Water scarcity is one of the most pressing and central issues that humanity faces in the 21st century. In addition to a responsible water use and management, sustainable, energy- efficient and cost-effective technologies for desalination of seawater and brackish water are required. There is also a growing need for increasing the water recovery and lowering the environmental impact of brine effluents. Furthermore, stricter regulations, rising costs for wastewater disposal and the increasing water scarcity are driving zero liquid discharge or minimal liquid discharge approaches to become a beneficial or even necessary option for wastewater management in many water-intensive industries.

Membrane distillation has attracted considerable attention as a potential alternative to conventional thermal and membrane-based separation and treatment technologies in various fields of application. It is a thermally driven process for the separation of vapour from a liquid stream through a hydrophobic microporous membrane. While desalination has been the most studied application so far, brine concentration and wastewater treatment were identified to be the most promising future applications for membrane distillation. Since reverse osmosis can be applied to feed waters only within a limited salinity range and membrane distillation is capable to treat highly concentrated brines without any significant flux decline, membrane distillation has emerged as alternative technology for brine concentration after the reverse osmosis stage.

However, a commercial breakthrough of membrane distillation on a large industrial scale has not been achieved so far. Fouling, which is the unwanted deposition of material on heat and mass transfer surfaces, is considered to be one of the barriers to the full implementation of membrane distillation. Experts from industry believe that the research focus should be on understanding fouling and wetting in membrane distillation. When applied to concentrated salt solutions, scale formation is the most common form of fouling expected in membrane distillation. A deeper understanding of scale formation is necessary for scaling prevention and process optimization and, thus, for a successful implementation of membrane distillation.

The current study focusses on numerical and experimental analyses of membrane distillation processes affected by scale formation. Mathematical models of coupled heat and mass transfer phenomena in direct contact and air gap membrane distillation processes were implemented using MATLAB and combined with the geochemical equilibrium reaction software iPHREEQC. The scale layer was considered as a resistance to heat transfer as well as to mass transfer. The numerical analysis was accompanied by an experimental study in a lab-scale membrane distillation system. Scale formation and the effects on the process performance were systematically investigated in direct contact and air gap membrane distillation with highly concentrated seawater brines under various operating conditions. Novel insights into the influence of the operating conditions on scale formation and the effects of scaling on the process performance will be presented. Limiting supersaturation conditions for an operation of the membrane distillation process without performance decline will be discussed.

Keywords: Membrane distillation; Brine concentration; Scale formation; Performance decline; Experimental study; Modelling

CFD parametrical study of spacer-filled channels for membrane processes

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This work presents a CFD analysis aimed at characterizing flow and mass/heat transport characteristics in spacer-filled channels for membrane processes. In particular, a parametrical study was conducted for spacers made of overlapped or woven filaments angled at 90°, by letting the pitch to height ratio, the flow attack angle and the Reynolds number vary. Under the assumption of fully developed conditions, a periodic unit cell was simulated as representative of the

whole module. The governing equations include continuity and Navier-Stokes equations, transport of enthalpy and convective-diffusive transport of solute. A grid-sensitivity of results was preliminarily assessed, thus choosing meshes providing results practically unaffected by the discretization degree. The finite-volume Ansys-CFX® code was used.

Simulation results were elaborated in the form of dimensionless quantities, namely friction factor (*f*), Sherwood number (Sh) and Nusselt number (Nu). Therefore, results apply both to membrane processes in which heat transfer plays the main role, such as membrane distillation, and to processes in which mass transfer dominates, e.g. direct and reverse electrodialysis or filtration and reverse osmosis.

CFD predictions for Nu and *f* were validated against experimental data. In particular, an experimental set-up was developed to get local information on heat transport by a technique based on liquid crystals thermography and digital image analysis.

Results showed that the parameters studied have complex effects on flow and associated transport phenomena. Overall, woven spacers are more effective in the enhancement of mass/heat transfer compared to overlapped spacers, but at the expense of larger pressure drops. In the transitional Reynolds number range, SST k-ω turbulence model predictions merge well with laminar simulation trends.

By implementing well-established and validated physical models and numerical methods, the present study produced a large database that provides a more systematic understanding of the transport mechanisms in spacer-filled channels for membrane processes. Moreover, the present outcomes provide correlations to calculate pressure drop and temperature/concentration polarization effects, which can be useful, for example, in comparative studies or process modelling.

Keywords: CFD; Membrane process; Electrodialysis; Reverse osmosis; Membrane distillation; Modelling

Highly efficient high-pressure pumps and energy recovery devices for retrofitting

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Nowadays due to serious water scarcity around the world, the desalination industry is looking for more efficient systems in order to save on energy and bring down CO_2 emissions.

Different key players are looking into other technologies and alternatives to an obsolete system with Centrifugal pumps and Pelton turbines.

The SWRO is an energy intensive process which demands a lot of energy, so it is now after several years of operation with old desalination technology when retrofits start making sense. The new configuration systems consisting in very efficient high-pressure pumps and energy recovery devices, can offer more flexibility, more energy savings and more important, can adapt to changing demands during the year.

This presentation will describe the benefits of using high pressure positive displacement pumps and energy recovery devices from Danfoss for retrofitting.

Keywords: Energy saving; Retrofit; Energy cost; Efficiency

A novel 2D process model of electrodialysis units in cross-flow layout for the assessment of membrane deformation effects

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Electrodialysis (ED) is an electro-driven process based on the use of ion exchange membranes (IEMs). In the last years, many studies have been conducted to promote its application for drinking water production at a larger scale. In

ED, an electric field is applied at the electrode compartments in order to desalinate the feed salt solution by exploiting the selective transport through the IEMs. The feed channels between the membranes are created by means of net spacers or built-in profiles. Detrimental effects of membrane deformation have widely been shown in different membrane processes. This aspect has been neglected with reference to ED applications. However, a transmembrane pressure (TMP) distribution may arise in ED units due to an uneven pressure distribution in the two fluid channels, thus causing membrane deformation and flow redistribution. This can occur in non-parallel configurations, e.g. cross-flow arrangements.

In this work, a novel multi-scale 2-D process model of ED cross-flow units is presented. The model describes transport and electrochemical phenomena occurring in ED systems at the scale of an entire cell pair. Moreover, the model includes the simulation of the fluid-structure interaction (flow redistribution and membrane deformation) [1] by using correlations obtained from small-scale numerical simulations (structural mechanics and computational fluid dynamics) [2,3]. Results show that mild deformations have a negligible impact on the performance of the ED process for water desalinations. On the other hand, configurations characterized by larger membrane deformations (e.g., thin membranes) had more significant effects. For example, the specific energy consumption per unit volume increased by 6% with respect to that predicted by neglecting membrane deformations.

Keywords: Electromembrane process; Water desalination; Membrane deformation; Flow reldistribution; Process model

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A novel 2D model for the assessment of deformation-induced flow redistribution phenomena in electrodialysis units

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Membrane-based processes are widely adopted in different industrial applications. Electrodialysis (ED) is an electro-driven process with promising perspectives for large-scale applications in water desalination, food industry and many other engineering fields. The repetitive unit of an ED stack is the "cell pair", which is made of an anion- and a cation-exchange membrane, and a concentrate and a diluate channel. The channels are created by net spacers or built-in membrane profiles, which separate the membranes. In the last years, the ED process has largely been characterized by both experiments and modelling tools. In particular, much effort has been devoted for a better understanding of hydrodynamics and transport phenomena. Although the pressure difference between adjacent channels (commonly referred to as transmembrane pressure, TMP) is often small in ED applications, significant pressure drops arising in large-scale stacks lead to non-negligible TMP values in non-parallel or asymmetric configurations. In turn, the TMP induces local membrane/channel deformations, which alter the hydraulic friction, thus causing an uneven flow distribution in the channel.

In the present work, a novel fluid-structure interaction model aimed at investigating the flow distribution in ED units associated to membrane deformations is presented [1]. Specifically, a 2D modelling approach simulating two adjacent fluid channels of a cell pair bounded by profiled membranes was adopted. Taking into account the spatial change of the channel permeability and its dependence on the local TMP, an iterative procedure was developed to solve the continuity equation and the Darcy law in the channels. Correlations for the permeability as a function of TMP and of the fluid velocity were obtained by mechanical and fluid dynamics numerical simulations of a small periodic domain of the same cell pair [2,3]. Square stacks of 0.6 m sides were investigated at superficial velocities ranging from 1 to 10 cm/s considering a cross-flow configuration.

Results showed that at low velocities the TMP distribution does not alter significantly the fluid redistribution. On the contrary, at a superficial velocity of 10 cm/s, the channel height was found to vary up to ~±17% with respect to the undeformed value. Moreover, the superficial fluid velocity exhibits a considerable redistribution, with departure from

the average from –25% up to 39%. The present results can be implemented into process models for better understanding the impact of the flow redistribution on the process performance of ED units.

Keywords: Electromembrane process; Membrane deformation; Flow maldistribution; Fluid structure interaction; Darcy flow

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Lessons learnt from the operation of solar membrane distillation pilot plants

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For more than 10 years, the operation of membrane distillation at pilot scale powered by solar thermal energy has been studied at Plataforma Solar de Almería and the University of Almería, in SE Spain. Different commercial MD modules have been evaluated, assessing their productivity, heat efficiency and permeate quality. Spiral modules and multi-effect plate and frame modules have been tested in several pilot plants, operating in different configurations: air-gap, permeate gap, multi-effect vacuum and vacuum-enhanced air-gap. All the pilot plants are powered by solar heat, using stationary solar thermal collectors in fields of different sizes both regarding total collector area and the storage tank used for buffering short-term variations in the radiation.

The objective of this work is to describe the different operational challenges that have been encountered during the tests and how they influence not only the performance itself but also its monitoring and subsequently the assessment of the performance. Different aspects found relevant are discussed, and suggestions and recommendations are given based on the experience and the conclusions reached after the analysis.

A decrease of permeate quality due to leakage or membrane wetting was observed. While this is a common feature of MD when restarted during intermittent operation, and is solved as the operation goes on, an irreversible increase of the permeate conductivity was reached as the feed concentration increased, indicating a limitation that changes for the different modules, although always above 175 g/l. The implications of this for the implementation of MD are discussed.

In addition, a discussion of the precision of the sensors (mostly the temperature probes) and how it affects the evaluation of the performance is presented. This is shown to be an important issue when monitoring the operation and is also subject to degradation with time. For example, corrosion and dirt on the temperature probes and the signal cables can have significant influence on the measurements with an impact on the calculations of the use of energy. It has been found that a temperature variation of 1°C in one sensor can reflect on an 8.3% change of permeate flux and a 7% change of specific thermal energy consumption, affecting the analysis of the performance in the long term. The correct placement of the sensors is also found important, illustrations and recommendations are given.

Furthermore, the influence of operation with solar energy, especially regarding the management of the heat supply and its buffering in the heat storage, is shown and discussed.

Finally, an overview of the best performance results obtained will be shown to illustrate the current state of the art of the technologies.

Keywords: Membrane distillation; Pilot plant; Energy efficiency; Experimental evaluation

Operational long-term experience in solar desalination of seawater using a commercial vacuum multi-effect membrane distillation system

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Membrane distillation (MD) is a low-temperature thermal desalination technology that can be implemented at small- and pilot-scale for the desalination of seawater in regions without high freshwater demand. A pilot-scale solar desalination system was assessed at the University of Almería for the desalination of real Mediterranean seawater from a beach well. This system integrates a solar field of 15 flat-plate collectors with total aperture area 35.9 $m^{2,}$ and a novel commercial MD unit (named MDS-40B) made by the Dutch company Aquaver. The desalination module is based on the memsys vacuum multi-effect MD (V-MEMD) technology, and consists of a steam raiser, a condenser, and four effects, in which the latent heat from the condensing distilled vapour is recovered serially for producing more vapour at reduced pressure from the circulating liquid phase. Additionally, the MDS-40B includes a particular modification in the condenser to recover latent heat from the last effect as sensible heat in the circulating cooling seawater, preheating thus the feed and avoiding the use of a separated cooling circuit. The best performance indicators obtained were 54.4 l h^{-1} permeate and 207.7 kWhth m^{-3} (equivalent to gained output ratio 3.19), with hot inlet temperature 75ºC and feed flow rate 150 l h^{-1}.

An experimental campaign long enough to cover different seasons of the year was made to evaluate the performance of the system. On one hand, limitations in the cooling capacity of the condenser were identified under different operational conditions, causing as collateral effect the loss of vacuum inside the module and hence system malfunctioning. On the other hand, the natural increase of seawater temperature yielded up to 40% loss of permeate productivity.

Experiments were performed in days with different availability of solar radiation (clear, cloudy and rainy days), in order to assess how the system deals with short-term disturbances in solar radiation, and to investigate subsequent control strategies of the facility. Tests results were used in a previous quasi-dynamical model developed at Plataforma Solar de Almería for estimating the annual permeate production under different setpoints of hot inlet temperature, taking into account typical meteorological data of Almería (Spain). Maximum annual permeate production estimated was 70.5 m^3.

Finally, significant scaling formation after the treatment of 36 m^3 seawater in absence of chemical pretreatments was observed, and a corrective measurement based on a biodegradable antiscalant was proposed.

Keywords: Solar desalination; Heat efficiency; Pilot plant; Vacuum multi-effect membrane distillation; Experimental tests

Technical and economic analysis of ultrafiltrated rain water for potability powered by photovoltaic energy

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An alternative process for water purification using ultrafiltration membranes (UF) possesses several benefits, including good permeate quality, low area requirement for installation and low energy consumption. Considering the average annual rainfall in Passo Fundo-RS (BRA) of 1,746 mm, this work aimed to evaluate the ultrafiltration process for rainwater potabilization, taking the technical and economic factors of the system into account. In addition, we evaluate the use of photovoltaic energy to powered the system. A pilot scale rig was installed for rainwater capture and purification by UF in the city of Passo Fundo-RS (BRA). For ten months, the quality of raw, filtered, filtered and chlorinated water was monitored and potability criteria were checked. With the average permeate flux of 135 L/hm^2, the filtered and chlorinated water did not present coliforms or organic matter above the allowed by the Brazilian legislation or Directives of the European Union (CEU, 1998). In addition to the operational criteria, the total system costs were analyzed to assess the feasibility of ultrafiltrating rainwater with and without solar energy. The economic analysis performed to this effect, consisted of six scenarios, 230 m^2 of coverage area, 2,300 m^2 and 11,500 m^2; for each coverage area the simulation was

also carried out with and without photovoltaic panels for system energization. For each case outcome was obtained in terms of Internal Rate of Return (IRR) and the Payback Period. The analysis revealed and confirmed the potability pattern for ultrafiltration of rainwater after chlorination. All scenarios were viable, except for the 230 m² without the adoption of solar panels.

Keywords: Drinking water; Solar energy; Ultrafiltration; Economic feasibility; Payback

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Membrane distillation for solar applications

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A new upcoming method, membrane distillation (MD), is a combination of thermal and membrane technologies. MD uses a temperature difference across a semipermeable hydrophobic membrane. The temperature difference creates a vapor pressure difference which is the driving force of MD to distillate seawater for drinking water purposes.

In conventional MD, the heat is usually provided by waste heat but can also be powered with solar energy. In the case of solar powered MD, PV panels are used to provide the electricity needed to run the pumps and heat collectors are used to heat the water to drive the process.

It can be imagined the production of water is dependent on the irradiance of the sun where the heat input temperature can range between 60°C on a cloudy day to 80°C on a sunny day [1]however, its intermittent nature requires a non-stationary optimal operation that can be achieved by means of advanced control strategies. In this paper, a hierarchical control system composed by two layers is used for optimizing the operation of a SMD pilot plant, in terms of thermal efficiency, distillate production and cost savings. The upper layer is formed by a Nonlinear Model Predictive Control (NMPC. Not only temperature but also location has a big influence on the production capacity.

During nighttime the input of heat will be stopped leading to a shutdown in water production which limits the uptime of the installation where higher costs per m^3 produced water is the outcome.

Night production is possible if addition measures like a tank for heat storage and batteries are added to the solar-MD system enabling to use the system more economically.

Several mathematical simulations [2] are made to optimize an solar-MD system for different locations to give an impression about costs and optimal configuration. Several parameters where taken into account for optimizing the costs of water production like solar thermal collector surface, thermal storage and membrane module configurations.

In contrary to most articles and presentations on MD describing flux optimization this application is all about energy optimization leading to an optimization of the water output against the lowest costs. Several strategies are studied, such as for example the use of thermal storage, and some main guidelines can be concluded for future projects.

Keywords: Membrane distillation; Solar power; Optimalization

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Long term operation of hollow fiber ultrafiltration plants

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Ultrafiltration was introduced into the water industry in the 1990's on a small scale. Since the 1990's ultrafiltration is becoming a mature technology. Over the past two decades multiple large scale plants have been commissioned and successfully operated. With an average membrane life time of 10 to 15 years, these plants are calling for membrane replacement.

This paper describes replacement strategies for a number of large scale potable water plants across Europe. Although a direct replacement with identical membranes can be done, a better strategy is to take product and process improvements into consideration. Pentair X-Flow is one of the pioneers in low pressure membranes; not only as one of the first companies to introduce ultrafiltration membranes in the drinking water industry, but also with continuous support of customers during operation of the membrane plants. This support allows us to gather valuable information that can be used for optimizing membranes and plant operation.

Two case studies are presented in this paper:

- One plant is located in Holland. This plant employed the first generation of Pentair X-Flow's ultrafiltration membranes (Xiga 35) and has been successfully operated since 2003. After 16 years of operation, the membrane replacement allowed for introduction of a new generation of ultrafiltration membranes (Xiga 40) and for a direct comparison of the original membranes and the replacement membranes.
- The second plant is located in Germany. This was one of the first plants to be equipped with the Xiga 40 membranes in 2005. After 14 years of operation, the customer opted for replacement with identical Xiga 40 membranes.

For both plants one of the surprising differences is that the permeability appears to be more stable. The initial (clean water) permeability of the newer ultrafiltration membranes is slightly lower as the original membranes, but the typical saw tooth profile is less pronounced: the permeability drop during filtration cycles is smaller. The end permeability, immediately before cleaning appears to be higher. This allows for more stable and predictable operation and overall lower operational costs.

In conclusion it can be stated that customers do benefit from a long term relationship with Pentair X-Flow as membrane supplier. This allows for planning and execution of membrane replacement in a timely manner and allows for improvements in operation to be done at minimal cost and effort.

Keywords: UF; Membrane lifetime; Membrane replacement; Hollow fiber

Innovative solar thermal-driven desalination systems based on solar microgas turbines: SOLMIDEFF project

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This paper deals with the preliminary design and cost assessment of a novel solar desalination technology that will be developed throughout the SOLMIDEFF project execution.

SOLMIDEFF is a multidisciplinary project aimed at conceptually developing an innovative, small-scale technology for water production in remote, off-grid locations thanks to its integration into a solar microturbine power generator. Solar micro gas turbines in the range from 5 to 30 kWe have recently been demonstrated in Europe (OMSoP project), crediting the potential to produce solar electricity and high-grade heat at 250°C, and enabling easy hybridization with liquid or gas fuels for extended (even continuous) operation. In this scenario, this project proposes the integration of a solar microturbine and a bottoming desalination system made up of an electric-driven reverse osmosis system and a heat-driven zero liquid discharge (ZLD) unit, both of which incorporate profound innovations with respect to the current technology.

For the reverse osmosis unit consuming the power produced by the turbine, new concepts on plant configurations are assessed considering both brackish water and seawater reverse osmosis desalination. For the ZLD system, in addition to the concentration of aqueous effluents from desalination and industrial processes, selective precipitation of dissolved components will be studied in a specific bubbling chamber design for the project.

Keywords: Reverse osmosis; Solar desalination; Seawater desalination; Zero liquid discharge

BWRO operatıon optımızatıon wıth energy recovery devıces

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The energy required to desalinated seawater has been reduced by half. Energy recovery devices (ERDs) have contributed more than half this reduction. Innovation and new generations of reverse osmosis (RO) membranes have also driven meaningful energy savings.

Available ERDs include isobaric and centrifugal devices. Isobaric ERDs, also called pressure exchangers or work exchangers, transfer energy from the membrane concentrate stream directly to the membrane feed stream, thereby reducing the duty of the high-pressure pump. Centrifugal devices, also called turbochargers, recovers hydraulic energy from the high-pressure concentrate (brine) stream in the RO process and transfers that energy to a feed stream. That feed stream may be seawater entering a single stage RO membrane block, or it may be first stage brine stream being boosted in pressure for a second stage membrane block for further recovery of permeate or flux balancing.

The majority of the two-stage brackish water reverse osmosis (BWRO) conventional designs require permeate backpressure, hybrid membrane designs, or an insterstage booster pump to balance the flux in each stage. This paper will present an analysis of six different configurations to optimize flux balance, minimize energy consumption, and increase membrane recovery rate. It addresses a full analysis for two stages of BWRO systems for a standard feed water quality with Total Dissolved Solids (TDS) 1500 ppm, 3000 ppm, and 5000 ppm. Estimated energy savings, fluxes, increase in permeate flow rate are presented.

Keywords: BWRO; Energy consumption; Flux; Membrane recovery

Current status and future outlook of sustainable seawater reverse osmosis desalination as “green desalination” in the 21st century

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1. The President Kennedy’s dream on 21 June 1961 is going to realize

1. “Today is an important step to the achievement of one of man’s oldest dreams, securing freshwater from saltwater”
2. “I can think of no cause and no work which is more important not only to the people of this country but to people all around the globe, especially to those that live in deserts on the edge of oceans.”
3. “This is one of the greatest scientific breakthroughs of history, and I am sure before this decade is out, we will see more and more evidence of man’s ability, at an economic rate, to secure freshwater from saltwater, and when that day comes, then we will literally see the deserts bloom.”
4. “This work is more important than any other scientific enterprise as it serves the interest of men and women everywhere.”

2. Background of “Green Desalination”

1. Big discussion happened from the two TV news on last January 2019.

- Bloomberg News/ 9 January 2019/ Saudi thirst for water is creating a toxic brine problem
- BBC News/ 14 January 2019/ Concerns over increase in toxic brine from desalination plants

2. These news sources were based on the article published in Elsevier: The state of desalination and brine production: A global outlook by Edward Jones et al.

Rising water demands and diminishing water supplies are exacerbating water scarcity in most world regions. Conventional approaches relying on rainfall and river runoff in water scarce areas are no longer sufficient to meet human demands. Unconventional water resources, such as desalinated water are expected to play a key role in narrowing the water demand-supply gap. About half of the world''s seawater desalination is produced in four countries in the Middle East. It pointed out that reducing the negative impact on the environment and reducing the cost of water production are the future issues.

SWCC responds sensitively to the above article, using advanced technology and science, emphasizing that water environment management is carried out at all stages of project development and implementation from planning to design, construction and operation. Furthermore, DTRI has announced that it is promoting "Green desalination initiative" in cooperation with developed countries.

IDA also responded to this article, and in an effort to publicize the IDA''s response to the IDA Global Connections Spring 2019, conducted an opinion gathering on the environmental impact of seawater desalination to Energy and Environment Committee (EEC) members.

"Mega-ton Water System" project in Japan has been involved in "Green Desalination" since 2009.

3. Current Status of SWRO plants –"Mega-SWRO" plants is coming as "Mega-ton Water System" project has been predicted in 2009

Seawater reverse osmosis desalination (SWRO) requires less energy compared with the distillation method and thus is an important technology except Middle Eastern countries where energy costs are higher. Recently, even Middle Eastern countries where the distillation method is still a major technology, have begun adopting the RO method in new desalination plants in line with government policy and the trend is for the development of larger (in excess of half mega-ton per day or mega-ton per day size) so-called "Mega-SWRO" plants.

4. Sustainable SWRO Desalination as "Green Desalination" "Mega-ton Water System" project

With these trends in the global market, the requirements of sustainable SWRO desalination as "Green desalination" for the 21st century are summarized under three subjects:

1. Energy saving:
   A. New Advanced Low Pressure SWRO membrane
   B. Low Pressure two stages high recovery SWRO System
   C. Expected Energy Reduction by using Mega-ton Technologies

By combining a new low pressure SWRO membrane and a low pressure two-stage high recovery SWRO system, 20% energy reduction was possible. And 30% energy saving in total was also possible as the SWRO-PRO (pressure retarded osmosis) hybrid system.

2. Low environmental impact
   A. History of anti-biofouling trials and New System for future SWRO system
   B. Chlorine sterilization of seawater has no effect
   C. Quantitative RO chemical cleaning interval due to biofouling by biofouling monitoring technology.

   For low environmental impact as "Green desalination", less chemical and less chemical cleaning for reliable operation have been established.
3. Verification project for energy saving & low environment impact seawater desalination system in Saudi Arabia

5. Concluding Remarks

1. Global SWRO Desalination Market has been expanded rapidly in the Gulf, especially Saudi Arabia and UAE. The Plant capacity development is good agreement with the prediction of the "Mega-ton Water System" project at 2009.
   1) The price of desalinated water dropped to \$0.50/m^3 or less than \$0.50/m^3.
   2) SEC (kWh/m^3) dropped to below 3.5 (kWh/m^3) at Red Sea, Saudi Arabia.
2. Energy saving and Low environment impact considering "Green Desalination" are very important.
3. Energy saving (20-30%) is established by advanced new technology such as recovery system of "Mega-ton Water System".

In addition to this, low cost new energy resources is very important.

4. As low environmental impact, new system proposed by "Mega-ton Water System" will contribute to less chemical for reliable plant operation and less chemical cleaning for "Green Desalination".

Keywords: Seawater reverse osmosis; Low pressure seawater reverse osmosis membrane; Biofouling monitoring technology; Pressure retarded osmosis (PRO); Renewable solar energy; Green desalination

Machine Learning saves energy in seawater reverse osmosis plant

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Seawater reverse osmosis requires a lot of energy to produce water and costs plant owners millions of dollars every year. Optimizing a plant manually, to match the design conditions, takes time that operators and control room operators do not always have. Additionally, optimization is made more difficult when a plant has multiple trains to track performance and optimize manually.

A Machine Learning algorithm was developed to help plant operators produce the right quantity and quality of water, without the distraction or need for lengthy calculations that require several assumptions that can often be inaccurate. Of note is that where the reverse osmosis math has limitations, machine learning was found to be more accurate. Machine learning was also codified and deployed to SCADA to predict variations/trends in water temperature and salinity and undertook multiple set point changes per day, ultimately minimizing energy use and adapting to consistently fluctuating feedwater conditions.

To achieve energy savings, the Machine Learning altered the RO plant recovery. While this parameter is static at many RO plants, by frequently analyzing plant operating conditions the recovery could be varied to achieve optimal energy use while still conforming to the main plant design constraints, such as lead element recovery, lead element flux constraints, etc. In this case the algorithm regularly recommended values for three set points to the seawater RO plant operators 1) high pressure pump flow, 2) pressure exchanger booster pump flow and 3) pressure exchanger valve to drain position.

By applying Machine Learning software to a 4,000 m^3/d seawater RO plant based in Australia, the plant could have saved daily up to 18% energy and on average 9.7% over six months. For this particular plant size, the OPEX saving would amount to EUR42,000 every year.

Results from the study will be presented in the full paper, showing energy savings and required changes to recovery set points. The plant remains in operation using the algorithm and continues to be fully deployed to the SCADA system which undertakes daily set point changes to the seawater RO process.

Keywords: Machine learning; Artificial intelligence; Seawater reverse osmosis; Energy saving

Towards an energy-efficient waste water recycling in industry: Extending conventional application ranges of pressure-driven membrane processes

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The approach of a circular economy involves an efficient use and reuse of raw materials in industry. In this regard it is one of the most important objectives to close water cycles and ensure the availability of this resource. Therefore, the development and optimization of innovative technologies for a sustainable water recycling are of major ecological, economic and social importance. Striving for a wastewater-free production, economically viable concepts for the concentration of process waters with high osmotic pressures are required. To replace energy-intensive thermal processes, it is expedient to extend the application range of energy-efficient pressure-driven membrane processes.

In this context, this study presents opportunities and challenges accompanied with the use of common membrane materials and element constructions for an application out of their conventional range. This approach aims to provide technical solutions with rather high readiness levels and the potential to maximize the achievable concentration factor and minimize the costs of the subsequent thermal concentration step. To overcome the limited application range of reverse osmosis and related processes and shift it towards higher concentrations, it is necessary to either increase the feed pressure or reduce the transmembrane osmotic pressure difference.

In order to establish a better understanding of the behavior of spiral-wound elements under exceptional feed pressures and concentrations, this study focusses on the experimental investigation of the performance of 4″- elements for feed pressures of up to 120 bar and concentrations exceeding 80 g/L NaCl. To identify application-specific performance-limiting aspects, permeability as well as salt rejection and their dependence on the operating conditions were examined. For post-experimental analysis various methods for element and membrane autopsy were used to characterize irreversible material changes caused by excessive mechanical stresses.

The results clearly indicate that available standard equipment can expediently be applied under extreme operating conditions to enable an energy-efficient concentration of high-salinity brines. The outcomes also reveal an intensified and undesired deformation of the polymeric membrane during high-pressure exposure considerably significantly affecting the process performance.

Keywords: Wastewater recycling; Pressure-driven membrane processes; Spiral-wound element; High-salinity brine

Efficient membrane distillation systems and their prospectiverole in industrial water desalination and reuse

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The world continues to face the serious challenge to provide sufficient, safe water supplies for populations and industries. In this context, desalination and water reuse play a key role to meet current as well as future clean water needs. Due to their main application for the production of drinking or fresh water for industrial processing or within water reuse concepts, water and seawater desalination technologies are fundamental for the development and ongoing operation of the industrial manufacturing.

Membrane distillation is dubbed as a promising technology with regard to various industrial and also drinking water desalination challenges. As persistently reported, different configurations as well as varying approaches for membrane modules exist. However, still only very few actual large-scale applications can be found.

This study points out the crucial criteria which must be met to beneficially use this technology in some major industry sectors. In this context, a straight comparison of typical key unit operation indicators (KUOI) for main state-of-the- art seawater desalination processes was used to clearly indicate the particular advantages offered by an efficient membrane distillation system.

Based on this information, specific industrial applications were identified and outlined regarding the fields of desalination, drinking water and beverage industry, pharmaceutical industry, agro-industry, chemical industry as well as oil and gas industry.

Complying certain technical requirements — especially concerning an efficient energy recovery concept — and positioned reasonably within a process chain, membrane distillation is a prospective technological solution for a sustainable treatment of process waters and contributes to improve the water management efficiency. This work shows that with its use advanced tasks concerning water use and reuse can be solved in an economically and ecologically favorable way, whereas unfavorable processes can be replaced. As membrane distillation can play a significant role to substantially increase the water availability across various important sectors in industry, every effort should be made to put this forward-looking technology into industrial practice.

Keywords: Membrane distillation; Industrial water desalination; Water reuse

Cleaning complex metal foulants from membranes

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Iron and manganese are the most commonly found metals in water and easily oxidize from the soluble to insoluble forms to precipitate within a membrane and foul the surface. The presence of these metals could also be due to use of coagulants (Aluminium and Ferric salts) in the pre-treatment of waters, both RO and UF membranes commonly show presence of metals as secondary component of fouling due to poor pre-treatment. Additionally, metallic particles may arise from corrosion and can cause membrane abrasion damage by scouring or imbedding into the surface; thereby effecting membrane integrity.

Multi component foulants with metals can be difficult to remove and require multiple cleaning procedures at varying pH. The extremes of acid and alkaline conditions can have a detrimental effect on the membrane reducing lifespan and salt rejection.

Our laboratories have conducted over 1200 membrane autopsies in the last decade. The autopsy identifies the nature of foulants and cleaning tests establish the best chemistry and protocols for foulant removal. This paper shows the results of the effectiveness of various cleaner chemicals for removing complex multi components foulants. Two specific cleaner formulations were compared against existing cleaners; one using a non-hazardous neutral pH cleaner and a new iron foulant cleaner.

Keywords: Fouling; Metals; Iron; Cleaning; Autopsies; Membranes

Water conservation in greenhouses using membrane-based desalination technologies for regeneration of liquid desiccants

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Greenhouses in desert areas are conventionally cooled through evaporative cooling, a process with high water requirements [1, 2]. In addition to this, crops require high amounts of water for irrigation [3-5]. This extensive water requirement limits the application of greenhouses in countries with scarce water resources. Desiccant cooling has been proposed to overcome this limitation, which may decrease the water requirements of traditional cooling technologies but has high energy requirements for the regeneration of the liquid desiccant (LD). By absorbing moisture from the greenhouse, liquid desiccant air conditioning (LDAC) systems are able to decrease the indoor humidity and temperature. During cooling and dehumidification, the LD becomes diluted and must be regenerated [1]. Traditionally, the regeneration is done by evaporating the absorbed moisture, but phase change makes this an energy intensive process [6]. Recent advances in LD regeneration aim to decrease the energy requirement of the LD regeneration by using membrane-based desalination technologies, such as membrane distillation (MD), reverse osmosis (RO) and electrodialysis (ED) [7, 8]. The use of desalination technologies has an additional advantage, that is the reutilisation for irrigation of the water that otherwise would be evaporated and wasted [9]. LDAC applications focus mainly on the cooling and dehumidification performance, leaving aside the possibility of water reutilisation. Apart from MD, RO and ED, also nanofiltration (NF), forward osmosis (FO) and thermoresponsive (TR) solutions could be employed as LD regenerators. The presentation will outline the feasibility of using product water from MD, RO, ED, NF and TR processes for irrigation, and the required post-treatment for each technology based on the sodium adsorption ratio (SAR) – an important parameter for crop quality and the longevity of the soil. We will also compare the desalination technologies based on performance parameters such as – specific energy consumption (SEC), recovery ratio, maximum allowable LD concentrations and availability of the technology.

Keywords: Desalination; Liquid desiccant; Sodium adsorption ratio (SAR); Nanofiltration; Membrane distillation; Solar

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Desalination processes optimization by online monitoring surrogates and specific composing parameters. The case of online LSI measurement and its benefits

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Although the advanced mature stage of desalination processes, the continuous advances in membrane technologies, pretreatments, and operating models, keep contributing to desalination areas to gaining momentum globally.

Desalination is an energy-intensive process requiring different pre-and post-treatments depending on the type, quality, and variability of water intake/source and produced water goals. Improving the efficiency of these processes, and enabling a full real-time visual picture of them is key for desalination applications sustainability.

Real-time data plays a crucial role in processes improving efficiency. Specifically, water quality parameters provide information on how processes perform, but most importantly, how processes can be optimized.

Presently, most traditional water quality parameters are being online monitored in practically all desalination plants worldwide, as the technologies used have been demonstrated well-proof for years (for example; turbidity; conductivity, pH, hydrocarbons, etc.).

However, in desalination processes involving membranes (UF, NF, RO) other specific parameters are very uncommonly to find as an online and real-time measurement. Parameters like the Silt Density Index (SDI) for pre-treatment processes and the Langelier Saturation Index (LSI) in post-treatments are two critical ones providing high-value and relevant information, and which usually are determined by discrete laboratory shots or field periodical measurements.

New advances in online instrumentation and sensors have enabled alternative methods and technologies to correlate very well SDI for pretreatment enhancing and real-time process picture performing, and deliver the LSI online by composing new sensors and instruments currently available in the market.

This paper targets and focuses on remineralization processes optimization (post-treatment), delivered product water quality reliability, and corrosion/scaling real-time information by the use of an online LSI panel.

System configuration, build-up components, and real-case demonstration will be delivered with detail and a real case for seawater desalination study will be shown the benefits and economical-technical sustainability of the investment. Also, an application note for industry application will be briefly presented as the importance of LSI in the desalination process for the power industry.

Keywords: Online water quality; Surrogates and composing parameters; Corrosion and scaling; Online panel; Langelier Saturation Index (LSI); Cost optimization; Remineralization

UF membrane fouling by sodium alginate in salinity conditions to mimic biofouling during desalination of seawater

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Ultrafiltration (UF) processes were used frequently in water treatment, food manufacturing and pharmaceuticals thanks to an easy operation at ambient temperature and lower energy consumption [1-3]. The membrane characteristics

play a significant role in that process. However, membrane fouling and smaller water flux restrict efficient UF process application in water purification and wastewater treatment. The production of low fouling UF membranes with rising water flux and selectivity for use in water purification is therefore of considerable interest. In this work, Low fouling hybrid ultrafiltration membranes were fabricated from a combination of sulfonic acid functionalized titanium nanotube (TNTs-SO_3H) and poly sulfone (PSf) by non-solvent induced phase separation approach. The results revealed that the water permeability and natural organic matter fouling resistances of the membranes were dependent on the fraction of TNTs-SO_3H in the membranes. The addition of TNTs-SO_3H, the surface hydrophilicity, and pure water permeation fluxes (J_{w1}) of the fabricated membranes are evidently enhanced. The fabricated membrane containing 5% TNTs-SO_3H has greater permeation flux and rejection value than that of the other membranes in the ultrafiltration of sodium alginate solution. In addition, The adsorption investigation of sodium alginate solutions at pH=7 were reduced with increasing of TNTs-SO_3H percentage.

The fouled membrane containing 5% TNTs-SO_3H is facilely recovered after ultrafiltration, and the repeating antifouling experiments did show a steady and best filtration efficiency.

Keywords: Ultrafiltration membrane; TNTs-SO_3H; Sodium alginate removal; Desalination; Antifouling

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Performance of a free-piston batch-RO desalination system

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High-recovery desalination is gaining importance to minimise harmful brine discharges, conserve limited water resources, and to recover valuable resources from brine. Nonetheless, high recovery tends to result in low energy efficiency and increased operating costs. Conventional reverse osmosis (RO) based on continuous flow suffers from decreasing energy efficiency at recovery > 50%. Batch RO is an alternative approach that maintains high efficiency at high recovery. So far, however, relatively few experimental results for batch RO systems have been reported. In this presentation, we will report on a batch RO system that has been developed at University of Birmingham. This system has been designed for treatment of brackish groundwater. It uses a single-acting free-piston design and an 8-inch RO module to achieve an output of about 10–20 m^3/d. The presentation will explain the design rationale and this system, contrasting it with existing continuous flow and semi-batch RO systems. We will present results with simulated brackish water in the lab and different RO membranes, operating at recovery of 80%, achieving SEC of <0.7 kWh/m^3 and rejection >94%. Design improvements and further applications of this batch RO system will also be discussed.

Keywords: Batch reverse osmosis; High recovery; Specific energy consumption; Resource recovery

Justification of batteryless PV-EDR for desalination in humanitarian emergencies

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Desalination is a relatively unexplored, but important element of humanitarian emergencies (e.g. disasters, conflict). When encountering saline or chemically contaminated water in emergencies, current procedures for prominent international nongovernmental agencies such as MSF, UNICEF, and Oxfam instruct aid workers to simply avoid saline sources [1-3]. There currently are no reliably employed desalination tools for humanitarian emergencies. Saline sources are becoming increasingly difficult to avoid, especially in areas with coastal flooding or in areas that have current or increasingly saline hydrology; disasters and conflict will hence progressively encounter the need to desalinate water.

This work highlights potential regions, including but not limited to East Africa, the Middle East, Southeast Asia, which are susceptible to the need to treat saline water in humanitarian emergencies. We define archetypes and requirements for desalination systems in humanitarian emergencies, present a sociotechnical analysis of current interventions and technology (i.e. RO, EDR, and thermal processes), and highlight challenges where developing desalination technologies have high potential. From these challenges, we conclude the merits of exploring batteryless PV-EDR and present its parametric design within the application of humanitarian emergencies.

Keywords: Disaster relief; Emergencies; Electrodialysis; Deployable; Batteryless

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Energy recovery system and its impact on the Copiapó SWRO plant operability and availability: a "real world" lifecycle cost analysis

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In April 2014, the Copiapó SWRO plant (IDAM del Valle de Copiapó) began delivering desalinated water with the goal of providing a secure and reliable water supply for the operations of Minera CAP, the municipal water supply for the nearby Caldera town and for irrigation into the Malpaso Canal. Located in the province of Copiapó, Atacama Region in Chile, the 54,000 m^3/d SWRO project was awarded to ACCIONA AGUA for the design, build, commissioning and operation under the structure of an EPC + 20 year O&M contract. It is the first multipurpose desalination project in Chile (industry, potable and irrigation), intended to overcome the extreme water scarcity conditions found in the Atacama's dessert, the driest in the world. The plant currently supplies water to 340,000 inhabitants in this arid region.

After seven years of successful operations, the plant has demonstrated an availability of 99% (including scheduled maintenance) and the energy recovery system recuperates 97.3% of the energy contained in the membranes high-pressure reject stream. This high availability is possible in spite of the relatively frequent red tides and jellyfish blooms in the Pacific Ocean thanks to ACCIONA's proprietary pre-treatment technology incorporated in the design, and due to the careful selection process for critical plant equipment such as the energy recovery devices. The energy recovery system's performance greatly affects the lifecycle cost of the plant while reducing product water cost, the overall carbon footprint and ultimately greenhouse gasses emissions in alignment with the United Nations sustainable development goals.

This paper will demonstrate how large SWRO plants can achieve sustained long-term availability and energy efficiency. The performance of the energy recovery system during commissioning will be compared to the on-site measured performance after seven years of continuous operation. To complete further this assessment, operating energy recovery devices were returned to the manufacturer's facilities for a complete inspection and performance test for comparison with the original factory test records for these specific units. As well, this paper will address the plant operating and maintenance history related to the energy recovery devices: uptime, maintenance, spare parts requirements, in order to asses a complete "real world" lifecycle cost analysis for the system. The role of advanced materials in sustaining performance over the designed life of the plant will be included in the analysis. In addition, we will highlight the importance of proper system design and especially good operation and maintenance practices for achieving maximum performance and longevity of the energy recovery devices and in general the complete installation.

Keywords: Desalination; Availability; Lifecycle cost; Energy efficiency

Desalination of the Jordan River – a challenging task

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It is a common knowledge today that an effective pretreatment is essential for a consistent operation of an RO desalination plant as RO membranes are sensitive to various contaminants that may be present in the raw water. Scaling species, suspended matter, colloidal particles, organic pollutants and biofouling species are the most abundant fouling contributors. Desalination of sea water and ground water are usually less complex as commonly they contain only part of these contaminants. However, desalination of surface water is complicated as surface water might have it all.

This paper describes the operation of a unique BWRO plant (Afikei Maim, 6500 m^3/d) that is fed by the Southern Jordan River water. The water of the Southern Jordan river is relatively saline (up to 3000 TDS) and contains a variety of contaminants originating from local municipal and industrial wastewater effluents. The combination of wastewater effluents and runoff from the Jordan river basin, creates a complex matrix of organic contaminants that is frequently enhanced by algae blooms. In addition, the composition of the river is not constant and may change on an hourly basis. This clearly makes the design and the operation of the pretreatment of this plant a super challenging task.

The paper presents the challenges encountered during the initial operation of the plant and the pretreatment modification that must have been carried out in order to ensure a steady and trouble-free operation of the RO system.

Keywords: Desalination; Surface water; Pretreatment; UF; RO; Fouling

Optimum design of PV-RO system solar powered seawater desalination without storage in Saudi Arabia (case study)

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Bad effects associated with drinking water are a serious problem in regions with low freshwater supplies and high frequency of droughts, just like Saudi Arabia. Desalination of water isan excellent solution to this issue; but this process uses a great deal of energy which mainly comes from fossil fuels. Power provided by photovoltaic cells for desalination provides a cleaner and cost-effective substitute. The focus of this survey is to find means to run a reverse osmosis desalination plants by the electricity generated by solar cells without storage to find the cost per unit electricity (kWh), and to estimate the highest energy percentage which can be generated by solar panels in daytime. That is why reverse osmosis plant was selected for the case study. The data for solar power produced and consumed for desalination of brackish water into potable water is based on actual measurements acquired from the direct observation of reverse osmosis desalination facility locatedin Saudi Arabia. It was observed that during summer months, larger amount of solar energy is produced as compared to the winter months because of greater day hours in summer. It was found that the maximum electrical power generated at midday by the photovoltaic solar plant lies within the range of 9.15 MWh to 17.95 MWh. By studying the results of the chosen plant as a case study, it was found that the percentage of non-usable energy is less than 2% in a plant whose size is 20 MW. In this case, 20% of totally consumed energy could be provided at the price around 0.025 €/kWh. The expenses for power produced exceeds 0.04 €/kWh when the plant is greater than60 MWp.

Keywords: Resource monitoring and mapping program reverse osmosis; Desalination; Photovoltaic cell; Renewable energy

Control of biofouling related risks by methods reducing the environmental footprint and optimising RO plant performance in the Gulf of Oman

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This paper is about a return of experience on the optimisation of the sea water line management of Sur Desalination extension Plant in the Sultanate of Oman. Challenges werefaced two years after the Commercial Operation Date due to uncontrolled biofouling growth inthe seawater intake system.

It is generally observed that sea water intake structures are an ideal environment that provideoptimal conditions for settlement and growth of marine biofouling organisms. This settlementleads to a significant head loss in the intake structure (increased wall roughness and reductionof the inner pipe diameter). This has a high impact on the operational reliability of the plant and could result in an unplanned shutdown of the plant. An unplanned shutdown has a high cost impact due to reduced production capacity.

To tackle this challenge, it is common to perform shock chlorination at the seawater intake atthe fixed intake screens. At the Sur plant this was done during the two first years of operationfollowed by neutralization with metabisulphite of the excess chlorine before the water enteredthe RO membranes. During this period the plant observed increased head losses in the intakepipe, leading to critically low levels in the onshore intake bay during low tides causing production capacity reduction. In addition, the intake screens had to be cleaned every two months, causing plant shutdowns and stress on the operation of the station. The mechanical cleaning of the intake pipe was performed every 3 years, which led to a long plant shutdown. Additionally, the DAF chambers had to be cleaned yearly to remove the excess of dead shellswhich had accumulated on the walls.

It was then decided to study and optimise the biofouling control procedure in order to avoid costly exercises and plant shutdowns. The Ecodosing™ procedure was implemented. Tailoredpulses of chlorine at low concentration were dosed at the intake screens. After almost 2 yearsof Ecodosing it was noted that no marine fouling was observed in the seawater screens, intake

system and DAF. This resulted in a guaranteed production capacity since no head loss was observed. In addition, the levels of residual chlorine were very low which did not require additional metabisulphite dosing. There was no impact on the RO membranes integrity or negative effect on the long term performances of the RO observed. Ecodosing improved the lifespan of the membranes due to reduction in biofilms. Although the cost for chlorine increased in comparison with shock dosing, overall a significant cost reduction was achievedby the reduction of mechanical interventions. A controlled biofouling process results in a reduction in Environmental footprint due to the balanced operation of the plant at design specification.

Keywords: Desalination; Biofouling; Chlorine; Membrane fouling; Operational reliability

Hybrid advanced oxidation process for the removal of dyes from synthetic industrial wastewaters

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Nowadays, traditional methods for dyes removal from industrial effluents have been replaced by chemical oxidation processes, mainly advanced oxidation processes (AOPs) which are able to degrade complex organicsubstances. As a matter of fact, the traditional schemes, combining biological/physical/chemical processes (*e.g.* adsorption on activated carbon, membrane filtration, ion-ex-change, coagulation precipitation, extraction)are often unsatisfactory because of the

high treatment times, especially for biological operations; the low efficiency and the transfer of colorants from the liquid stream to the solid or another liquid phase that is an additional secondary source of pollutants.

On the contrary AOPs such as Fenton, photo–Fenton, sonolysis and photocatalytic oxidation, constitute an efficient alternative to traditional processes especially for their strong oxidative capacity, able to degrade manysubstances. One of the most innovative AOPs is the hydrodynamic cavitation (HC), which provides for the formation, growth and collapse of bubbles in a liquid phase followed by the release of a significant amount ofenergy. It is possible to generate the cavitation process by passing liquid at high pressure through one or morerestrictions or holes, such as a Venturi tube. Physical consequences due to the passage through the cavitating device are the substantial pressure reduction and generation of bubble cavities, and local hot spots in which high local temperature and pressure are reached. These extreme conditions cause the collapse of the bubbles and the decomposition of water in free radicals that can be used to oxidize many substances. In the present work, the degradation of Methyl Orange (MO), chosen as model molecule of an azo-colorant, has been investigated by using hydro-dynamic cavitation alone and in the presence of hydrogen peroxide.

During the experimental tests, the effect of various operating parameters on the decolorization efficiency are investigated. In the first series of experiments, the hydrodynamic cavitation is optimized in terms of operatinginlet pressure and cavitation number to get the maximum decolorization yields of the dye, at the constant temperature of 20°C and with an initial methyl orange concentration equal to 5 ppm. Subsequently, the combined effect of hydrodynamic cavitation and hydrogen peroxide on dye degradation is studied. Finally, the effect of ions such as salts producing high conductivity in the solution as occurring in real effluents isinvestigated.

Keywords: Azo-dye; Methyl orange; Hydrodynamic cavitation; Advanced oxidation processes; Industrial wastewaters

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Donnan dialysis for drinking water production: a circular process for increased water recovery and remineralization

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In the Netherlands and many other countries, drinking water is produced from groundwater reservoirs and surface water sources. However, the availability and quality of water sources keep decreasing due to inadequate disposal of wastewater, increased presence of organic micropollutants, and rising salinity stemming from the intrusion of seawater and intensified fresh water use. Because of this, reverse osmosis (RO) is being applied to ensure that the drinking water is free of micropollutants and excess salts. However, RO has two negative aspects: 1) limited recovery due to scaling occurring on the membranes, and 2) the treated water is not ready for consumption as it needs to be re-mineralized (see Fig. 1A). This means that calcium and magnesium ions need to be supplied to achieve the adequate water hardness, frequently involving transport of the minerals and additional costs. However, both problems could be tackled by pretreating the feed water with Donnan dialysis (DD), as will be further explained.

The **Do**nnan Dialysis **ReMi**neralization (DoReMi) process is a recently patented scheme designed to tackle the previously mentioned problems. As shown in Fig. 1B, DoReMi uses Donnan dialysis (DD) as pretreatment for the RO process, where divalent cations (Ca^{2+}, Mg^{2+}) from the feed water are exchanged with the monovalent ions present in a draw solution. Later, these divalent cations are recovered using nanofiltration (NF), which separates these ions from the sodium (Na^{+}), and used to remineralize the drinking water.

In this work we present the DoReMi process, explain the initial experiments at laboratory-scale, and describe its implementation onto pilot scale. The pilot, consisting of a DD, a NF and a RO unit was designed and operated to treat onsite 100 L/h of fresh groundwater in a continuous form. During the operation, parameters like temperature, conductivity, ionic composition and concentration of micropollutants were monitored for the different streams. These values allowed to calculate the transport rates of salts and micropollutants under different process conditions. Ultimately, we analyze the economy of the process with the improved water recovery and the retrieval of minerals from the groundwater, and present our suggestions for future developments in the field.

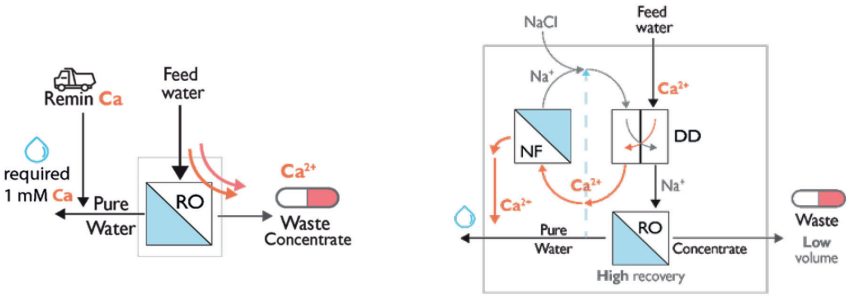

Fig. 1. A) Current status of drinking water treatment to guarantee the removal of micropollutants. B) DoReMi process for drinking water production (Dutch patent NL2021733). The feed water is pre-treated with Donnan dialysis and the hardness minerals are recovered with a nanofiltration unit.

Keywords: Donnan dialysis; Drinking water; Softening; Remineralization; High-recovery RO

Assessment of processes to increase the lifetime and potential reuse and recycling of reverse osmosis membranes towards a circular economy. Case of study of Cape Verde and Macaronesia area[#]

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This study is based on the study for the evaluation of the processes of reuse and recycling of reverse osmosis components and membranes in the Canary Islands and Macaronesia, within the DESAL+ project and in the framework of the DESAL+ LIVING LAB platform, coordinated by the Canary Islands Technological Institute (ITC) and the Canary Islands Agency for Research, Innovation and Information Society (ACIISI), with the support of the Interreg-MAC Programme. Reverse osmosis membranes could be reused in the same or another desalination plant by replacing the membranes in the first, dirtier positions with those in the last, less damaged positions. Also, by changing the best first-stage membranes to the second and vice versa, the useful life of these membranes could be extended through chemical cleaning and a second life could be given in tertiary treatment plants, reuse in industrial processes where they use special reverse osmosis membranes and degrade rapidly, in processes with leachate from landfill waste and also an interesting option is the oxidation of reverse osmosis elements to obtain nanofiltration, ultrafiltration or micro-filtration membranes for the removal of physical dirt. The main categories of thermal processing recycling commonly used in industry include incineration and pyrolysis to produce energy, gas and fuel. These processes can be applied to mixed plastic waste, such as the combination of materials used in the manufacture of reverse osmosis membranes. The recycling of reverse osmosis elements from desalination plants is shown as an opportunity, nowadays existing pioneering initiatives in Europe. Energy recovery, via incineration, is feasible but is not considered in accordance with the environmental, social and political problems that this may generate. However, the recycling of the reverse osmosis elements via pyrolytic industry for fuel production can be centralized in a new industry already planned in the Canary Islands and all the osmosis membranes that are obsolete can be sent there. This is a technically and economically viable business opportunity with a promising future in today's recycling market as studied in the study.

Keywords: Recycling; Reverse osmosis; Membranes reuse; Valorization

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Wetting behaviour and scaling propensity of polymer composite evaporator tubes for brine concentration

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The importance of recovering valuable minerals and metals from seawater brines is rising with steadily increasing supply risks of critical raw materials. Prior to the recovery of the valuable minerals and metals, the brine must be concentrated to ensure high separation rates in the downstream separation processes. In evaporators commonly used for brine concentration, the heat exchange surfaces are usually made of metals such as titanium or stainless steel grades. However, metals may suffer from failure due to corrosion and erosion, especially in harsh environments. In addition, they have further disadvantages in terms of high weight, high and fluctuating costs and they are prone to crystallization fouling.

Within the Horizon 2020 project "Development of radical innovations to recover minerals and metals from seawater desalination brines" (SEA4VALUE) aiming at a multi-element recovery in a modular process and applying a circular supply model, a new cost-effective polymer based falling film evaporator with enhanced corrosion and fouling resistance is being designed for brine concentration using advanced multiple-effect distillation.

Therefore, polymer composite tubes based on polypropylene or polyphenylene sulphide filled with graphite particles are under development. A special extrusion process allows high filler contents and the orientation of filler particles in the polymer matrix to enhance the thermal conductivity. However, the polymer tube surfaces exhibit a poor wettability. For successful implementation of polymer composite tubes in brine concentrators, it is necessary to develop surface treatments that will enhance the wetting behaviour while maintaining the low crystallization fouling propensity of the polymer surfaces.

Wetting characteristics, heat transfer and crystallization fouling have been studied in various test rigs. In the present study, different surface treatments such as flame treatment and coating are investigated in terms of wetting and scaling propensity. Contact angle and surface energy measurements are performed to characterize the tube surfaces.

The polymer composite tubes with surface treatment exhibit a significantly higher wettability than the respective untreated tubes. Additionally, they show a lower crystallization fouling tendency compared to common metal tubes. The induction time is longer and the reduction of the overall heat transfer coefficient over time is notably lower.

Keywords: Recovery of minerals and metals; Brine concentration; Advanced multiple-effect distillation; Polymer composite tubes; Surface treatment; Tube wetting; Scale formation

Seawater desalination with TFN membranes in the Canary Islands: over 10 years of experience

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The Canary Islands is a world benchmark in desalination technologies. This region has always been a pioneer in the use of seawater and its transformation into drinking water. For nearly half acentury, various desalination techniques have been put into practice in many installations, including novel operation and maintenance procedures, research, development and innovation.

Today there are more than 300 desalination plants in operation in the Canary Islands, mainly concentrated in Gran Canaria, Lanzarote, Tenerife and Fuerteventura. The majority of these installations are using reverse osmosis technology. The total desalinated water productionexceeds 700,000 m^3/d and approximately 90% of it is produced by this membrane technology.

Moreover, boron is one of the important regulatory constituents for drinking and irrigation water in the Canary Islands. Several countries in the Mediterranean Sea area and East Atlantic coast stipulate the maximum boron concentration to be less than 1.0 mg/l for desalinated water. The implementation of these stringent standards to the quality of water produced by reverse osmosiscreates a challenge to the seawater desalination industry.

Thin-film nanocomposite (TFN) technology, introduced in the desalination industry by LG Chem, incorporates nanomaterial into the polyamide layer of RO membranes to improve membrane performance. This technology delivers membranes with competitive permeability and very high salt rejection, up to 99.89%. In addition, membranes produced by this technology also show an outstanding boron rejection. These key features are extremely valuable in desalination industry as they allow the reduction of energy consumption while maintaining permeate quality requirements.

Because of the existing potable water regulation in the Canary Islands and feed water conditionsin this area, the implementation of TFN membranes has grown rapidly in the last decade reachingat least 218,000 m^3/d production capacity. Several case studies with detailed field operation dataanalysis will be shown to demonstrate successful performance of TFN membranes in this iconic place for desalination.

Keywords: SWRO; Boron; TFN; Canary Islands

Filtration of salts in polyeletrolyte-modified nanofiltration membranes

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Migration of ions across commercial nanofiltration membranes is normally governed by diffusion and charge effects. Indeed, the pH of the solution will determine the zeta potential of the membrane and the electronic state of the species to separate, which will migrate according to equilibrium principles of concentration and charge (Donnan effect). Surface modification of such membranes by depositing layers of alternatively charge polyelectrolytes enables to tailor, to a certain extent, the membrane charge density and charge, which in turns determines the rejection during ion transport. Additionally, the conditions during preparation of the polyelectrolyte solution as well as the conditions during deposition on the membrane will determine the pore size and porosity of the polyelectrolyte layer, which will also have an influence on the diffusion of ions through it. In our work, polyelectrolytes of different nature have been systematically deposited on the membrane at different conditions, and charged solutes of different molecular weights have been passed through. The results revealed that the passage of ions can be controlled, albeit there are limitations in terms of molecular weight and stability of the polyelectrolyte layer.

Keywords: Nanofiltration; Polyelectrolytes; Ion migration; Zeta potential

Antifouling efficiency and high-flux ultrafiltration membrane comprising sulfonated poly (ethersulfone) and TNTs-g-PSPA nanofiller

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Climate change, population increase, pollution of water and misuse of water resources add to the depletion of freshwater [1,2]. Therefore, efficient and sustainable technology is needed to treat polluted water. Membrane technologies are being developed to offeran affordable and efficient solution for water treatment to fulfill the ever-increasing demand quality water [3].

In this research, a facile strategy was performed for fabrication ultrafiltration (UF) membrane with outstanding hydrophilicity, fouling resistance, rejection rate and water flux. The membranes were made utilizing a non-solvent induced phase separation (NIPS) approach by combination of sulfonated polyethersulfone (SPES) and Titania nanotubes (TNTs) modified with sulfopropyl methacrylate (TNTs-g-PSPA) as a nanofiller. The produced membrane was investigated using atomic force microscopy (AFM), field emission scanning electron microscopy (FESEM), thermogravimetric analysis

(TGA), Fourier-transform infrared (FT-IR), contact angle, and surface charges. The hybrid membrane's pure water flux containing 5 wt% TNTs-g-PSPA hybrid was 402 L m^{-2} h^{-1}, around 2-fold that of the pristine membrane. The fouling resistance of thefabricated membranes was explored using various foulants, comprising humic acid(HA), sodium alginate (SA), bovine serum albumin (BSA), and natural organic matter (NOM) solution. The fashioned membrane with 4 wt% TNTs-g-PSPA able to remove greater than 98% of NOM, without a rejection rate losing.

Keywords: Titania nanotube; Ultrafiltration membrane; SPES, antifouling; NOM; Foulant

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Comparative study for the performance of 10 and 20 μm cartridge filters in a large scaledesalination plant

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Two commercial sizes cartridge filters (CFs) with absolute rating 10 and 20 μm were operated simultaneously in one of the largest desalination plants in the world (Ras Alkhair Power and Desalination Plant). The objective was to understand the impact of filter rating on the overall reverse osmosis (RO) process performance. The lifetime of the CFs has increased from 90 to 125 days when 20 μm CFs were used compared to 10 μm CFs. This saved around 39% of CFs replacement cost. Continuous measurements for one year were carried outfor the industry standard parameters used to evaluate the performance of CFs such as Silt Density Index (SDI), turbidity, particle count and outlet flowrate. The results for the CFs outlet samples and flowrate logs showed that there was no significant difference in the suspended solids concentrations and biological activity between 20 and 10 μm CFs.

Keywords: Cartridge filters; Filter rating; Reverse osmosis; Desalination

Evaluating the performance of chitosan and chitosan-palm membrane for water treatment: preparation, characterization and purification study

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In this research, the membranes were stemmed from the biopolymer containing quaternary amine moieties (chitosan and chitosan-palm) for nanofiltration purposes. The developed membranes were fully featured using different characterization techniques (SEM), (TGA), zeta potential, and contact angle measurement. The membrane's features were systematically characterized in hydrophilicity contact angle, surface morphology, and charge on the surface, acidity, and water permeability. The permeability of water for the chitosan membrane with palm was 3.04±0.12 L m^{-2} $h^{-1}$$bar^{-1}$ twice as the average permeability of the pristine chitosan membrane 1.68±0.04 L m^{-2}.h^{-1}.bar^{-1}. The salt rejection was enhanced (from 5% for NaCl to 70% for $MgCl_2$ in the same condition). These membranes could endure up to 22 bar. Therefore, the developed Chitosan and chitosan-palm membranes are more noteworthy for water treatment than the other commercially available membranes and costly activated carbons.

Keywords: Membrane; Nanofiltration membrane; Chitosan; Water treatment

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Keywords: Membrane; Nanofiltration membrane; Chitosan; Water treatment

Cleaner and efficient membrane systems for better water desalination and water reuse

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Water scarcity can be a regional phenomenon around the world, but water reuse is a global trend that has grown rapidly over the two first decades of 2000. The preferred technology for water desalination is with no doubt membrane filtration. The International Desalination Association reports that close to 18,500 desalination plants are in operation, however the number can be "doubled" by including system with sizes in the range 20 to 1000 m^3/d. The installed reuse capacity (130 million m^3/d) has passed the installed high brackish water, seawater desalination capacity (89 million m^3/d).

Membrane fouling is a known problem in membrane filtration that impacts and deteriorate membrane performance. A reduced membrane performance will translate into higher operational costs. To ameliorate fouling problems, processes and operational procedures are implemented. For instance, backwashing of MF/UF membranes, and flushing in MF/UF/NF/RO membrane systems. Water pre-treatment will define the subsequent steps or levels of further treatment. Membrane scaling can be reduced by effectively controlling pH and adding antiscalants in the feed line. The role of antiscalant chemicals has been recognized from early days of boiler applications, and that knowledge has been in principle adapted to membrane filtration.

Smart Filtration Suite (SFS) is the answer to achieve cleaner and efficient unit price of cleaned water in desalination and water reuse. Our eco-system of intelligent control algorithms effectively enhances capabilities of operators in membrane filtration systems, automates the complex commissioning process and assures significant operating cost savings, both in newly-built and retro-fitted installations. SFS includes control algorithms covering micro- and ultrafiltration, as well as nanofiltration and reverse osmosis. The algorithms target the most challenging aspects of commissioning and process-control, assuring real-time and intelligent operation. The implementation of the algorithms is very flexible – an inexpensive control box with remote access assures trouble-free installation and the possibility for hassle-free updates. The algorithms make it possible to take full advantage of the capabilities of any filtration system, effectively giving them extra processing capacity and real, tangible savings in terms of energy, water and chemical consumption, as well as better insight of the performance of the plant, both actual and historical performance. The present work will elaborate on the technical details of optimization of three case stories, one brackish desalination plant, a water reuse system in a petrochemical industry and a surface water treatment.

Keywords: Water reuse; Automatization; Control algorithm

Continuous evolution of control technology

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The water industry is witnessing a continuous evolution of control technology that goes beyond measurement and surveillance of water quality, processes, and operational parameters. In applications of water reuse and desalination, controls and automatization of water treatment systems are becoming even more relevant since the importance if a reliable system operation is highly demanded. End-users and OEMs are experiencing a transition from systems with limited performance surveillance and data collection to systems where process control, data collection and surveillance are perceived as added value for OEMs and likewise for end-users. The presentation will first introduce the topic, to further elaborate and give a broader understanding of what is required to make the integration of sensors and controls into an extra layer of automization.

Subsidizing water cost by value-adding to desalination plant concentrate: key criteria for success

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Prospects for brine mining are being pursued with great enthusiasm by researchers all over the world, with regular publication in prestigious journals of experiments where exotic elements are extracted using exotic materials. Projections based on the commercial value of elements and the amount of that element present in seawater are waved about excitedly. A new 'gold rush' is anticipated, and there is talk of companies rebranding themselves as 'brine producers' rather than 'water producers', with water as a cheap or even free by-product of their main operations.

It is instructive to remember the words of Thomas Midgeley, the Dow Chemical executive who brought us tetraethyl lead as an anti-knock additive in petrol and chlorofluorocarbon refrigerants, who said in 1934: 'Ten years ago commercial extraction of any of the elements present in the ocean was as impossible as alchemy. Today it is an accomplished fact in the production of bromine … And I feel safe in predicting that within the next decade- and possibly even within the next year- we will be able to recover gold, silver, radium and all the other untold wealth from the sea. Now that we have made one dream a reality, it is only a matter of further technical development and refinement of process before we make the sea loosen its hold on a fortune so fabulous that it staggers the imagination.'

It is true that it is only a matter of further technical development and refinement of process – but in the same sense that it is only a matter of further technical development and refinement of process before we all have holiday homes on Mars. Given almost a century of development, this fabulous fortune has not yet materialized, and even chemical species that were once obtained from the sea, such as bromine and magnesium, have run into economic barriers and are no longer viable.

Is mining the sea viable today? What makes today different?

At the Saline Water Conversion Corporation (SWCC) we believe that technical developments and refinement of process have now advanced to a stage that it makes commercial sense to extract some products from seawater desalination concentrate. Other products will remain in the realm of laboratory curiosities for many decades to come. This talk will be a sober analysis of the current position of the economic limits to production of potential commercial materials from brine – sodium chloride, bromine, magnesium salts, potassium salts, etc – how these limits relate to our projected costs, and the factors acting in our favor to make SWCC uniquely well-placed to take advantage of this 'new frontier'.

Keywords: Brine mining; Concentrate management; Water cost

Bisphenol removal in water by micellar enhanced ultrafiltration

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The bisphenol removal in water by using the micellar enhanced ultrafiltration (MEUF) was studied. Bisphenol is one of the highest tonnage chemicals produced in the world. Like other endocrine toxicants, bisphenol is quite poorly removed from water by traditional methods of water purification. In this work the cationic 1-hexadecylpyridinium bromide (HDPB), the non-ionic p-(1,1,3,3-tetramethylbutyl)-phenoxypolyoxyethylene glycol TX-100 and their mixtures were investigated to evaluate efficiency in removal of bisphenol in water by the MEUF method with using of UP010 ultrafiltration membrane (Mycrodyn-Nadir, Germany). MEUF is based on the properties of surfactants to spontaneously aggregate in aqueous solutions and form micelles. The hydrophobic nucleus of the micelle solubilize molecules of non-polar hydrophobic organic substances in water, in particular bispenol molecules, and the surfactant micelles are well retained by the membrane together with the solubilized substance. It was shown that for mixtures of HDPB and TX-100 there is a so-called synergistic effect, when the formation of mixed surfactant micelles occurs at a much lower concentration than the formation of micelles in solutions of individual surfactants. It was found the introduction of a synergistic mixture of cationic and nonionic surfactants promotes the process of solubilization of bisphenol in the hydrophobic nucleus of the formed micelles. The conditions for bisphenol removal were optimizes in terms both of single surfactants concentrations and their molar fractions in the mixtures. It was found that at the optimal conditions a high efficiency of bisphenol removal from water (84–96%) and at high permeate flux of 90.2–96.4 LMHs were provided.

Keywords: Bisphenol; Micellar enhanced ultrafiltration; Triton X-100; Hexadecylpyridinium bromide; Water treatment

Societal and economic aspects of a novel circular system for the valorisation of desalination brine and waste heat from a power plant

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Direct disposal of concentrate brines produced in industrial plants can have a relevant impact to environmental systems. For this reason, brine treatment and valorisation could help to avoid disposal and produce marketable salts, thus representing a possible economic benefit. With this aim, a novel process, where advanced separation technologies are combined with waste heat recovery, is proposed within the EU-funded WATER MINING project. The case study presented in this work concerns the power plant in Lampedusa island, where waste heat and desalination brine are available to implement the process via a pilot plant to be installed for alternative thermal treatment of the brine. The aim is to achieve energy and water valorisation and producing high-quality salts (NaCl, Na_2SO_4, $Mg(OH)_2$) and chemicals (HCl and NaOH).

Beside the technological aspects, the novel process' impacts to society, market and policy were investigated through a Value Sensitive Design approach (VSD) (Palmeros Parada et al., 2018). VSD is a design approach to proactively accommodate stakeholder values during the design of technologies (Friedman, 2017). For this, quantitative and qualitative data was collected from a review of the literature, and through interviews with four different type of stakeholders: (a) innovative technology suppliers (ResourSEAs), (b) local salt supplier (SoSALT); (c) innovation ecosystem representatives (ARCA); and (d) desalination user (SOFIP). From these data, societal values and tensions around the development and implementation of the innovative technologies, as well as both market and policy barriers and enablers have been identified. Stakeholders have been invited to participate in what we call a Community of Practice (CoP). Through the CoP, stakeholders have discussed the identified values, tensions, barriers, and opportunities for implementing the seawater desalination and brine treatment processes. In particular, societal concerns around impacts on water and energy use,

especially considering the scarcity of these resources in the island, were analysed. The aim was to derive recommendations for the development of the technologies and their implementation.

Overall, stakeholders have participated with enthusiasm to this experience by bringing their vast amount of practitioners' knowledge and market insights that were explored, indispensable for setting a discussion on the market systems for circularly produced wastewater products.

Keywords: Desalination; Waste heat; Wastewater recovery; Seawater brine; Value sensitive design; Policy.

Acknowledgements

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The authors are grateful to ResourSEAs, SoSALT, ARCA, SOFIP for supporting the project activities embracing the role of stakeholders.

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Experimental evaluation of a low-cost zero liquid discharge system driven by a micro gas turbine

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In previous works by the authors, the synergies between a zero liquid discharge and a solar microgas turbine have been described. This paper deals with the experimental proof of concept of the zero liquid discharge system, applicated to seawater desalination by means of brine concentrationpowered by the exhaust gases of a micro gas turbine which, although the engine installed in the test facilities is a conventional micro gas turbine, simulates the performance of a solar micro gasturbine following either a recuperative or non-recuperative power cycle to increase the exhaust thermal power if needed.

The design phase, in which previously a hydraulic evaluation has been considered to assessing the general behaviour of the gas stream-brine interaction, has been carried out firstly with a coldair stream, employing different system configurations and delimiting the working region to, oncethe hot exhaust gases had been considered, address correctly the sizing and internal arrangementof the concentration chamber where the exhaust gases will be bubbled through the concentrate bulk. Furthermore, even if this process would be operated continuously in a real application, the experimental tests had been made in batches in order to fully characterise the thermo-chemical performance of the system.

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

Energetic and economic comparison of solar powered multi-effect desalination (MED) with different configurations

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Solar desalination is considered a mature technology that facing the challenge of the shortage of fresh water and clean environment where fossil fuels are the primary source of energy in desalination. Where the reverse osmosis (RO) has a high share in the desalination market, multi-effects desalination (MED) is getting more attention due to comparable

in the cost and less power consumptionthan the multi-stage flash (MSF). Multi-effects desalination has threeconfigurations: MED standalone where the motive steam entering to the first effectis heated by heat exchanger boiler, multi-effects desalination assisted by thermal vapor compressor (MED-TVC) where part of the motive steam heated through theheat exchanger boiler at higher pressure and entrain part of the vapor from last ordifferent effects at low temperature and pressure, and multi-effects desalination assisted by mechanical vapor compressor (MED-MVC) where the vapor in the last effect is compressed by mechanical vapor compressor. In the previous paper the authors presented an innovative design that connected supercritical-ORC with MED-MVC for solar field which has 150°C, a fair comparison between three configurations of MED has been conducted in solar area and the specific thermal power consumption. The supercritical-ORC assisted MED-MVC and MED-TVC havelower specific thermal power consumption and solar area compared to solar-MEDstand alone and the supercritical assisted MED-MVC has the lowest specific thermalconsumption. The cost analysis for the three configurations has been performed.

Keywords: Solar desalination; MED

Experimental analysis of a reverse osmosis membrane suitable for wave powered desalination

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The global shortage of drinking water has led the researchers to look for alternative sources to produce fresh drinking water. While desalination is a mature technology for production of fresh water from sea water, these desalination plants are highly energy intensive. A desalination plant directly coupled with a wave energy converter is a potentially sustainable solution for freshwater production. A wave-powered desalination unit that directly drives a high-pressure water pump avoids the intermediate conversion of renewable energy to electricity and back to pressurised water for reverse osmosis (RO) plants resulting in a potentially lower specific energy consumption. However, a wave powered desalination system has its own challenges. One of the important challenges is the performance of the RO membrane under variable pressure, which arising because of the variable characteristics of ocean waves. A laboratory-scale RO plant, capable of testing RO membranes under variable pressure and flow conditions, as may be experienced in a directly wave-powered desalination plant, has been developed. This paper will report the impact on the performance of a commercial RO membrane subjected to variable pressure and flow conditions. Specifically, the experimental results will help to develop an understanding of how variable pressure/flow impacts RO plant water quality and specific energy consumption. Thus, the present work aims to provide critical information for further development of wave energy technologies required for the design of wave-powered desalination plants so that this technology can reach utility-scale production through a commercially robust and viable path.

Keywords: Wave powered desalination; Reverse osmosis; Wave energy; Desalination, Experimental data; Specific energy consumption; Water quality

Case study: the use of a novel antiscalant to prevent iron fouling in a brackishwater RO system

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A municipality in Texas had been operating its new reverse osmosis (RO) trains for only a few months when it started experiencing severe decline in flux and an increase in salt passage. Membrane cleaning did not restore performance. Cartridge filter analysis found heavy iron loading. Membrane autopsies revealed heavy iron hydroxide fouling across the entire length of the system, with the concentrate elements experiencing the worst flux decline and severe surface abrasion. The plant was designed with the RO system being fed from a 189 m^3 storage tank. The feedwater contained a

significant concentration of iron which was completely soluble under anoxic conditions but oxidized to insoluble ferric hydroxide in the atmospheric feed tank. The concentrations of iron exiting the feed tank were highly variable as precipitated iron sludge would slough off from the bottom of the tank. While bypassing the feed tank and installing a VFD on the well pump would have been the ideal solution, the plant needed to operate, and such a major undertaking could not be performed overnight. A chemical solution was therefore needed to resolve the issue. After verifying the cause of the fouling by membrane autopsy, an iron-specific CIP chemical was used to restore performance. A novel iron-control antiscalant was then put online, upstream of the feed tank, resulting in stable normalized performance for a full year, and eliminating the need for further cleaning. This case study describes how the owner, the consulting engineer and the chemical solutions provider worked together to troubleshoot, select and validate the optimal chemistry, and most importantly, make changes in the process to allow for the correct application of the chemistry and restore system performance.

E-hyrec® technology

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Eni trademark, registered in the EU in January 2018, defines the technology for the selective recovery of hydrocarbons from groundwater and the associated automatic device.

The e-hyrec® technology is applicable in the case of groundwater contamination by organic compounds slightly soluble in water, generally hydrocarbons, with low density, present as supernatant product (Light Non Aqueous Phase Liquids, LNAPLs).

The e-hyrec® device works on the principle of selective permeation, thanks to the use of a hydrophobic and oleophilic filter capable of recovering only the organic phase. Due to the chemical-physical characteristics of the material, when it is immersed at the interface between the supernatant hydrocarbon layer and the groundwater, the LNAPL permeates through the pores of the filter and the water is rejected from the surface.

E-hyrec® is a highly selective and efficient system: by separating the aqueous phase from the oily one and recovering only the latter, it allows a drastic reduction in the quantities of extracted water to be sent for disposal, thus allowing a very positive impact on the environmental and economic sustainability of remediation.

Even from an energy point of view, e-hyrec® is very sustainable, guaranteeing lower consumption compared to traditional recovery systems, thanks also to the possibility of being completely self-powered by renewable sources (photovoltaic).

Since the end of 2018, e-hyrec® has been installed and is currently in operation in various Italian sites managed by Eni Rewind: the applications in the field have demonstrated the effectiveness of the system in term of selectivity and recovery time of the LNAPL compared to traditional technologies.

The system ensures a constant check on the thickness of the supernatant, provides information on the refilling of the piezometer and is particularly useful to delineate with great precision the areas on which it is necessary to intensify the recovery and where this is marginal, without disturbing the hydrodynamics in the area of installation.

Keywords: E-hyrec; LNAPLs; Groundwater contamination; Hydrocarbons; Remediation; Organic phase; Selective permeation; Sustainability; Hydrophobic filter; Supernatant product; Recovery time; Eni Rewind

Design of marine outfalls for reducing environmental impact of brine[#]

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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 Company INCREA has been designing marine installations for desalination plants for the last 18 years around the world. Its projects have been developed in all the continents and for any size of desalination plant: water intakes developed by Increa range from 300 mm of diameter to 3000 mm.

The aim of this presentation is to show the way INCREA solved the issue of reducing impact of brine in the environment and avoiding recirculation of brine into the intake. It will show different solutions for solving specific problems.

The use of software tools for studying the behaviour of the brine plume is essential. Increa mainly uses Brihne and Mohid for this anaysis.

We will also present the lessons we learned thanks to our experience in this field in several desalination Projects designed by INCREA (all of them constructed or under construction):

- Skikda, Beni-Saf, Cap Djinet and Mostaganem in Algeria.
- Valdelentisco, Aguilas, Mutxamel, Santa Eulalia, Campo Dalías and Escombreras in Spain.
- Sorek in Israel.
- Qingdao in China.
- Mantoverde and Spence Growth Option in Chile.
- Nungua in Ghana.
- Al Ghubrah in Oman.
- Djerba and Zarat in Tunisia.
- El Alamein, El Arish, Negeelah, Taba, Sharm El Sheikh and East Matrouh in Egypt.
- Jazan Economic City, Red Sea and Shuqaiq-3 and Shuqaiq-1 in Saudi Arabia.
- Lima Sur in Peru.

Many pictures of these plants will be shown, for an easy understanding of the works.

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

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Experimental study of flow and fouling in a membrane channel using micro-particle image velocimetry

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Fouling in a reverse osmosis (RO) membrane is one of the main challenges in RO technologies as it increases maintenance requirements and shortens membrane life. The aim of this work is to experimentally investigate fouling phenomena within membrane channels by measuring and characterising the microscale flow in RO membrane channels. This is accomplished using a micro - particle image velocimetry (micro-PIV) setup which allows measurements at a spatial resolution of theorder 1-10 μm. The volume illumination in micro-PIV can also be used to provide information of the flow pattern at various heights within the channel. A fully transparent bench scale (~8x3 cm) plane ROchannel for housing different RO membranes is constructed. PIV measurements will use fluorescent latex beads of similar size to typical fouling particles, such as calcium sulphate and colloidal silica (~0.1μm), which are expected to provide direct observational insights into the behaviour of these particles and their deposition against the membrane. The spacers in the membrane channel are known to create recirculation zones which are likely important for fouling; therefore, the area of interest is one square element enclosed by spacer filaments. Of particular interest is how conditions such as an unsteady inletwould affect the local transport and flow characteristics and how it can be used as a control measure to optimise flow within the channel. The work will be complemented with numerical study of a similar setup using Direct Numerical Simulation (DNS) carried out by the authors in order to investigate the linked phenomena of concentration polarisation, crystal nucleation, and particulate fouling.

Keywords: Reverse osmosis; Spiral-wound membrane module; Particle image velocimetry (PIV)

Development of operational technology for ultrapure water process based on digital twin

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The ultrapure water production process is complexly operated by combining more than 20 unit processes. It is difficult to predict water quality and understand characteristics of process operation because the combination varies depending on the characteristics of raw water and the objectives of water quality. Therefore, it is essential to develop an optimal operation algorithm and disaster prevention technology based on operational data for complex water treatment processes. In this study, we plan to build a digital twin system that can increase production stability and reduce operating costs and develop an artificial intelligence-based operational disaster prevention model using closed-circuit television image data to establish a plant safety management system. To this end, a digital twin has been developed based on the operation data of K-water's 25 m^3/d pilot plant and will be applied to the 2,400 m^3/d demonstration plant of the customer, which is scheduled to be built by 2023. Through this study, it is expected that the digital twin technology will be applied for the first time in the field of high-purity industrial water to support quick and accurate decision-making, and to contribute to improving plant operation stability in various water treatment processes.

Keywords: Ultrapure water; Water treatment process; Operational technology; Digital twin; Video recognition and analysis

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

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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 prevent 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 and Wetsus became finalists using this technology in several large contests such as the George barley water prize in the US and the Baltic Sea challenge. A new fully automated system is now being demonstrated in the EU project "Water Mining". An overview of the technology together with achieved results and potential in membrane systems will be presented.

Keywords: Biofouling; Nutrient recovery; Nutrient removal; P-removal

Novel polypyrrole/zirconia tubular ultrafiltration membrane developed for efficient Congo red dye rejection and desalination

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A novel tubular ultrafiltration membrane was prepared using a commercial, carbon-based zirconia support modified through the chemical deposition of a selective layer of polypyrrole. The chemical synthesis of the polypyrrole polymer was confirmed by Infrared Spectroscopy and X-Ray Diffraction analyses, whereas scanning electron microscopy and contact angle techniques revealed the thickness (4 μm), coherence, homogeneity and hydrophobicity (138 ± 3°) of the polypyrrole layer surface, respectively. To study the filtration efficiency and desalination ability of the resulting membrane, the rejection of inorganic salts (Na_2SO_4, $MgSO_4$, NaCl) as well as that of Congo red dye, was measured. The experimental results at optimized conditions determined that the polypyrrole tubular membrane has a permeance of 5.2 ± 1 $L.h^{-1}.m^{-2}.bar^{-1}$. At high pH it removes Na_2SO_4 (92.6 ± 3%), $MgSO_4$ (59.8 ± 3%), NaCl (38.8 ± 3%) and at low pH, it efficiently removes Congo red (99.7 ± 2%).

Keywords: Polypyrrole; Zirconia membrane; Tubular membrane; Ultrafiltration; Congo red; Desalination

Upscaling large-area machining of complex structures through multi-modal laser processing

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Laser material processing offers a unique and scalable approach to develop functional surfaces with highly defined surface geometries, pore sizes or surface functionalities. Laser structuring of surfaces can increase the antifouling properties of conventional materials, especially in marine applications. Similarly, laser thermal hardening can be utilised to increase corrosion or wear resistance, extending the lifetime of water-facing motion components. While these are traditionally approached as separate processes, a multi-modal approach combining multiple laser sources would allow for rapid and scalable manufacturing of these functional surfaces.

Within the NewSkin project, we have developed a multi-modal processing system combining ultra-fast laser machining (for surface structuring or pore-drilling) with laser thermal hardening (for increased wear and corrosion resistance). These two processes can be operated independently, or combined into a single-step process for the production of functional surfaces with applications in water filtration and treatment, anti-fouling and water facing motion components.

Keywords: Laser processing; Filtration; Anti-fouling; Surfaces; Membranes

Assessment of the integration of a MED-TVC plant into a solar tower with Brayton cycle

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Seawater desalination is an energy-intensive process, and to mitigate freshwater scarcity in a planet threatened by climate change, the use of renewable energy sources to meet at least part of its power requirements is mandatory. Among the different renewable energy sources, concentrating solar power (CSP) plants is a dispatchable technology that provides heat and electricity simultaneously. It is therefore considered one of the most promising options to be combined with desalination. This is totally aligned to the EU's commitment to global climate action under the Glasgow climate conference (COP26) to be climate-neutral by 2050, an economy with net-zero greenhouse gas emissions. Among the different CSP technologies, those featuring a power block configuration based on a Brayton cycle rely on major advantages, making it the most promising CSP technology for its coupling to desalination systems in arid and semi-arid regions. Particularly, several advantages can be highlighted on this option: non-consumption of water by the power cycle, capacity to integrate high-temperature desalination systems (higher thermal efficiency) in the Brayton cycle with almost non-penalty on the power cycle efficiency, and the high modularity and capability of developing small power systems for remote areas with water scarcity. These advantages make Brayton CSP technology much more competitive than the Rankine CSP technology for its coupling with desalination systems. This work presents the assessment on the integration of a thermal seawater desalination system, based on multi-effect distillation technology with thermal vapor compression (MED-TVC), into a high-temperature power cycle (air Brayton cycle) and high-temperature CSP technology (central receiver solar tower). For such integration, the exhaust gases from the gas turbine are addressed to a recovery boiler where steam is generated to drive the MED-TVC unit. Models of the central receiver solar tower (heliostat field and receiver) together with the air Brayton cycle have been implemented Python. The heliostat field model was developed using SolarPILOT (solar power tower integrated layout and optimization tool) from NREL, whereas the solar receiver and Brayton cycle were developed in Modelica. These models are based on the AORA solar power plant located at Plataforma Solar de Almería (PSA). Regarding the MED-TVC unit, a model that evaluates its thermodynamic performance by applying mass and energy balances has been firstly implemented in Engineering Equation Solver (EES). Then, to model the integration of the MED unit with the rest of the CSP plant in Python, a multi-variable polynomial regression has been developed from the results delivered by the EES model. Annual simulations have finally been performed to analyze the total fresh water and electricity produced as well as the efficiency of the power cycle considering a coastal location in the Middle East.

Keywords: Power and desalination integration; Multi-effect distillation with thermal vapour compression; Central receiver solar tower; Air Brayton cycle

Energy recovery and jet quality evaluations of flow injection nozzle

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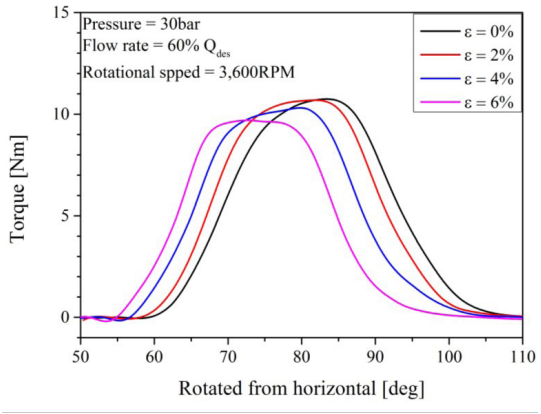
The performance of a flow injection nozzle to recovery energy from high pressure water deeply depends on the quality of the jet flow, which was mainly influenced by the nozzle upstream conditions such as uneven flow like jet deformation, deviation and secondary flow structures normally generated by bifurcations or bends of flow pipes.

This study is focused on the injection flow quality evaluation of a jet nozzle with a spear needle and on torque variations of turbine buckets, which are energized by collisions in the jet injection. This study was carried out through water injection test and numerical analysis using commercial codes.

The eccentricity of the nozzle equipped with the spear needle is an important parameter that determines the quality of the injection flow because that increases the spray angle and reduces the nozzle performance. As a result, the torque transmitted to the turbine bucket is reduced due to the increased diffusion angle of the jet flow, resulting inincreased energy loss. In particular, the smaller the nozzle flow rate, the larger the injection angle, and ultimately,the torque is also greatly reduced, resulting in a sharp increase in energy loss.



Keywords: Flow injection nozzle; Jet quality; Eccentricity; Power generation; CFD; Torque

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Standardized and decentralized nanofiltration potable water plants for remote locations

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In recent years, surface water purification with nanofiltration membranes has become an attractive alternative to conventional clarification and low pressure membranes such as ultrafiltration. Very low consumption of chemical agents, good quality produced water independent of feed water quality, good removal efficiency towards micro organisms, no production of sludge, compact process and easy automation are some of the potential advantages of nanofiltration compared to conventional treatment.

This paper describes a newly developed hollow fiber nanofiltration membrane that addresses the disadvantages of traditional spiral wound membranes: its open structure, chlorine resistance and backwashability allow for easy cleaning. It can be integrity tested and repaired to guarantee long term micro biological removal. Membrane pore size is specifically tuned for organics removal (e.g. humic acids) while minimizing the retention for hardness. The low retention of divalent salts enables operation without the need for upfront softening or anti scalant dosing. Waste water from the plant contains no chemicals and has a near identical salt balance to the feed water and can therefore be safely discharged downstream into the source water.

In order to address the need for smaller systems, Pentair X-Flow has designed a line of standardized package plants. These plants are available in four different sizes from 2 to 10 m^3/hr of capacity, with larger capacities available by operating units in parallel. The plants are robust in design and require minimal operator attention, thus making them particularly suited for remote locations. Chemicals are only needed for occasional membrane cleaning. Consumption is so low that waste water can be removed by tanker truck if no sewer connection is available. The two longest running plants have been successfully installed in remote locations: one on an island First Nation community in Canada and one near a hydroelectric power plant in Australia. Both plants have been in operation for 3 years now. This paper will describe design and operational experiences of the package plants: lessons learned and improvements implemented in the second generation of package nanofiltraiton plants.

Keywords: Nanofiltration; Hollow fiber; Organics removal

Development of new isobaric energy recovery device

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Keywords: Energy recovery; Reverse osmosis; Desalination; Pressure exchanger; Work exchanger

1. Introduction

1.1 General background

Flowserve is a leading supplier of flow control devices to the desalination industry. This includes all kinds of pumps, valves and energy recovery devices (ERD). This paper will explain the development of Flowserve latest ERD technology for use in desalination.

1.2 Energy recovery devices

Originally Flowserve provided reverse running pumps as energy recovery devices in sea water reverse osmosis (SWRO) projects. In many projects in the 80's and early 90's they were the only and best option to recover the energy from the brine and make the (SWRO) process more efficient and commercially attractive. Towards the end of the 90's the energy recovery turbines (ERT) became the most dominant energy recovery devices in the industry – especially for large scale projects. Flowserve was working closely with Calder™ as their supplier for the high-pressure pump trains including electric motors, HP pump and energy recovery turbines. In parallel, isobaric energy recovery devices were developed for highest efficiency and to make the SWRO process even more competitive. In Ashkelon, Israel, in the early 2000's, isobaric devices were supplied for the first time in a large-scale desalination project. Calder™ manufactured and supplied the DWEER™ product and the plant achieved record-setting power consumptions allowing the SWRO industry to further improve the competitiveness. In 2009 Flowserve acquired Calder™ and extended their portfolio to a complete desal pump and energy recovery product range, including Reverse Running Pumps (ERP), Energy Recovery Turbines (ERT), DWEER™ and ROVA energy recovery devices.

2. The new rotary energy recovery device

2.1 The product

Isobaric energy recovery devices can be split in two main technologies:
- Work exchanger (such as the DWEER™ product of Flowserve)
- Rotary pressure exchanger (such as the PX of Energy Recovery Inc. or XPR of Isobarix)

While Flowserve already had the DWEER™ technology in its product portfolio, it began several years ago to investigate developing a rotary technology product. The aim was to further improve the existing rotary pressure exchanger technology in several aspects:
- Size
- Performance (efficiency)
- Availability
- Controllability
- Maintainability

2.2 Size of new energy recovery device

In light of the growing plant sizes - and with it the train sizes - target was to develop a product that can achieve flows above 120 m^3/h (> 520 gpm) per unit.

Increasing the capacity per unit provides multiple operational and commercial advantages:
- Simplified installation
- Reduce the number of connections/couplings
- Simplified header design
- Less maintenance
- Lower specific costs
- Smaller footprint

2.3 Performance

Key to achieve lowest specific power consumption is to improve the performance. While the efficiency – based on low-pressure and high-pressure differential losses - has already achieved very high efficiencies in the range of 98%, other aspects of rotary pressure exchanger technologies can still be improved, such as:

- Mixing (contamination of feed water with brine)
- Leakage (loss of high-pressure brine energy)
- Back pressure (brine outlet pressure)

2.4 Availability

In addition to very high performance and efficiency required to economically produce fresh water the availability is another very critical element to ensure the reliable production. A robust design with less parts and minimal maintenance requirement is another driver of the development.

2.5 Controllability

In today's large-scale SWRO projects, energy recovery devices are typically installed in parallel in order to accept the high flow requirements – for example per train. Especially in large and mega desalinating projects this could result in hundreds of rotary devices connected through large headers. Such projects are normally equipped with a highly sophisticated control system allowing the operator to control the plant from a centralized control room monitoring the complete process and production. Data logs are generated and analyzed in order to optimize the safe operation and maintenance of the plant. Therefore, the possibility to ensure monitoring of the equipment is another aspect of this development.

2.6 Maintainability

Another important aspect related to the economical operation of an energy recovery device is the maintainability. In order to achieve optimized results, the following aspects were considered:

- Simplicity (reducing the numbers of parts)
- Nonmetallic or highly corrosion resistant materials
- No/Minimal wearing parts

2.7 Main features and principle

The new Flowserve ERD is an isobaric energy recovery device designed for reverse osmosis seawater desalination applications. In an RO desalination application the high-pressure waste stream entering the ERD is brine leaving the membrane filters. The energy from this brine is transferred to low-pressure seawater provided to the ERD from the system's low-pressure feed pump. Seawater then leaves the ERD at nearly the same pressure as the incoming brine. A small booster pump is used to overcome piping friction losses between the brine outlet of the membrane, and the point that this seawater will be injected back into the membrane inlet. The final outlet of the ERD unit is the brine reject leaving at low-pressure. A control valve is used at this location to maintain a minimum backpressure on the device.

Low-pressure seawater flows into the ERD, filling a portion of the rotor. At the same time, high-pressure brine reject from the membranes enters the same rotor from the opposite side. As the ceramic rotor spins, the low-pressure seawater is exposed momentarily to the high-pressure brine reject stream, at which point hydraulic energy is transferred from the brine to the seawater. As the rotor continues to spin, the now high-pressure seawater and low-pressure brine reject are discharged out of their respective sides.

ERD recovers more than 98% of the hydraulic energy of the brine stream and has an extremely low mixing rate, substantially reducing operating costs.

The new Flowserve ERD consists of only a few internal components made of durable and corrosion-resistant materials. The housing including a sight-glass to monitor rotational speed and a port for vibration transmitter installation. Compact, lightweight and high-capacity design allows a reduction of the ERD system footprint, piping and connections savings and best manageability for new installations and easy drop-in replacement for other isobaric energy recovery devices installations.

3. Testing of the new Energy Recovery Device

Flowserve designed and built a test stand specifically to test the performance of our new energy recovery devices. Besides the flow and pressure measurements that are required to calculate the hydraulic efficiency, the test stand is also able to carry out leakage and mixing measurements. These are critical losses that need to be considered to further optimize the efficiency of an energy recovery device and therefore the power consumption of a SWRO plant.

Besides the pressure losses to calculate the hydraulic efficiency the test stand can measure and monitor:

- Leakage
- Mixing
- Vibration
- Noise
- Back pressure

4. References

The new Flowserve Energy Recovery Device was already supplied to 2 installations and is successfully in operation. First operating results and experiences will be presented in more details.

Industrial scale pilot at Maspalomas I desalination plant demonstrates the efficiency of DuPont™. B-Free™ pre-treatment – a new breakthrough solution against biofouling#

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Biofouling is one of the most common and severe issues in the operation of seawater reverse osmosis (RO) systems with open intake. Unchecked, it causes significant operational problems such as frequent interruption, damage to the membranes, intense chemical and energy use, and regularcleaning-in-place (CIP) of the RO membranes. A novel, vessel-based media technology utilized as a membrane pre-treatment service has shown to efficiently mitigate the effects of biofouling in membrane filtration. DuPont™ B-free™ pre-treatment works under different main mechanisms which are smartly combined to provide a biostatic environment for downstream RO operations.

The Maspalomas I desalination plant with a capacity of 14.500 m^3/d in the Gran Canaria island (Spain), has been suffering from biofouling problems in the RO. To resolve the biofouling challenges, experts from Elmasa, a company with more than 45 years of experience in the water industry, collaborated with DuPont Water Solutions and tested for more than a year and a half a novel pre- treatment technology – DuPont™ B-Free™ designed to eliminate the effects of biofouling in the ROsystem. An extensive trial using seawater open intake as source water showed biofouling prevention and trouble-free operation in an industrial scale pilot plant, while the parallel full-scale plant did continue to suffer from the negative effects of biofouling. B-free™ creates an instant and sustained biostatic environment for the downstream RO operations and is and resilient to upstream upsets.

Keywords: Biofouling; Reverse osmosis; Media; Bacteria; Chemical cleanings

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Development of a novel method for biofilm visualization on reverseosmosis membranes

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Imaging techniques are an important research tool for the qualitative study of static biofilms. Biofilm samples should ideally be visualized with minimal sample preparation to not alter its original structure. However, it can be challenging, as these compounds have little or no color, because are highly hydrated. Traditional image-based techniques such as confocal laser scanning microscopy or optical coherence tomography are expensive, challenging and labor intensive. This report explains the development of a novel method to visualize in situ biofouling on a solid surface. The principle of Fortilife™ Director™ method is to cover the fouled membranesurface with a special reagent, creating a homogeneous and thin layer that reveals areas where biofouling is deposited. Finally, the surface covered is quantified through an image analysis software. This protocol offers several benefits. Procedure is simple, the reagents and theequipment can be readily available and offers a high contrast of the boundaries of biofilm and itsmorphology. Images of biofilm at different growing phases and calculations of biofilm impact based on surface area are provided. It is worth remarking that good correlation was found between the biofilm coverage quantified and pressure drop increase, as well as traditional analytical parameters quantified.

Keywords: Reverse osmosis; Biofouling; Membranes; Brackish water; Fouling; Biofilm.

Photoactive PVDF membranes for direct solar membrane distillation

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Membrane distillation (MD) appears to be one of the best technologies for the development of off-grid desalination/wastewater treatment plant due to its modular configuration, low power consumption and ability to harness low grade energy resources [1]. To this end, many attempts to design solar MD plants have been carried out.

Direct solar membrane distillation (DSMD) process has been proposed as an effective solution to develop larger MD plants. One of the main advantages of this concept is that the feed temperature is raised in the boundary layer in contact with the membrane surface. Therefore, the temperature polarization effect is drastically reduced, increasing the effective driving force of the process [2]. The majority of the research efforts on the development of photoactive membranes for DSMD have been focused on the surface modification of commercial hydrophobic membranes applying an additional layer containing different fillers such as carbon nanotubes, carbon black and silica-gold nanoparticles.

In this work, hydrophobic photoactive membranes have been prepared including carbon black (CB) inside the starting polymeric dope solution. The nanocomposite membrane was then prepared easily with a common non-solvent induced phase separation technique. The influence of the CB loading in the dope solution on the photothermal properties of the membranes as well as the performance during vacuum membrane distillation tests have been investigated.

During traditional VMD tests, these membranes were able to deliver distillate fluxes up to 36 L/m^{2}h and a complete salt rejection even treating a concentrated NaCl solution (90g/L) working at moderate feed temperatures (50°C). Moreover, the broad light absorption of such membranes made them suitable for DSMD application. In fact, when put under a light source, the membrane surface was heated and reached temperatures as high as 60°C allowing a direct heating of the feed during the distillation operation. This feature was finally confirmed during the DSMD test carried out using two different light sources and pure water as feed.

Keywords: PVDF; Photoactive; Solar; Membrane distillation; Carbon black.

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Methodology for the implementation of a steady state simulation model in a multi-effect distillation plant. Case study: PSA MED pilot plant

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Multi-effect distillation (MED) is an attractive sustainable solution for its simultaneous application in water mining and desalination processes [1]. This technology, combined with solar energy, also contributes to the decarbonization of the desalination industry [2], increasing its potential in this sector even more. This work presents a methodology for the development of a steady state simulation model of a MED plant based on a pilot plant located at Plataforma Solar de Almeria (PSA) [3]. It allows for the evaluation of performance indexes such as performance ratio (PR), specific thermal energy consumption (STEC) and system variables (pressures and temperatures inside effects, per effect production, etc) at a wide range of operating conditions. The methodology has been implemented aiming at two main objectives: i) saving costs and time avoiding the high time-resource consuming operation of a real MED plant at certain operation conditions and, ii) using this model to feed an optimizer in a hierarchical control architecture to achieve optimal operation when coupled with a variable energy source, namely solar energy.

The methodology to obtain the simulation model is shown in Fig. 1. Themodel (based on the one proposed in [3]) (i), is able to estimate the outputsfor a given input if the plant parameters are provided (mainly the heat transfercoefficients). To obtain these, a plant parameter estimator function is used (ii).This estimator is fed by a database (iii) containing information about

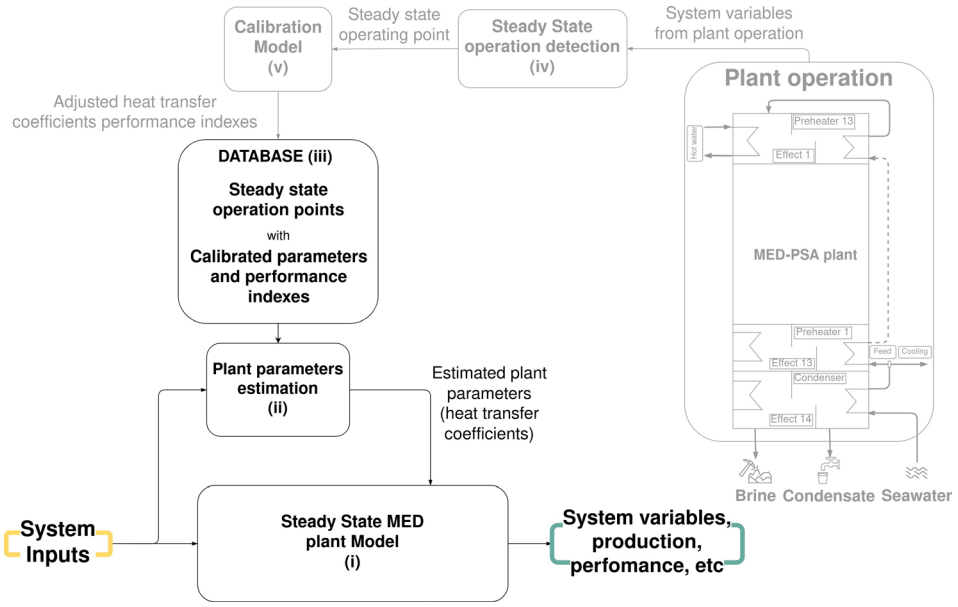

Fig. 1. Diagram of the proposed methodology (black). Database update scheme during plant operation (grey)

the historicoperation of the plant and thus considering a wide range of operating conditions.This database is updated during normal plant operation by constantly monitoringand evaluating the steady state operation periodically (iv). This is achieved usinga moving window average and checking its deviation. In the case that all variablesof interest are within allowed margins, then the calibration model (v) is run andthe plant parameters are obtained and stored in the database.

The implementation of the proposed methodology has been validated at the PSAMED pilot facility.

Keywords: Steady-state model; MED; Solar energy

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Residence time distribution in reverse osmosis/nanofiltration spiral-wound modules in a laboratory scale desalination unit

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Membrane processes are dominating the desalination techniques. Reverse osmosis (RO) is currently the most used technique for seawater desalination. Nanofiltration (NF) could be an interesting alternative option for brackish water desalination. As global warming is unleashing its disastrous impact on fresh water availability, desalination techniques are helping ensuring supplies to cover the increasing water demand for drinking and for all economic sectors.

The overall performances of such membrane processes depend on many factors. Flow hydrodynamics within membrane modules is particularly critical for insuring better salt retention, higher recovery rate and longer modules life span by helping preventing fouling. In this work, we attempted to determine the residence time distribution (RTD) as flow hydrodynamics characterization method in spiral-wound membrane modules. The experimental work was performed on RO and NF modules of a laboratory scale unit. The results will be analyzed and discussed.

Keywords: Desalination; Spiral-wound modules; Reverse osmosis; Nanofiltration; Flow hydrodynamics; Residence time distribution

CFD modeling of concentration polarization in full size spiral wound element with a commercial feed spacer

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In this work we demonstrate a computational fluid dynamics (CFD) model that describes the water flux, salt passage and pressure loss for a spiral wound element, over a length of 1000 mm. The geometry was generated from a CT-scan of a commercial feed-spacer. Thus, under assumption of lateral periodicity, the model represents an entire spiral wound membrane element. The ability to describe an entire element in high detail presents a potential paradigm shift in multi-scale modeling, namely, it is not strictly necessary to use simplified models to describe large systems. The model is used to establish a characteristic relations for concentration polarization (Sherwood) and pressure loss (friction factor). The results show that entrance effects can play a role in experimental determination of a Sherwood-relation.

Keywords: Computational fluid dynamics; Feed spacer; Concentration polarization

Advanced technologies and solutions in thermoplastics for marine intakes and outfalls in desalination

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New technologies in HDPE materials and in the production process of extruded pipes enable to manufacture high-quality XXL pipes by extrusion process in diameters up to OD 3500 mm. This sophisticated XXL piping system provides many benefits compared to other materials and technologies used in the past by needs of such large diameters. AGRU will

present features of large diameter extruded pipes and fittings as well as production, logistics and installation. Examples of applications for offshore and onshore (seawater intake, outfall, mariculture, water supply lines) will underline the technical benefits of such a system. Today's modern seawater desalination plants (SWRO) utilizes thermoplastic solutions in many different fields. Drinking water is a scarce resource, as only one percent of the world's water supply is suitable for drinking. Due to the growing world population and climate changes, the desalination of seawater for drinking water production is becoming increasingly important. AGRU engineers and supplies thermoplastic technology and solutions for seawater desalination which uses the reverse osmosis (R-O) technique. The range of solutions encompasses piping systems, concrete protective liners (CPL) and semi-finished products made from different materials. The main field of application for these solutions are marine pipelines e.g. seawater intakes, particle settlement tanks, filter feed pumps, pre treatment filters, R-O-modules, product-water holding tanks, potable water supply lines, process chemical tankfarms, brine discharge tanks, discharge lines including diffusor solutions, storage tanks and many more.

Keywords: XXL piping systems; Concrete protective liners (CPL) semi-finished plastic products; Marine pipelines; Seawater intakes; Particle settlement tanks; Filter feed pumps; Pre-treatment filters; R-O-modules; product-water holding tanks; Potable water supply lines; Process chemical tank farms; Brine discharge tanks; Discharge lines including diffusor solutions; Storage tanks; HDPE; ECTFE; Chlorination; PP; Industrial piping

Retrofitting SWRO to increase capacity without modifying intake or pretreatment

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This paper re-examines widely held premise that operating above 45% recovery in Atlantic/Pacific seawater is impractical and energy intensive. It demonstrates the technical and economic rationale for increasing SWRO recovery from the standard practice of 40-45%to 60%, and shows the scale of the opportunity to increase water produced by existing desalination facilities with no need for additional infrastructure.

Conventional SWRO systems are designed to operate at 40-45% recovery, and discharge brine with TDS of around 70,000 ppm. However, conventional SWRO membranes can operate with brine TDS of up to 90,000 ppm. This means that the true limitation on SWROproduction is around 50% higher than is commonly practised.

This paper demonstrates that the performance of modern RO membranes and turbochargers is sufficient to increase system recovery to 60%, without a significant impacton SEC compared to conventional SWRO designs.

Retrofitting an existing SWRO system has the environmental and economic benefits of avoiding additional intake infrastructure and pretreatment capacity. We also demonstratethat the flux balancing achieved in multi-stage RO results in superior membrane performance and better system reliability.

The paper concludes with an economic analysis of two scenarios in the Canary Islands, comparing the life costs of (a) expanding an RO facility and (b) increasing production by retrofitting the existing RO system. This analysis shows that capital savings far outweigh amarginal increase in SEC.

Water-Energy-Food nexus: an opportunity for promoting socio-economic development in Algeria

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Water resources in Algeria are scarce, often low quality, fragile, and unevenly distributed in space and time. The pressure on water resources can be associated with industrial development, a steady population growth, and demanding land irrigation measures.These conditions createa tense competition for managing water resources and sharing thembetween agricultural development, drinking water supply, industrial activities etc. Moreover,the impact of climate change has placed in the forefront national policies focused on the water-energy-food nexus (WEF). In this context, desalination membrane technologies could play an increasing rolefor supporting segments of the Algerian economy that are heavily water-dependent. By implementing water reuse and desalination strategies together in the agricultural sector, there is an opportunity to expand the access to healthy food and clean water, thereby keeping the WEF nexus effects under control.

Keywords: Desalination; Climate change; Sustainable development goals (SDG's); Water scarcity mitigation.

Use of vacuum enhancement in multi-envelope membrane distillation modules: effects on internal hydraulics

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The best performance so far in pilot-scale membrane distillation (MD) has been achieved with multi-envelope spiral-wound modules working in vacuum-enhanced air gap configuration (V-AGMD). Onone hand, increasing the number of internal circulation channels allows to increase the feed residence time,improving thus the thermal recovery without resorting to unfeasibly long channels. On the other hand, sucking air from the gap decreases the mass transfer resistance and thus enhances the vapour flux through the membrane pores.

Three different multi-envelope modules differing in the number and length of their channels have been assessed in a thorough experimental campaign carried out at Plataforma Solar de Almería (in SE Spain), using simulated seawater as feed and different operating conditions of hot and cold inlet temperatures, andfeed flow rate. In all the modules assessed, the role of air suction for improving the performance was moreremarkable the worse the operating conditions were for permeate productivity. At low hot inlet temperatureand low feed flow rate, permeate productivity was 3.6 times higher than that obtained without vacuum enhancement, and 66% lower STEC was obtained.

In addition, another remarkable effect observed was that working with reduced absolute pressure in the gapreduced the hydraulic pressure drop (PDrop) inside the channels. The largest difference between operationwith and without vacuum enhancement was observed in the module with the longest channels. In this case,PDrop decreased up to 48% with respect to conventional AGMD operation. Possible causes of such reduction in PDrop when operating with air suction are discussed. The interest of this is that the lower PDrop allows to operate at larger feed flow rates without damaging the internal structure of the module, and this facilitates the treatment of high salinity sources for which the driving force reduction at low flow rates can be a limitation.

Keywords: Membrane distillation; Pilot plant; Vacuum-enhanced AGMD; Experimental test

Water treatment by polyethyleneimine enhanced ultrafiltration membrane for heavy metals removal

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In this work, we studied the performance of the ultrafiltration membrane in the process of wastewater treatment in the purpose to be used as a complementary resource in agriculture. Water scarcity has been extremely pronounced over the past five years in Algeria, leading to serious management of all resources to meet ever-increasing needs.

The ultrafiltration pilot (UHS 620-A), manufactured by the company Amenhyd, has allowing decreasing of all the residual pollution indicators such as suspended solid, non biodegradable organic mater and biodegradable one in the respectively proportion of 95%, 47% and 44%, but very little impact on the removal of heavy metals. These metals even they are in small quantities and below the required limits, however the phenomena of bioaccumulation must be taken into account, in particular during agricultural irrigation. This led us to consider the addition of polyethyleneimine as a chelating agent against heavy metal during ultrafiltration procedure. The advantage of PEI modification in the polyelectrolyte enhanced ultrafiltration membrane is characterized by its good solubility in water and very low membrane fouling. The results obtained show complete elimination of iron, cadmium and cobalt and significant reduction in the contents of other elements such as nickel and zinc.

Keywords: Ultrafiltration; Polyethyleneimine; Metal removal; Water treatment

Carbon footprint in the treatment of urban wastewater in peripheral or insular territories: Example in analysis of Canary Island (Phase 1: Inventory)

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Wastewater treatment plants play an important role within the urban water cycle to prevent the natural water environment and human health from being negatively affected by human activities. However, wastewater treatment processes, such as effluent discharge and indirect emissions resulting from energy or chemical production, also negatively affect the environment. The carbon footprints have been used to track human influence on the environment across different areas of interest and have been applied to assess the sustainability of wastewater treatment plants. A comprehensive review of carbon footprint assessment for evaluating the wastewater treatment process in wastewater treatment plants was investigated in this article. The review showed that the carbon footprint was used to assess the sustainability of WWTPs, and other footprint assessment applications (such as nitrogen and phosphorous footprints) were also introduced to assess the eutrophication of water bodies. To promote the application of the footprint evaluation, this article regulates the objectives of the study, the frameworks, the limits of the system, the methods of data treatment and the resulting interpretation process. The pros and cons of the footprint assessments were discussed and investigated in detail, examining the CO_2 production on each island of the Canary archipelago, and various suggestions for improving the footprint assessments were proposed. Analysis of footprint assessments at different wastewater treatment plants revealed that these technologies and scales had a significant impact on CO_2 emissions. Furthermore, research hotspots identified using a keyword network diagram showed the water-carbon-energy nexus was a promising direction for future study. Finally, possible application scenarios were proposed, element tracking through modified footprints and management improvement through mathematical optimization, to optimize the WWTP operating strategies. The main objective of the study is to try to reduce the production of emitted CO_2 from electricity consumption, carrying out studies in the field of the implementation of PV solar panels and, on the other hand, carrying out a study of the sludge itself produced by the

treatment plant and reconverting them into bio-fuel for the plant itself among other possible consumption optimization studies. In general, the research on the footprint assessment of wastewater treatment plants is still in the early stage and needs further exploration and improvement, introducing new tools, exploring the variation of the system under various scenarios, combining other footprints and implementing the nexus assessment.

Keywords: Wastewater; Carbon footprint; Water treatment; Emissions

Nitrogen and phosphorus recovery and separation from agricultural wastewater effluents — role of electrically conductive membranes

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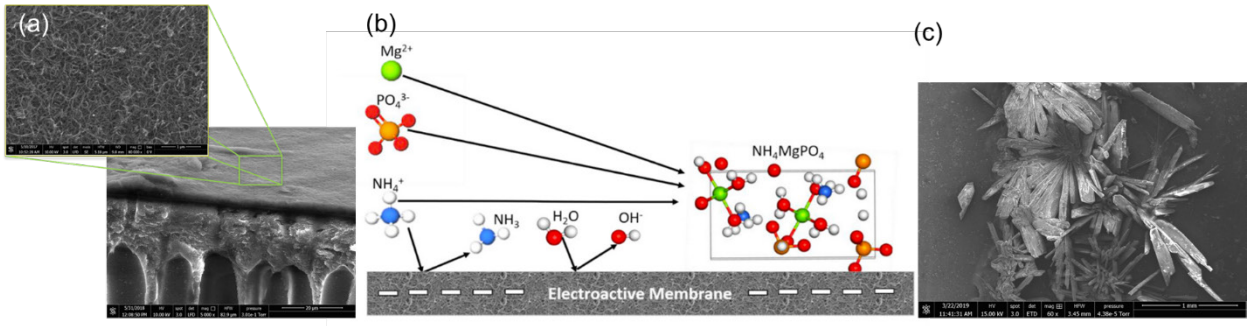
Nitrogen and phosphorus are essential elements needed for agricultural crop fertilization, used in increasing quantities to feed an ever-growing population. Production of both nitrogen and phosphorus fertilizers is energy intensive and their demand is expected to increase in the coming decades due to changes in human population, diets, and agricultural practices. Agricultural wastewater from livestock (AWL) farms contains high concentrations of nitrogen and phosphorus in addition to organic loads. AWL runoff to aquatic ecosystems leads to severe environmental impacts such as eutrophication of rivers, lakes, and coastal oceans. Currently, conventional wastewater treatment plants are unable to remove such high concentrations, which require complex anaerobic/anoxic treatment stages and reduce the efficiency of the treatment. Consequently, use of primary-treated agricultural wastewater effluents for agricultural irrigation gradually deteriorates the quality of soil, ground, and surface-water resources through loading of nitrate, nitrite, pharmaceutical byproducts, and/or antibiotics. An important strategy to mitigate phosphorus and nitrogen scarcity is to recycle them from waste streams back into agricultural production. Our research shows the ability of P and N recovery from concentrated and diluted solutions (1–100 mg L^{-1}) of synthetic AWL. The recovered P and N are in the form of Struvite which is considered an "eco-friendly" fertilizer. The recovery is based on an electrochemical reaction near an electrically conducting ultrafiltration membranes (ECM). The electrochemical reduction of dissolved oxygen and water molecules generate a local pH gradient in the close vicinity of the electrode. The pH near the cathode increases, leading to nucleation and growth of Struvite (Fig. 1) and, importantly, high yield with no chemical additives. As the recovery process utilizes permeate to control mass transfer, diffusion limitations are eliminated, leading to a significant increase in reaction rates and removal ratio. In terms of collecting the recovered Struvite, our ECMs have pores in the range of 10-100 nm which are significantly smaller than the size of Struvite particles, therefore, Struvite solid particles which are filtered by the ECM accumulate on the membrane's surface, to be collected by a pressurized backwashing process or by simply blocking the permeate flux.

Keywords: Electrically conducting membranes (ECMs); Struvite recovery; Ammonium/ammonia recovery; Fouling mitigation



(a) SEM image of the ECM; (b) schematic diagram of struvite formation; (c) SEM image of precipitated struvite crystals on the ECM

Reactive membranes for membrane distillation

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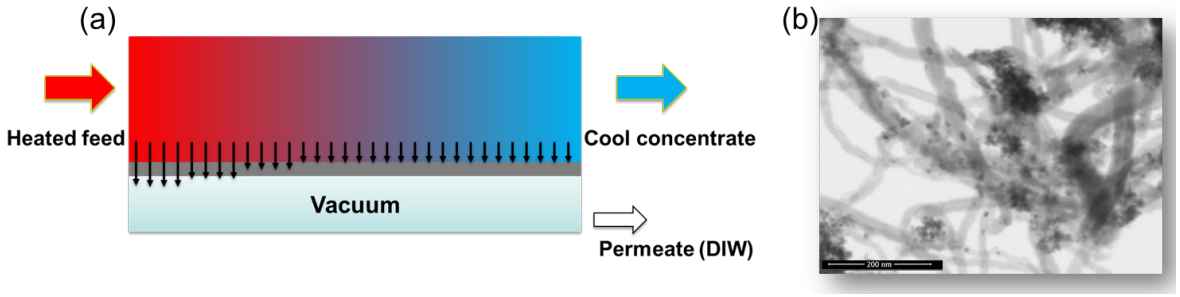
Electroactive membranes (ERMs) are composite membranes that can change their properties according to electric and magnetic fields. Lab-scale ERMs were fabricated by depositing carbon nanotubes (CNTs) and metal oxides onto PES and PVDF support membranes followed by chemical cross-linking. We use ERMs to demonstrate a radio-frequency induced heated (RF-IH) membrane distillation process.

'Self-heating' thermally conducting membranes were heated by radio frequency induction heating (RF-IH) to overcome distillation limitations. A composite membrane containing iron oxide coated carbon nanotubes (Fe-CNTs) was spray-coated on a PTFE membrane and heated by induction heating, using radio frequency altering magnetic fields. The performance of RF-MD system was evaluated in terms of distillate flux and specific heating energy consumption at optimized operating conditions and results were compared to a conventional MD system. In addition, the impact of RF heating on calcium sulfate ($CaSO_4$) scaling was addressed in terms of distillate flux and crystal formation. Results show the ability of heating water directly on the membrane surface in RF-MD systems, leading to low TP, high distillate flux, and low specific heating energy compared to a conventional MD system. Analysis of the RF-MD membrane surfaces, showed only sporadic small $CaSO_4$ crystals, while high concentrations of small crystals were detected at the concentrate. These results are promising as they show the RF-MD system has potential to improve MD processes, specifically for high salinity distillation where pressure-based applications cannot be used.

Keywords: Membrane distillation; Electrically conducting membranes; Induction heating



(a) Setup of the RF-heated MD system; (b) TEM images of the FE coated CNTs used for RF heating

Clean in place for the cartridge filters system in a large scale desalination plant

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A full scall system of chemical cleaning in place (CIP) of cartridge filters was developed and implemented in Ras Al-Khair (RAK), one of the Saline Water Conversion Corporation (SWCC) plants in Saudi Arabia with a capacity of 310,000 m^3/d. RAK seawater reverse osmosis (SWRO) plant is located in the Arabian Gulf. RAK plant consists of dissolved air floatation (DAF), dual media filter (DMF), and cartridge filter vessels (CFs) systems in the pretreatment of the plant. The purpose of the CIP system is to modify the current practice of the replacement of cartridge filters and extend the lifetime of cartridge filters by minimizing the differential pressure in the CFs. The cartridge filter elements are replaced for any vessel with a flowrate less than 80% of the maximum flow and when the maximum differential pressure is 1.2 bar in the CFs line. A novel CIP system was developed and implemented at the RAK plant. Hydrochloric acid (37%) is used for the CIP. The objective of this method is to diminish the replacement rate of the CF. Consequently, The cost-saving in RAK from CF replacement reduction after the CIP is approximately 109,000 $/y. The initial cost of installation

of the CIP system was 34,000$ for the two systems with a payback period of less than 4 months. The chemical cost for the CIP for 31 CFs is just 111$/y. Furthermore, the filtered water production increased by 42% and the lifetime of the CFs increased by 51%.

Keywords: Clean in place (CIP); Cartridge filter (CF); Pretreatment.

Assessment of water-energy-waste resources in rural houses in Gran Canaria Island, as a tool for the climate change mitigation

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The potential application of renewable energies is diverse, which have demonstrated their suitability in their application to the size and operation of activities. Rural tourism is one of the products with the greatest potential for growth within the tourist offer of Gran Canaria island, as it combines sustainable development and respect for the natural environment. Among the renewable energies with high applicability in rural environments, we highlight: the solar photovoltaic, as low temperature thermal, and methanization of the waste and wastewater generated in the tourist activity. This work shows a methodology adapted and developed for the study of the water-energy-waste nexus, considering parameters of waste generation, water and energy consumption, occupied area and potential renewable energy generation in rural houses in Gran Canaria island and evaluate their environmental profitability. It has been concluded that applying these renewable technologies can significantly reduce the carbon and ecological footprint of the activity of rural houses based on the available surface. This contributes to achieving the energy and environmental objectives proposed by the EU to achieve decarbonization by 2050.

Keywords: Water-energy-waste; Carbon footprint; Ecological footprint; GHG; Rural tourism

Proposal of a Climate Change Mitigation tool implemented through an Integrated and Resilient System (IRS) to monitor and measure operation variables for Natural Depuration Systems for livestock farm wastewater effluents in islands and isolated territories

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In this study, the main elements that can make up a natural treatment system for wastewater have been developed. The most important phenomena, parameters and properties of operation and design of Natural Depuration Systems (NDS) for effluents from livestock farms in isolated island territories have been analysed. Likewise, a bibliographic review of the main monitoring techniques to control the anaerobic process and/or the quality of the water currently used has been carried out, with the aim of clarifying their strengths and weaknesses. To propose a system for the observation and treatment of the variables and parameters that affect the SDN, seeking the simplicity of application and the economic technical feasibility of said implementation.

To do this, it has been proposed an Integrated and Resilient System (IRS) to measure the variables through low-cost and open-hardware (sensors, data loggers, control systems, …) technology, and applying IoT strategies to share, and analysis the information collected. In addition, it has been added energy variables in the data acquisition strategy for the IRS to assess the energy resource from renewable sources available in the area, with the aim of providing the system

with autonomy and/or improving the operation of the plant. This last work proposal includes the possible use of the energy resource of potential renewable gases (Biomethane, H2,...) produced by the anaerobic digestion of the NDS.

It has been possible to conclude that it is feasible to make a measurement system of these characteristics, not only for the parameterization of the NDS, thanks to the great resilience and simplicity that this type of technology presents, as well as its low cost. Therefore, the SDN operation process could be improved thanks to this technology.

Design of a small-scale thermal vapour compression system driven by low-temperature solar heat

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Desalination technologies are essential for dealing with fresh water scarcity. Their use is sustainable as long as renewable energy sources are used to drive them. Multi-effect thermal vapour compression desalination driven by low-temperature solar heat is suitable for small-scale applications [1]. Unfortunately, the performance of the key component (steam ejector) deteriorates due to the transient nature of solar energy. Here, a variable geometry ejector is suggested to overcome the problem of variable operating conditions [2].

The objective of this study was to design a small-scale multi-effect thermal vapour compression desalination system driven by low-temperature solar heat. The design approach included development of a one dimensional mathematical model for the system, performing numerical modelling of the fluid flow inside the steam ejector by means of computational fluid dynamics, hydraulic connection design and material selection [3]. The results demonstrated that a triple effect configuration assures compactness of the system while resulting in a reasonable performance [4]. It was found that a variable geometry ejector can improve the entrainment ratio up to 400% for high primary inlet temperatures and that the system can operate with high performance under variable conditions [5].

Keywords: Multi-effect thermal vapour compression; Small-scale; Variable geometry ejector; Entrainment ratio

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Biofilm formation on SWRO membranes caused by planktonic bacterial aggregates from pretreatment and rotary energy recovery devices

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The formation of biofilms on reverse osmosis RO modules, including RO membrane spacer and RO membrane surface, involves the presence of planktonic bacterial aggregates that can be present in the seawater RO feed after the pretreatment system and from a rotary energy recovery device (RERD). The formation of these planktonic aggregates is dependent upon their transition from planktonic individual bacteria and these planktonic bacterial aggregates have the same properties as membrane-attached biofilms and are sometimes referred to as protobiofilms (planktonic pre-formed biofilms).

The planktonic bacterial aggregates from the pretreatment and the rotary energy recovery devices existed as two separate molecular weight components. Seawater ultrafiltration (UF) pretreatment will remove the particulate planktonic bacterial aggregates but not the colloidal bacterial aggregates. The dispersal of a biofilm on a RERD will result in the biofilm formation on membrane spacers and membrane surface, depending upon the feed flow velocity. It is suggested that the presence of planktonic bacterial aggregates, whether from the pretreatment or the RERD deigns, is the main cause of RO spacer and membrane biofouling. Other than removing the planktonic bacterial aggregates from the RO feed and from the RERD, the only other means of controlling planktonic colloidal bacterial aggregate attachment to the SWRO membrane surface is to limit the flux and increase the feed flow velocity which effectively limits the concentration polarization (CP).

Keywords: Biofouling; Planktonic bacterial aggregates; Protobiofilms; Rotary energy recovery device

Making seawater desalination more sustainable: a techno-economic analysis based on circular economy approach

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The increasing role of seawater desalination plants to minimize the supply-demand gap of potable water is accompanied by its negative environmental impacts (EIs) which includes, among others, damage to the local marine environment where the highly saline effluents of these plants are discharged. This can be mitigated by, for example, reducing the effluent's quantity and concentration before discharge (called minimum liquid discharge or MLD) by recovering water and other minerals using a circular economy approach which could also potentially reduce the operational costs by marketing the recovered products. This study presents a novel techno-economic analysis of two treatment chains for recovering water, NaCl salt and other minerals like calcium and magnesium from seawater by integrating techno-economic models of technologies like nanofiltration (NF), crystallizers, reverse osmosis (RO), electrodialysis (ED), and multi-effect distillation (MED) (the first chain with and the second without MED), wherein RO and ED are connected in a unique recirculatory flow. The two chains are analyzed for a range of diluate-to-concentrate flow ratios in the ED (between 5 and 80). The chain with MED is found to recover twice as much water as the one without. The electricity consumption of NaCl crystallizer is the highest, which increases by more than twice in the chain without MED. While NF and RO account for 3/4th of the capital expenditures, a large revenue stream generated by the recovery of mangesium helps in placing the levelized cost of NaCl salt (LSC) for almost all the cases within its market price range of 80 and 150 USD/ton$_{NaCl}$. To check its sensitivity, the simulated chains should be further examined by varying some key parameters while also testing them for different seawater concentrations. This study proves the economic feasibility of seawater desalination using the modeled treatment chains that can also help reduce its environmental footprint.

Keywords: Seawater desalination; Mineral recovery; Circular economy approach; Minimum liquid discharge (MLD); Techno-economic analysis

Polymer-based thermal water treatment systems for highly corrosive solutions and high-concentration applications

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The supply of suitable and sufficient water for human consumption as well as for industries is increasingly limited all around the globe. Many natural sources are exhausted while others are contaminated from industrial waste waters. Also, large amounts of desalination reject brine increasingly causes problems. Hence, the closing of water cycles and zero liquid discharge (ZLD) become more and more important in order to reduce freshwater demand as well as contamination

and are increasingly enforced by authorities. However, in many cases it becomes technically challenging to reach the required high concentrations, avoid severe corrosion and keep the energy consumption at reasonable levels.

A modular system was developed by theVap which allows the implementation of a variety of processes, especially the multi-effect-distillation (MED) and multi-stage-flash distillation (MSF) as well as liquid to liquid and liquid to gas membrane contactors. The high flexibility of the system allows to cover a wide range of capacities while at the same time offering a high degree of customization of individual water treatment units. The application of polymer materials allows the processing of highly corrosive solutions while the thermal approach is suitable to achieve concentrations close to or even slightly beyond saturation. Multiple energy reuse within the processes ensures thermal efficiency while moderate process temperatures of less than 85°C allow the use of waste heat to drive the process. Moreover, the processes can be combined with mechanical vapor recompression (MVR) and thermal vapor compression (TVC). The presented process implementations are part-load capable over a wide operational range and are internally balanced only by passive devices without moving parts, which explicitly includes the MSF.

theVap technology can be applied in a wide range of applications from generation of freshwater to wastewater treatment. Several pilots are already in operation. The biggest potential is seen in highly saline and extreme pH applications going close to saturation limits. This can involve industrial waste waters, diluted process streams and RO brine.

Keywords: Multi-stage flash; Multi-effect distillation; Polymer-based; Thermal process; Zero-liquid- discharge; Membrane contactors; Corrosion resistant; Industrial wastewaters; Desalination; Brine concentration

Treating challenging industrial wastewater by membrane distillation: understanding the impact of the fouling

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This study investigates the efficiency of membrane distillation (MD) for the treatment of challenging industrial wastewaters, by focusing on process performance and membrane fouling. The study is divided into two parts based on the type of treated wastewater: textile wastewater (i) and desalination brine (ii).

The treatment of textile dye solution is considered one of the most challenging wastewater treatments, representing a major concern for the ecosystem. The effect of the feed temperature and feed flow rate on the MD fouling were investigated at different feed water temperatures and feed flow rates. Results show that (i) negligible fouling was observed at a feed temperature of 40°C, (ii) the increase in temperature impacted the process performance, leading to severe flux decrease (~70%) and to the formation of a thick fouling layer (240 μm) at a feed temperature of 80°C, (iii) fouling thickness was reduced with increasing feed flow velocity, (iv) the fouling increased toward the inlet side of the membrane cell due to the variation of the driving force along the module. *In-situ* non-invasive fouling monitoring by optical coherence tomography (OCT) allowed evaluating the fouling spatial distribution on the membrane and linking the MD process performance to the fouling accumulation, indicating a linear correlation between the flux decrease and the fouling deposition.

In this study, we present also the data on the treatment of multi-effect distillation (MED) brine with MD by focusing on process performance and membrane scaling. The influence of chemicals present in MED brine as well as feed temperature on the scaling process was addressed in terms of vapor flux and salt crystals formation. The scale formation was monitored with the OCT, and results were validated by scanning electron microscopy (SEM). Results show found that depending on its concentration, the antiscalant prolonged the induction time of salt crystallization whereas antifoaming showed the opposite effect. Scaling mostly occurred due to calcium sulfate crystals formation with the large size needle-shaped crystals favored at higher feed temperature. Results show that thermal desalination brine, which is already preheated and chemically pretreated, could be an appropriate feed source for MD to further increase the overall water recovery and reduce the marine environmental impact by reducing the brine discharge volume and its temperature.

Keywords: Desalination brine; Textile wastewater; Optical coherence tomography (OCT); Membrane scaling; Membrane fouling

Valorization of vegetal residues from invasive species for wastewaters treatment

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This paper aims at analyzing the performance of natural fiber filters, coming from *Pennisetum setaceum*, an invasive plant, as a first step of a wastewater treatment. This paper shows the results obtained for filtration of wastewaters, determining conductivity, chemical oxygen demand, turbidity, suspended solids, and pH. Filters were obtained with two different fiber lengths (2.5 mm and micronized fibers), obtaining better results for these last ones; besides, fibers ware also treated with a NaOH solution in order to avoid the crumbling of the filter. Obtained results show a decrease in the organic matter and suspended solids in the filtered samples; better results are obtained for micronized fibers. This filetering system is thus proposed as an alternative method for wastewater treatment in small isolated villages or as a complementary step in natural treatment systems to reduce suspended solids and achieve permissible limits for regenerated waters.

Keywords: Wastewaters; Fountain grass; Filtering

Impact of hydraulic retention time and membrane pore size on submerged gravity-driven membrane performances for seawater pre-treatment

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In seawater reverse osmosis (SWRO), membrane fouling is considered one of the main operational problems, which negatively affects process performance and membrane lifespan [1]. To this extent, seawater pre-treatment plays a crucial role in improving the seawater entering the membrane feed. Among the conventional seawater pre-treatments (such as media filtration and coagulation), membrane pre-treatment processes (microfiltration or ultrafiltration) have been investigated for more than 20 years [2]. However, the major disadvantage is the high operating costs due to intensive fouling control strategies (chemical and/or physical), which significantly increase the overall energy demand of the desalination process [3]. Recently, gravity-driven membrane (GDM) filtration process has been investigated as an alternative seawater pre-treatment [1]. This system does not require any additional energy for the filtration since it is driven only by hydrostatic pressure, leading to the achievement of a stable permeate flux without any chemical or physical cleaning. In addition, as low energy and chemical-free process, GDM displays lower costs compared to conventional membrane processes for seawater pre-treatment [1].

In this study, three lab-scale submerged gravity-driven membrane reactors were investigated as pre-treatment of raw seawater collected from Red Sea. The impact of membrane pore size (UF/MF) and hydraulic retention time (HRT, 12 h and 24 h) on process performance and water quality was evaluated. Operating the submerged reactors (MF and UF) with longer HRT (24 h) led to the best permeate quality with higher Assimilable Organic Carbon (AOC) removal efficiency (~+50%) Interestingly, AOC has been considered as an advanced indicator for the assessment of the seawater biofouling potential, where the lower AOC level in the seawater could effectively reduce the biofilm development in the RO process [4]. Moreover, it was found that the membrane pore size affected the water productivity resulting in higher performance with microfiltration compared to ultrafiltration (~+50%). The characterization of fouling layer morphology and foulant properties revealed that a thicker but more porous structure contributed to permeate flux enhancement.

To sum up, the key findings of our study suggest that the combination of MF and longer HRT (24 h) in GDM seawater pre-treatment could be considered a promising solution in terms of water productivity and quality.

Keywords: Desalination; Seawater pre-treatment; Gravity-driven membrane; Optical coherence tomography; Biofouling; Assimilable organic carbon

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New automatic control system to optimize biocide dosing for stable RO operation

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It is well known that biofouling is a major problem in membrane systems, causing increases in differential pressure, decreases in permeate water flow, and frequent cleaning. In order to solve the trouble and realize the stable operation of reverse osmosis (RO) systems, a unique biocide, named KuriverterTM IK-110, has been widely utilized for many years. It is, TP 4 and NSF-certified biocide, consisting primarily of stabilized chlorine. The main effects of Kuriverter IK-110 are to efficiently deactivate living microorganisms and prevent production of biofilm, resulting in suppressing differential pressure increase.

A big challenge of biofouling control is how to deal with biofouling potential changing from moment to moment. By providing the right amount of biocide at the right time, the efficacy of IK-110 can be maximized. Therefore, continuous and automatic adjustment of dosage of the chemical is an effective measure to achieve further stable operation of RO systems with the minimum required operating cost. Moreover, controlling dosage of reducing agent, which is added to reduce free chlorine in feed water, can also contribute to the cost-saving.

This paper explores methods to optimize the chemical treatment against biofouling and how the combination of the sophisticated biocide and the dosing controller impacts operation of RO systems. In particular, the following two studies are focused.

(1) Automatic on-site analysis of fouling rate to control dosage of Kuriverter IK-110
(2) Optimum control logic of reducing agent based on chlorine concentration in feed water

A case study covering a successful application of dosing controller in a food factory is also included. Not only stable operation but also significant annual operational cost saving, such as less frequent cleaning of membrane, less chemical consumption, longer lifespan of membrane and saving of labor for adjusting dosage, has been proved to be achieved by this automatic optimization of chemical treatment.

Keywords: Reverse osmosis (RO); Biofouling; Biocide; Optimization of chemical treatment; Dosing

Performance improvement of dual media filter in Ras Al Khair desalination plant

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Dual media filtration is the most commonly used pretreatment process of seawater reverse osmosis (SWRO) desalination plant in Middle East. Plant operation point of view, performance of dual media filter can be shown as Silt Density Index (SDI) and filter run time. Operators have monitored them hourly or daily. Nevertheless, there is insufficient information on the methodologies to improve the performance of dual media filter. Accordingly, the objective of this study was to examine the ways of improvement of dual media filter's performance. Pilot testing was conducted for the effect of media depth on the filter performance. And several kinds of backwashing optimization were conducted in Ras Al Khair SWRO plant.

Results showed that the performance of dual 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. By the measurements of turbidity during rinsing period and media depth, anthracite media losses were found in all filters. To minimize media loss, the optimization of backwashing velocity was conducted. It was found that one filter produced high turbid water after completion of rinsing period. This filter performance was recovered by improved acid cleaning.

Keywords: Dual media filter; Silt density index; Filter run time; Media depth; Chemical cleaning

Modeling and optimal control of convection-enhanced evaporation (CEE) system for a modular, cost-effective brine volume reduction

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This study presents a convection-enhanced evaporation (CEE) system as a modular brine volume reduction device for decentralized desalination plants and small-scale industries. The proposed CEE system is comprised of a set of packed evaporation surfaces at uniform spacing. Liquid (brine) is sprayed along the width of each evaporation surfaces forming thin films, and forced convection is induced either by means of a fan, natural wind, or a combination of both. As air flows over the liquid films, the difference in vapor pressure between the air and liquid surfaces induces evaporation. Mathematical and cost modeling of the system are presented. Brine preheat temperature and air flow speed were found to be the primary variables affecting the evaporation performance and were set along with the brine flow rate as decision variables in the cost-optimization problem. CEE capital and operating costs were selected as objective functions and were normalized to generalize the results to application with varying material and energy prices. A set of Pareto-optimal designs showing the trade-off between operating and capital costs are presented, and two operation modes for CEE are characterized. The generated Pareto-fronts were used as a dataset to control the operation of CEE in real-time. A case study simulation of CEE and the controller showed an operating cost ranging from \$0.1/m^3 to \$2.4/m^3 of evaporated volume.

Keywords: Convection; Evaporation; Brine; Optimization; Cost

Novel functionalized graphene oxide for capacitive deionization

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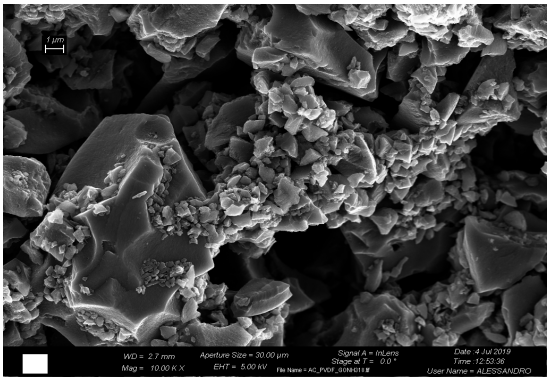
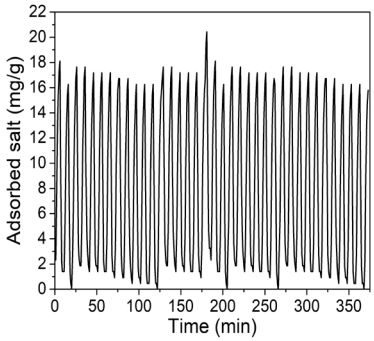
Graphene oxide functionalized with a novel positively charged monomer is proposed for application in water desalination. The functionalized graphene oxide has been obtained by a simple and scalable method, based on a modification of the one recently proposed by Roppolo et al [1]. The material obtained in this way has been mixed in organic solvent with activated carbon and hydrophobic polymeric binder to obtain a stable dispersion. The as prepared slurry has been coated on a metallic current collector with the doctor blade method and then dried at 50°C in order to obtain an electrode useful for capacitive deionization. The counterpart is obtained by replacing the functionalized graphene oxide with pristine graphene oxide in the preparation previously described. The final device, exploiting high surface asymmetric electrodes with opposite charges, is obtained juxtaposing a pair of these electrodes inside a homemade cell specifically designed for capacitive deionization application. Inlet and outlet are connected to a peristaltic pump. All the capacitive deionization tests have been performed in batch configuration, using NaCl 10 mM. A conductimeter is used for real-time measurement of the solution's conductivity. Material characterization techniques such as electron microscopy and infrared spectroscopy are employed to study the physical and chemical structure of the proposed materials. Thermogravimetric analysis is used to investigate the effectiveness of the functionalization procedure. Electrochemical methods are chosen to investigate the performance of the proposed materials. The final device demonstrates a remarkable desalination performance, reaching a value of 17 mg g^{-1} of salt removal, with a charge efficiency of 98%.

Keywords: Graphene oxide; Capacitive deionization; Functionalization; Salt removal





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Separation of drugs by commercial nanofiltration membranes and its modelling

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The present work investigates the performance of commercially available polyamide thin-film composite NF membranes (AFC 40 and AFC 80) to remove polluting pharmaceutical drugs namely caffeine, naproxen and paracetamol. The structural features of the NF membranes used were first estimated by water permeability measurements and by

retention measurements with aqueous solutions of organic uncharged solutes. In the second part, the effects of various operating conditions, i.e. applied transmembrane pressure, tangential feed flow velocity, and concentration of feed solution, on the retention of solutes by AFC 40 and AFC 80 membranes were evaluated. It was found that the rejection of drugs was directly proportional to transmembrane pressure and feed flow rate. Due to the size differences between caffeine (MW=194.9 g/mol), naproxen (MW = 230.2 g/mol) and paracetamol (MW=151.16 g/mol), AFC 40 membrane proved to be efficient for caffeine and naproxen with rejection efficiency of 88% and 99%, respectively; whereas AFC 80 membrane proved to be better for paracetamol with 96% rejection (and 100% rejection of caffeine and naproxen). It was also observed that AFC 80 membrane did not suffer any rejection efficiency with change in external operating conditions as compared to AFC 40. The membrane performance was predicted using Spiegler–Kedem model and were found to be in good agreement with the experimental results, which were successfully used to explain the transport mechanism of solutes through the AFC 40 and AFC 80 membranes in the NF process.

Keywords: Nanofiltration; Pharmaceutical drugs; AFC 30 and AFC 40

Acknowledgement

The Ministry of Education, Youth and Sports of the Czech Republic, Project CZ.02.2.69/0.0/0.0/18_053/0016969 "International mobility of employees of the University of Pardubice II", financially supported this work.

Multistage reverse electrodialysis with natural waters: a long term pilot study on performance and fouling

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Reverse electrodialysis (RED) is an electro-membrane process used to harvest salinity gradient energy [1]. The process consists of piling alternately anion- and cation- exchange membranes in a stack and supply, in between the membranes, waters with different salinities, e.g. seawater and river water. The chemical potential present due to the salinity gradient difference can be harvested through the selective migration of cations and anions through the ion exchange membranes (IEMs). Cations selectively pass cation exchange membranes (CEM) and anions selectively pass anion exchange membranes (AEM). At the electrodes, the ionic current is transformed into an electrical current using, e.g., an electrode rinse solution with a redox couple.

Conventionally, RED consists of a single stack producing power. However, this single-stage will limit either the power output or the energy efficiency. To overcome this trade-off, a multistage system has been proposed which connects multiple stacks in series [2]. Through modelling and experimental work with pure NaCl solutions, higher efficiencies were obtained while keeping the same power output. In addition, flexibility in electrical control and possible application of different IEMs per stage is gained [3,4].

In this study, we conducted a pilot multistage RED experiment with natural waters for 30 consecutive days, at a research facility operated by the company REDstack at the Afsluitdijk, in the Netherlands. The system consisted of two 22 x 22 cm^2 cross-flow stacks in series using 32 cell pairs for stage 1 and 64 cell pairs for stage 2. The installed membrane area of both CEM and AEM was 3.1 m^2 for stage 1 and 6.2 m^2 for stage 2. Woven spacers of 155 μm thickness separated the membranes making the compartments. The seawater (Wadden Sea) and river water (Lake IJssel) compositions were measured several times during the experiment. The research goal was to investigate the application of multistage RED with natural waters and the interaction of the different ions (mono- and multivalent) in natural waters with staging and membranes. Furthermore, at the end of the operation, a membrane autopsy was done to evaluate the membrane and fouling.

The operation showed a stable performance over 30 days with total energy efficiencies up to 37%. Fluctuations in registered gross power density were due to variations in salt concentrations in the inlet waters. Fig. 1 shows the gross power density and energy efficiency in each stage over the experiment period. The lower power density in stage 2 is caused by the lower salinity gradient available combined with longer residence time. The multivalent ions (SO_4^{2-}, Mg^{2+} and Ca^{2+}) showed different transport behaviour between stages. The pressure drop across both stages increased over time, due to fouling, first for stage 1 and later also for stage 2, which decreased the net power density. Lastly, the membrane autopsy revealed microorganism structures larger than the cartridge filter mean pore size used as a pre-treatment for

the natural waters. The agglomeration and growth of these structures in-situ can be the root cause of increased pressure drop in the compartments.

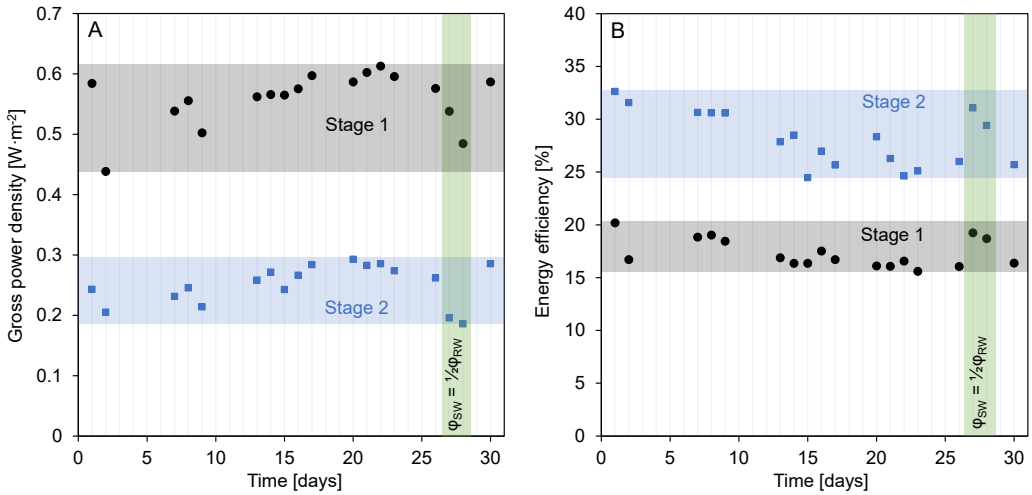

Fig. 1 (attached) – Stage 1 (dots) and stage 2 (squares) contributions to gross power density (A) and energy efficiency (B) over the experiment run. Different flow rate conditions were used on days 27 and 28, shadowed in green.

Keywords: Renewable energy; Ion exchange membranes; Multistage reverse electrodialysis; Natural waters; Salinity gradient energy

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Effluent pH determines electrochemical nitrogen recovery efficiency demonstrated at pilot scale

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An electrochemical pilot plant including 3 m^2 of cation exchange membrane was operated for ammonia recovery. The pilot treated source-separated urine (1 g/L NH_4^+). Ammonia recovery at pilot scale presented different challenges than lab-scale, as previously set operation parameters such as current density and nitrogen load did not directly influence the stack performance. It was shown that operating under effluent pH control (pH = 4) was more efficient than controlling current density or nitrogen loading. Moreover, it accounts for wastewater availability and composition fluctuation. The pilot plant removed up to 88% of the nitrogen in urine and recovered around 700 g/d (from a 1 m^3 of urine). The energy consumption was reduced by combining pH control with Donnan Dialysis (around 13 Wh/gN). Nevertheless, the energy can be further improved if ion shortcuts are addressed in larger cell designs.

Keywords: Upscaled electrochemical systems; Pilot nitrogen recovery; pH control; Nutrient recovery; Source-separated stream

Effects of current on the membrane and boundary layer selectivity in electrochemical systems designed for nutrient recovery

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During electrochemical nutrient recovery, current and ion exchange membranes (IEM) are used to extract an ionic species of interest (e.g., ion) from a mixture of multiple ions. The species of interest (ion 1) has an opposing charge to the IEM. When ion 1 is extracted from the solution, the species fractions at the membrane and the adjunct boundary layer are affected. Hence, the species transport through the electrochemical system (ES) can no longer be described as electrodialysis-like. A dynamic state is observed in the compartments where the ionic species are recovered. When the boundary layer-membrane interface is depleted, the IEM is at maximum current. If the ES is operated at a current higher than the maximum current, the fluxes of both ion 1 and other competing ions, with the same charge (ion 2), occur. This means, for example, ion 1 will be recovered, and the concentration of ion 2 will build up in time. Therefore, a steady state is never reached. Ideally, to prevent the effect of limiting current at the boundary layer-membrane interface, ES for nutrient recovery should be operated at low currents.

Keywords: Limiting current; Dynamic state; Electrochemical systems; Boundary layer-membrane selectivity; Nutrient recovery

On the development of flow capacitive deionization for sustainable recovery of lithium from saltworks bitterns

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Flow capacitive deionization (FCDI), proposed for the first time in 2013, is a new and promising desalination technology where at which flow electrodes (e.g., carbon slurries) are used to remove ions from saline streams based on the electro-sorption principle. Flow electrodes can be recirculated and regenerated in a loop arrangement between cathode and anode, which allows for increasing salts removal and make the process continuous and energetically efficient.

The SEArcularMINE project aims (among other objectives) at development of a lithium membrane flow capacitive deionization prototype (Li-MFCDI), which consists of incorporation of lithium selective membranes in a FCDI device (Fig. 1), in order to recover lithium from saline streams (such as saltworks bitterns). The following objectives are targeted:

- To develop novel Li-selective membranes with cost below 300 €/m^2 and selectivity ratio targeting values from 2 to 4 for Li^+/Na^+;
- To optimise conductivity and viscosity of the flow-electrodes (carbon slurries) to grant their efficient charging and discharging;
- To integrate the Li-selective membrane and carbon slurries into a single Li-MFCDI stack;
- To design, construct and test a Li-MFCDI prototype based on optimisation analysis performed with computational fluid dynamics (CFD) tools.

The progress of the first 24 months of the project will be shown during this presentation.

Keywords: Lithium; Flow capacitive deionization; Lithium selective membranes; Flow electrodes; 3D printing; Computational fluid dynamics (CFD)

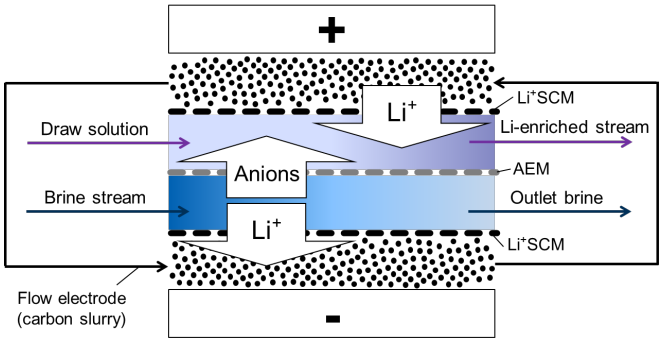

Fig. 1. Schematic representation of the proposed FCDI cell with lithium-selective membranes (Li+SCM).

Acknowledgments

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 869467 (SEArcularMINE) and from Fundação para a Ciência e Tecnologia, I.P. under grant agreement No PTDC/EQU-EQU/6193/2020 (Se(L)ect(i)vity). This work was also supported by the Associate Laboratory for Green Chemistry – LAQV which is financed by national Portuguese funds from FCT/MCTES (UIDB/50006/2020).

Sustainability, exploitation and future market uptake – a market analysis

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The aim of Sea4Value is to recover minerals and metals from seawater desalination brines. The use of brines from seawater desalination plants has the competitive advantage of using already preconcentrated streams, compared to extraction of raw materials directly from seawater. The main benefits are clear:

- recovering valuable elements that can be reintroduced into the manufacturing and industrial processing,
- reducing environmental impact due to the decrease of brine dumping,
- and decreasing capital and operational expenditure cost of operating plants.

Instead of focusing on single elements, which makes the process economically unfeasible, a combination of advanced separation technologies is being explored to develop a technical and economically feasible process for multi-element recovery. In this project, the key elements Mg, B, Sc, In, V, Ga, Li, Rb and Mo will be recovered.

A reliable supply of these metals is crucial for a broad range of products, applications, and modern technologies. If a reliable and unhindered access to these metals in the European Union is limited, they are classified as so-called critical raw materials. The project contributes to the security of supply and aims to reduce the dependency on raw material imports by providing these elements to the market.

Since the application and use of elements recovered from brines is new in practice and unknown to existing markets, it is being investigated how these elements can enter the value chain. The high-quality characteristics and requirements that the industries have set up, is also a key challenge to be addressed when it comes to market exploitation. The project will address supply and demand and give ideas, which strategies could be applied to benefit of the recovered materials.

Sea4Value has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°869703

Keywords: Recovery of minerals and metals; Market uptake; Resources; Brines

Experimental designs and preliminary results of the study of the adequacy of desalinated water for the irrigation of bananas in the north of Tenerife

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In the context of the E5DES research project, two experimental setups were established to study the effects of irrigation with desalinated water on the soils and plants of banana plantations. A pilot-plant was located in a greenhouse at the University of La Laguna facilities and an experimental plot was selected at a commercial banana plantation in the Buenavista area in the north of Tenerife.

The pilot plant consisted of 24 soil containers of 300 l capacity each, equipped with systems for drainage water collection, a home-size reverse osmosis system, separate fertilization equipment for 4 different treatments, and a localized irrigation installation for each container. The containers were planted with in-vitro plantlets of the "Gruesa" cultivar and assigned to one of the four treatments (standard vs. desalinated water crossed with re-mineralized vs. non-re-mineralized irrigation water) according to a random-blocks statistical design. Plants were grown for 6 months under standard irrigation and fertilization practices.

For the experimental plot, a homogeneous area of a commercial banana-producing farm (Finca La Laja) was selected, and 16 plant rows with 12 plants each were randomly assigned to four treatments according to a random-blocks statistical design. Treatments tested are four different mixtures (from 33% to 100%) of two irrigation waters: the standard fresh-water supplied to growers in the area (provided by Balsas de Tenerife - BALTEN) and desalinated water obtained by reverse osmosis from ocean water by a private provider (Comunidad La Monja). Monitoring equipment for soils and environmental parameters was installed and the plants are presently being grown.

Results obtained so far indicate that, following adequate procedures for the fertirrigation of bananas, there is no need to re-mineralize the desalinated water, and no statistical differences have been found among the different treatments tested. The ongoing research will generate knowledge about the mid-term effect of desalinated water on soil physical and chemical properties as well as on the development, nutritional status and yield of the banana plants.

Keywords: Pre-treatment; Re-mineralization; Osmosis; Agriculture; Canary Islands

Modification of commercial NF membranes with polyelectrolyte multilayers to enhance selective removal of divalent cations from brine of seawater desalination plants

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In the desalination process, the seawater as feed with 30–50 g/L of total dissolved solid (TDS) is converted into two streams, the pure water as product in permeate side and the brine with more than 50 g/L of TDS as by-product in retentate side [1]. Due to the large number of desalination plants all over the world (more than 16,000 plants in 2020) [2], brines are an enormous potential source of minerals and metals, but they are usually disposed of in the environment. Due to the importance of this issue, Sea4Value project [3] is designed to recover these valuable materials. Aim of this study as part of above project is to use NF membranes to separate magnesium (Mg) form bine. Commercial NF membranes cannot be used for this purpose for two reasons. Firstly, they are not designed for feeds with strong ionic strength like brines, secondly their Na^+/Mg^{2+} selectivity is not very high. One of the effective ways to overcome both problems is the coating of NF membranes with the oppositely charged polyelectrolytes (PE) by layer by layer (LbL) technique. The polycation of poly(diallyldimethylammonium chloride), PDADMAC and polyanion of poly(sodium 4-styrenesulfonate), PSS, were used and sequentially deposited on two commercial NF membranes (NF270 and Desal 5-DL). As post-treatments, chemical cross-linking by glutaraldehyde and heat treatment were also used in this study to stabilize the LbL architectures against high ionic strength of brine. The best result was observed in post-treated membrane composed of 5.5 bilayers of PDADMAC/PSS polyelectrolytes on Desal 5-DL with almost 95% rejection of Mg^{2+} and more than 50% increase in Na^+/Mg^{2+} selectivity.

Keywords: Nanofiltration; Desalination; Polyelectrolyte multilayer; Divalent cation selectivity

Acknowledgements

SEA4VALUE project European Union's Horizon 2020 research and innovation programme under grant agreement N°869703 is acknowledged for financial support.

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3D-printed ion-exchange materials for recovering valuable elements from the seawater brines

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Seawater brine contains various valuable elements therefore it should be considered as a source of raw materials rather than waste. Recovery of minor elements from seawater brine may be complicated due to their low concentrations and multi-element composition of the brines. Thus, separation method is required to provide selectivity toward specific elements together with stability of the system in saline water. Polymer ion-exchange resins containing organic functional groups have been extensively used for the selective recovery of different metals. However, their use as powders, beads, and granules might in some cases cause extra expenses due to uneven loading and high back pressure. The proposed solution is to use additive manufacturing (AM) techniques to produce sorption modules from ion-exchange materials for metal recovery. 3D printing allows to design geometries in a way that the factors such as surface area and flow distribution can be improved. Therefore, our part in Sea4value project, funded by European Union's Horizon 2020 research and innovation programme under grant agreement N°869703, is to developed 3D-printed sorption modules for recovery of indium, scandium, vanadium, molybdenum, and boron from seawater brine and compare their performance to that of self-prepared and commercial ion-exchange resins. Different designs of sorption modules have been tested to find the optimal geometry and conditions to improve metals recovery. Results are promising and 3D-printing has been shown as viable tool for production of novel separation materials.

Keywords: Seawater brine; Selective recovery; 3D-printing; Ion-exchange materials

Membrane reactor concept for the removal of arsenic from drinking water supplies

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This work discusses the concept of ion-exchange membrane reactor, which combines the transport of charged solutes through ion-exchange membranes by a Donnan exclusion mechanism, with the removal of the transported solutes by (bio)conversion or by reaction / precipitation with specific agents added to a receiving compartment.

This concept had been extensively studied and evaluated for the removal of target ionic pollutants from drinking water supplies - nitrate, nitrite, perchlorate, bromate, ionic mercury – and, recently, it was extended to the removal of arsenic species.

This presentation is focused in this last development, starting from the selection of adequate ion-exchange membranes and operating conditions that assure an efficient removal of arsenic for extended periods of work, under stable conditions and with a minimal requirement of chemicals and need of technical assistance. The process proposed is mathematically modelled and upscaling criteria are presented and discussed.

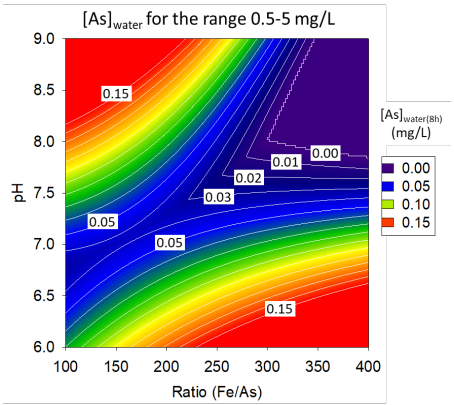

Fig. 1. Response contour plots for different As water contamination levels (up to 5 mg/L).

Keywords: Drinking water supplies; Arsenate removal; Ion-exchange membranes; Ion-exchange membrane reactor

Acknowledgments

This work was supported by the Associate Laboratory for Green Chemistry – LAQV which is financed by national Portuguese funds from FCT/MCTES (UIDB/50006/2020).

Investigation on wetting mechanisms and wetting dynamic in plasmonic silver/PVDF membranes for desalination by photothermal membrane distillation

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Introduction

Photothermal membrane distillation (PMD) is an emerging configuration of membrane distillation (MD). In PMD under sunlight irradiation, the photothermal active layer provides a localized heating at the evaporation surface [1,2] and the temperature polarization problem can be overcome. Considering all advantages of PMD configuration compared to conventional MD, it seems interesting to investigate more on this process. Indeed, the effect of nanoparticles on wetting mechanisms and occurrence is still unknown as well as the best conditions for manufacturing membrane with good photonic properties and low wetting propensity.

This work aims: i) identifying wetting mechanisms when operated in vacuum membrane distillation (VMD) under standard and identical conditions and comparing values of wetting indicators, for a reference PVDF membrane and for PVDF membranes in which silver NPs are included, and ii) studying the influence of the load of silver NPs on wetting mechanisms, indicators and wetting dynamics [3]. The originality of this work is based on the evaluation of membrane by two complementary methods previously developed in our group: the detection of dissolved tracer intrusion (DDTI) and an optical method allowing in operando dynamic study of wetting.

Material and methods

Different membranes were prepared according to Politano et al work [4] with PVDF polymer, Dimethylformamide (DMF) solvent and proportions of Ag NPs in the final membrane varying from 0 to 50 wt.%. Ultra-pure deionized water and sodium chloride were used to prepare the saline solutions at 35 g/L for MD operation. VMD experiments were performed with a previously described pilot plant [5,6] under standard operating conditions (T_{feed}= 42.5°C, $P_{permeate}$ = 60 mbar). Membrane structural properties, wettability indicators (contact angle, LEP_w) were measured according to our previous publication [5]. SEM/EDX was used to characterize membrane morphology and for the DDTI method.

Results and conclusions

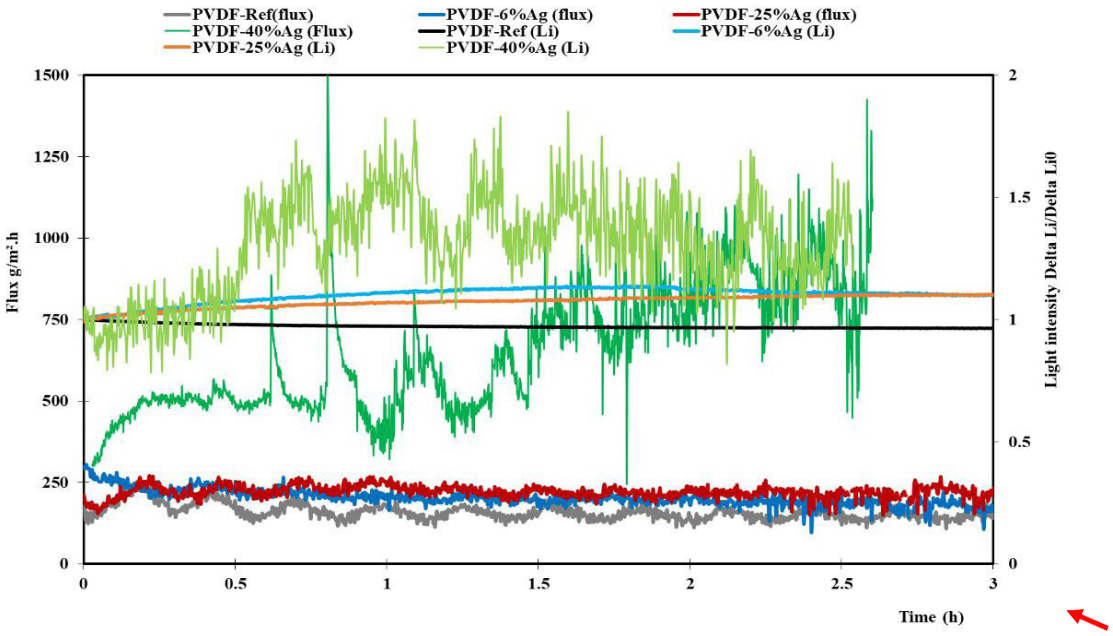
DDTI method allows identifying the wetting mechanism and quantifying wetting indicators (pore wetting ratio w_p) which represents the proportion of the membrane thickness in which liquid has intruded in. w_p can be calculated at global or at local scales by using the definitions given in [5].The results are regrouped in the table below:

Membrane	w_p global (%)	w_p local (%)								
		Feed inlet zone			Middle zone			Feed outlet zone		
		I_1	I_2	I_3	M_1	M_2	M_3	O_1	O_2	O_3
PVDF-Ref	1.6	0	0	3	0	0	8.3	0.6	0.9	1.9
PVDF-6%Ag	18.6	0	44.1	4	16.3	93.1	1.2	2.1	0	6.7
PVDF-25%Ag	20.1	0	81.7	95.4	0	0	0	0	0.3	3
PVDF-40%Ag	84.5	100	100	100	100	100	100	35.6	54.3	71

Green: no wetting; Yellow: surface wetting; Orange: partial wetting, Red : total wetting

At global scale, for the same operating conditions, and depending on the NPs load, partial wetting occurred, whereas the reference PVDF membrane remained non-wetted. The wetting indicator increased with the percentage of Ag NPs introduced into the membranes. At local scale, the results observed on 9 exploration zones depend on the NP load:

- **PVDF-Ref:** Only no wetting or surface wetting mechanisms are observed whatever the sampling zone, this membrane is not significantly affected by wetting
- **PVDF-25%Ag and PVDF-25%Ag:** all wetting mechanisms forms can be observed: non wetting, surface, partial and total wetting in one of the zones. Their behavior corresponds to no wetting or to surface wetting in 6–7 zones.
- **PVDF-40%Ag** presents severe forms of wetting and only partial and total wetting mechanisms are observed.



On other hand, the optical tool allowed following the wetting dynamics in operando during VMD operation. The following figure presents the permeate flux and wetting indicators time-variations for the different membranes. It shows that the dynamics of wetting varies with the Ag NP load, which increase reduces the duration of the MD operation. For the PVDF-40%Ag: the optical indicator fluctuated a lot and globally increased since the operation start, as well as the flux. Total wetting occurred very fast, and the operation had to be stopped before 3 h.

Finally, this study shows that the quantity of NPs should be limited to avoid wetting problem. The methodology used here can be used for further investigations on the influence of NPs at lower loads in the Ag-PVDF membranes, and more generally to optimize the elaboration of photothermal membranes, based for example on other photothermal NPs more efficient and cheaper than silver.

Keywords: Photothermal membrane distillation; Photoplasmonic membranes; Wetting mechanism; Wetting detection; Silver nanoparticles

Acknowledgements

The authors are grateful for financial support provided by : the National Research Agency (ANR) of France through the project ERANETMED3-166 EXTRASEA "Extracting water, minerals and energy from seawater desalination brine". Also, Engineer Gillet Angelique and LCPNO laboratory for useful technical assistance for nanoparticles characterization.

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Potentials for critical raw materials recovery from Mediterranean saltworks bitterns

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Minerals extraction from seawater brines is currently regarded as the most practical approach to reduce European dependency from the import of many Critical Raw Materials. The technical feasibility of such approach has been widely demonstrated in several different research and development projects but the economic sustainability has always been found to depend on the local demand for sodium chloride, which is always the most abundant product of the extraction.

Starting from this crucial node, the SEArcularMINE project has investigated the possibility to use the residual brines originated by sea-salt extraction in traditional saltworks, regarded as an already well-established marketplace.

The Mediterranean area as a whole, can rely on a diffused industry including South-European coast, North-African and Close East coast and portions of the Atlantic regions. Additionally, many inland salt-lakes and subsoil waters are traditionally operated in the same way as the coastal facilities to produce solar-salt. Interestingly, each saltworks have a slightly different approach, adapted to feed quality or local climate conditions.

Accordingly, different types of brine are produced, having unique features. These "bitterns" are extremely interesting to characterize, focusing on their hidden potential.

In this work, an extensive analytical campaign has been conducted exploiting the wide saltworks network established within the SEArcularMINE project. Main results are here reported, highlighting the possibility of contributing to secure the access to some Critical Raw Materials for EU.

Keywords: Critical raw materials; Circular economy; Brine; Minerals; Sea-salt; Saltworks

Carbon footprint reduction of desalination plants through the retrofit of lime dosing systems

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Europe has pledged to achieve carbon neutrality by 2050. To achieve this ambitious target, the European Council has set themselves at interim target to achieve 55% reduction by 2030 for carbon dioxide emissions in comparison to levels measured in 1990. Many industries are starting to feel the impact of these legislative targets, but those most affected are producers, who directly emit greenhouse gases such as carbon dioxide. Two of these include lime producers and producers of industrial grade carbon dioxide, for which the carbon dioxide production and capture is a by-product of other chemical processes. For desalination processes, these chemicals are used within post-treatment processes for the remineralization of desalinated water, and operators of desalination plants who employ lime dosing systems can expect operating costs to increase over the coming years. Excessive costs can be avoided however, as plants that are retrofitted with powdered calcium carbonate can benefit from the low carbon footprint, and decreased carbon dioxide consumption offered by calcium carbonate. A desktop study looking at the drivers for consumable costs, and providing a production on their evolution from now until 2030 estimates that for a 100 MLD plant, somewhere between 3 and 4 million EUR may be saved by switching from powdered lime to powdered calcite.

Keywords: Remineralization; Post-treatment; Decarbonization; Carbon footprint; Calcite; Lime; Carbon dioxide

Modeling pH effects on transport and rejection of ions in reverse osmosis membranes

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Modeling mass transport of ions across the active layer of a reverse osmosis (RO) membrane requires a comprehensive understanding of the membrane structure and chemistry. We experimentally and theoretically investigate the effects of feedwater pH on membrane charge ionization as well as transport and rejection of Na^+ and Cl^-. A one-dimensional

numerical model for the intricate couplings of ions is developed using the extended Donnan steric partitioning pore model [1]. The model includes the membrane charge ionization and interaction with H^+ and OH^- ions.

We qualitatively compare predicted profiles of ion rejection (Fig 1a) and permeate pH (Fig 1b) as function of the feedwater pH with experimental data. We perform model fitting using the Nelder-Mead technique. We also show the membrane charge density being a function of local pH [2] and how it varies on the upstream (feed) side and on the downstream (permeate) side of the membrane (Fig 1c). We discuss how the protonation and deprotonation of functional groups at low and high feed pH respectively brings about the Donnan electrostatic exclusion (DEE) which affects rejection of ions [3].

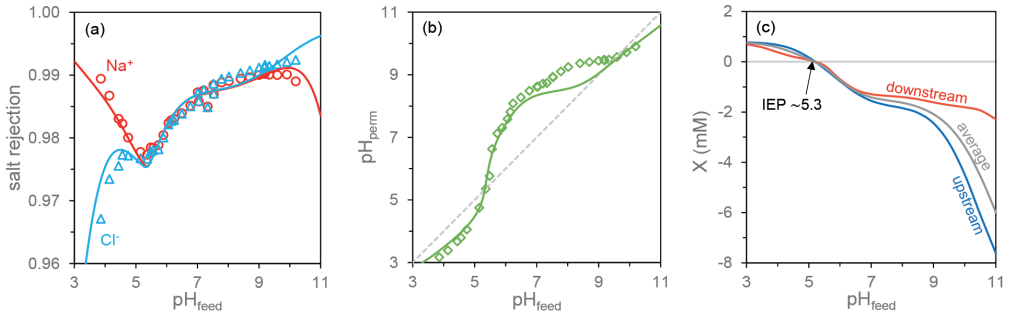

Fig. 1. Experiments (markers) and theory (lines) results illustrating effect of feed pH on (a) rejection of Na^+ (red circles and line), and Cl^- (blue triangles and line), (b) permeate pH (green boxes and line), and membrane charge density, X in mM.

Our findings reveal the key role the local pH plays in the ionization of the functional groups and their interactions with H^+ and OH^- -ions. This greatly affects the DEE mechanism which determines the overall rejection of ions as well as the permeate pH.

Keywords: Reverse osmosis; Membrane charge; Ion transport; Ion rejection

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Monitoring and characterization of biofouling development in a membrane fouling simulator (MFS) supplied with UF pre-treated seawater from the Red Sea

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The cost-effective operation of seawater reverse osmosis (SWRO) systems is hindered by membrane fouling. Biofouling is considered the largest problem of SWRO as it cannot be eradicated due to the variability and adaptability of microorganisms. Biofouling is a complex phenomenon since living microorganisms from the feed water can attach to the feed spacer and membrane surface and grow by using biodegradable nutrients available in the feed.

This study investigates the impact of nutrient concentration on biofouling and operational performance in membrane fouling simulators (MFS) fed with real seawater after pre-treatment by ultrafiltration (UF) before being fed to the SWRO installation. Studies were done with a large-scale pilot plant located at the Red Sea near Jeddah, Saudi Arabia. The characterization of biofouling, based on methodologies previously used for the study of biofouling in freshwater, includes monitoring operational performance, determination of biofilm parameters such as adenosine triphosphate (ATP) and total cell count (TCC), and direct visual monitoring of fouling (using the MFS sight window) with optical coherence tomography imaging.

Results demonstrated for seawater that (i) biofouling development presented a minimal effect when nutrient concentration was quadrupled, (ii) there was no correlation between the nutrient concentration and growth rate for seawater experiments, suggesting biofilm development under conditions close to the maximum growth rate. Compared to tap water at the same nutrient concentrations, seawater showed much faster biofilm development, pressure drop increase, and strongly different biofilm morphology.

The information obtained from this study aims to develop novel cleanings or biofouling control strategies in pilot and full-scale SWRO systems.

Keywords: Seawater; Biofouling; RO membranes; MFS; Nutrient concentration

Mineralization of persistent organic pollutants using a novel electrochemical advanced oxidation process

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The release of contaminants into natural waters can cause harm to terrestrial and aquatic ecosystems. One of the stressors of this resource are organic substances. Municipal and industrial effluents from wastewater treatment plants serve as point sources, because of inadequate elimination of trace organic substances by conventional treatment. Moreover, the demand for fresh water in the industry can be reduced by recirculating the process water. Undesirable organic trace substances must be removed for this purpose. For both targets, removal of interfering organic residues is necessary.

In the project RADAR, the elimination of organic substances occurs via radicals. The radicals, in particular hydroxyl radicals (OH radicals), are produced electrochemically. Thus, the method is counted among the so-called Electrochemical Advanced Oxidation Processes (EAOP). The boron-doped diamond electrode (BDD) is one of the favourable electrodes used to synthesize OH radicals in situ by electrolysis due to the high overpotential for oxygen evolution reaction (OER). In this approach, it is investigated, if the oxidation performance can be improved by combining the BDD with a gas diffusion electrode (GDE). Depending on the applied catalysts it is possible to produce hydrogen peroxide at GDEs via the two-electron oxygen reduction pathway. The additionally produced hydrogen peroxide complements the oxidation process with another strong oxidizing agent, while lowering the cell voltage, and consequently the energy demand of the electrolysis. The experiments demonstrate that use of the GDE in combination with a BDD reduced the cell voltage, which reduces the energy requirement of the overall elimination process. X-ray contrast agents have been chosen as model substances for the degradation and/or removal from different wastewaters matrices. Different influence factors on degradation rate such as current density, cell design, and electrolyte compositions were investigated. The degradation experiments showed that with the presented combination of electrodes the complete mineralization is almost possible even for very stable and persistent compounds. The project RADAR received funding from the German Federal Ministry of Education and Research.

Keywords: Advanced oxidation process; Wastewater treatment; Micropollutants; Electrochemistry

Development of the membrane for osmotically assisted reverse osmosis (OARO) and its commercial applications

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Osmotically assisted reverse osmosis (OARO) has been recently proposed for concentrating high-salinity brines for zero liquid discharge (ZLD) and also mining valuables from brine and wastewater streams. In the OARO process, two solutions of similar or identical salinity concentrations with low or no osmotic pressure difference are applied to both high-pressure and low-pressure sides of the membranes to generate concentrated and diluted streams. This concept

effectively minimizes the osmotic pressure difference across the membrane, and significantly reduces the hydraulic pressure required for water passing through the membrane.

In this paper, we wish to introduce our newly developed hollow fiber membrane applicable to OARO process. We call its membrane as BC (Brine Concentration) membrane because of its ability to concentrate high salinity brines. One of the biggest benefits of our BC membrane is high membrane surface area thanks to hollow fiber membrane configuration and our 10-inch commercial BC membrane element has around 600 m^2 with the length of 1.4 m. Some pilot testing studies are being conducted all over the world to show the advantages of the process with our newly developed BC membrane.

Also, we are currently under construction of the large-scale commercial plant at Cilegon, Indonesia for the upcoming commercial operation at 1st quarter of 2023. In this project, Toyobo works together with Hyrec who has an ability to design the concentration system all the way from the sea water to the solid salt. We will make a food grade salt using Hyrec's OARO system using Toyobo's BC membranes and annual salt production will be 220,000 tons. We will be presenting the demonstration result at Cilegon before commercial construction and also the progress of the construction.

Keywords: Hollow fiber membrane; Brine concentration; Osmotically assisted reverse osmosis; Salt production

Progress in the seawater desalination using renewable energy sources

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Currently, the increasing world population, exploitation of resources, growing consumer demand, and climate change have contributed together to a scarcity of clean water availability. Therefore, the desalination of seawater and brackish water is extensively employed to produce fresh water. Adequately meeting the water requirements in an eco-friendly, inexpensive, and effective manner needs the correct combination of desalination technology and renewable energy. In this study, a comprehensive review of different desalination technologies based on renewable energy is presented. Various types of energy like wave, geothermal, solar photovoltaic, solar thermal and wind are discussed in detail. The above-mentioned renewable-based energies could be employed in various desalination techniques like electrodialysis, forward osmosis, membrane distillation, multi-effect desalination, mechanical vapour compression, electrodialysis, and reverse osmosis. It is significant to note that the most efficient desalination systems comprised of a combination of the sources of renewable energy, and some possessed an energy storage device for maintaining a uniform energy flow in the system. Possibilities of employing the different renewable energy resources in GCC region to desalinate water was also investigated. Furthermore, the expenses for the renewable energy desalination process were studied, together with the associated challenges as well as outlook. It is observed that the right combination of desalination technologies and renewable energy is important to meet the developing freshwater demand in an appropriate manner.

Keywords: GCC countries; Geothermal; Wind energy; Solar energy; Reverse osmosis; Renewable energy; Desalination.

Acknowledgements

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Operating parameters influencing the performances of a solar powered hollow fiber membrane distillation module

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Actually, there is an urgent need to continue developing desalination processes with renewable energies for reducing the GHCs emissions linked to desalination. MD offers as main advantages the possibilities to achieve higher

recovery than RO and to be coupled with low grade energies such as solar energy. Different options for coupling solar energy and MD have been proposed [1] and explored [1-5]. Among them integrating MD membranes and solar heating integrated together in a solar collector MD (SCMD) module is likely to lead to an intensified and promising process for solar powered desalination for small scale unit in remote places, with reduced energy losses [5]. Different attempts have been done to experiment or to simulate operation of solar collector integrated MD modules. For example, simulations allowed optimizing the operating conditions of a flat-sheet module with one membrane and its integration in a whole system for VMD or DCMD [5,6].

Using outside-in hollow fibers in a SCMD module (so called HF-SCMD module) in which solar heat is supplied at module surface is likely to produce a more compact system and to take benefit of the cylindrical geometry and of the radial heat transfer for a better use of the heat. This concept was yet experimented by the integration of hollow fibers inside evacuated solar tubes, in a relatively small scale systems (0.2 m^2 of membrane area) to be assembled, with the objective of co-producing energy and water in buildings [3,4].

This work aims optimizing the operating conditions of a larger scale (2.1 m^2) HF-SCMD module that could be integrated in a small unit for providing fresh water in remote areas. Considering that the solar heat is provided at the module surface a radial thermal profile will take place between the bundle surface and its center. It is thus very important to be able to evaluate this profile and in which proportion it is influenced by the operating parameters such as feed inlet temperature, fluid velocity and the solar heat provided at module surface. This will then allow determining the most influential factors on module performances and determining the best values of these parameters for achieving high productivity, water flux or gain output ratio and producing guidelines for the operation of the HF-SCMD module. In addition, it will be illustrated the relative influence of solar and feed heat on performances. This work was performed thanks to a scientific approach based on a developed modeling of MD that describes radial and longitudinal heat and mass transfers. It considers the cylindrical module geometry, heat supply at its surface and temperature polarization, which omission could produce an overestimation of permeate flux. This model was validated experimentally and then used for simulating the achievable performances and the thermal profiles as functions of the target parameters.

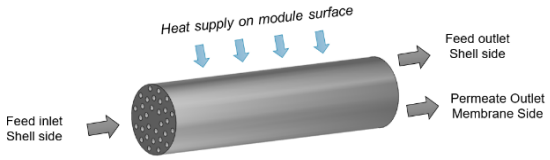

Fig. 1. SPC MD module geometry.

For a given permeate pressure (of 60 mbar in example shown here), the influence of fluid velocity (v) and temperature at module inlet (T_{in}) as well as of module heat wall temperature (T_{wall}) was studied on permeate flux and on radial temperature. Example results are illustrated in Figs. 2–3.

It is observed in Fig 2a that at constant T_{in} there is an increase from 14 to 19 kg/h.m^2 permeate flux with fluid velocity and a slight growth with T_{wall}. The influence of fluid velocity is due to its impact both on the inlet Heat flux and on temperature polarization.

Fig 2b shows, that at constant fluid velocity, the permeate flux increases nearly linearly with T_{in} (as the inlet heat flux) from 2 to 18 kg/h.m^2 and increases with T_{wall}. Global performances are more sensitive to the inlet temperature than velocity.

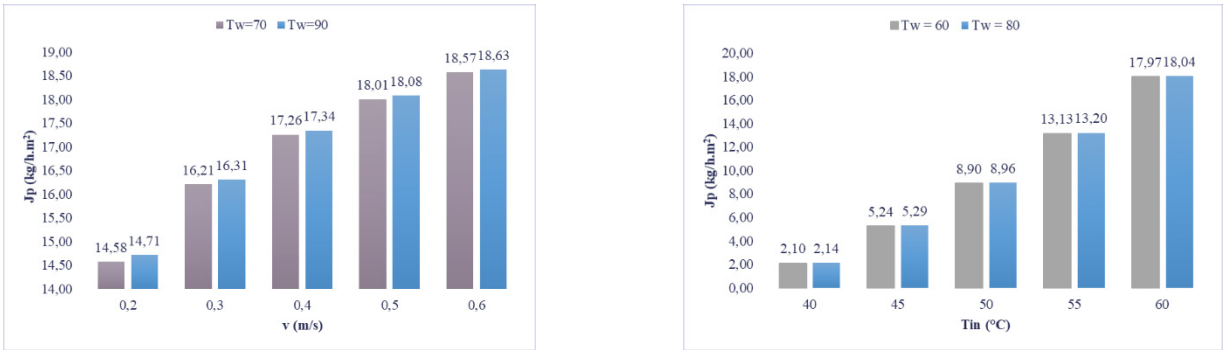

Fig. 2. Permeate flux (a) vs. fluid velocity for different T_{wall} at T_{in}=60°C (b) vs. T_{in} for different T_{wall} at v = 0.5 m/s.

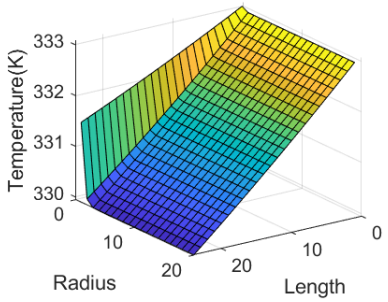

Fig. 3. Radial and longitudinal temperature profile for a T_{in} = 60°C, T_w = 70°C, v = 0.5 m/s.

Fig 3. illustrates module temperature profile which allows to determine HF-SCMD performances and understand temperature polarization phenomena. These first results show that, with the assumptions made, module water productivity in between 25 to 224 kg/m^2/d could be achieved on a single HF module on 12 of production per day, which is 0.8–7 times what was obtained in flat sheet module[6]. Further work will aim optimizing module performance by playing on module design and by its integration in a complete system with latent heat recovery. In parallel experimental testing is under progress.

Keywords: Hollow fiber; Membrane distillation; Solar collector module; Process operation; Simulations

Acknowledgement

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Performance evaluation of forward osmosis modules via computational fluid dynamics and porous media flow models

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The spontaneity of a forward osmosis (FO) process makes it a viable option for wastewater treatment, seawater/brackish water desalination, hydraulic power generation (pressure-retarded osmosis mode), and food processing. In this study, a computational fluid dynamics (CFD) model is developed to evaluate the performance of a FO module under various operating conditions. It is found that external concentration polarization (ECP), which is usually neglected owing to low osmotic pressures in the module, has pronounced effects on the system performance at high solute concentrations in the feed and low stream flow velocities. Conventional FO models also use Sherwood number correlations that are defined for flow over an impermeable flat plate. This study found that using the said correlations for evaluating mass transfer across the membrane significantly overestimates the transmembrane water flux. Porous media flow equations are used instead of mass transfer correlations to resolve this problem. Extant studies have evaluated FO module performance characteristics at various operating conditions, but they rarely consider an exhaustive set of operating conditions and parameters. This study assesses the system performance (water recovery and flux, reverse draw solute flux, specific energy consumption) for different inlet stream flow velocities, feed and draw solute inlet concentrations,

flow directions, and membrane orientations. The simulation results suggest that a comprehensive evaluation of system performance is crucial in optimizing modules with the appropriate design conditions to enhance water recovery and ensure sustainable operation.

Keywords: Forward osmosis; Concentration polarization; Membrane desalination; Parametric studies; Porous media flow

Novel membrane processes for target elements recovery

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The main objective of this study is to develop novel ion-selective membrane-based processes to separate and recover target elements. New membranes have been produced by applying synthesis based on organic chemistry and have been tested for its flux and selectivity by different driving forces such as concentration difference, electric potential and pressure. To promote the feasibility and to prove the concepts, the main targets were:

- Improve the separation of monovalent and multivalent ions using chemically modified nanofiltration (NF) membranes.
- Recover Ga and Rb selectively from the multivalent ions stream and monovalent ions stream respectively by producing polymeric ion-selective membranes that include organic macromolecules (ionophores) selective for Ga and Rb.
- Enhance the selective transport of ionophore-based membranes by producing a novel polymeric membrane where ionophores are covalently attached to the polymeric backbone.
- Investigate the use of electrodialysis with bipolar membranes (EDBP) using improved ion-exchange membranes to produce H_3BO_3 from a borate-rich stream generated after application of borate-selective 3D-printed adsorbent.

This study shows the highlights of results of these technologies.

One ionophore selective for each one of the target ions has been identified regarding its selectivity, non- complex chemical structure, its solubility into polymeric matrixes, and its feasibility to be included in the fabrication of PIMs.

Keywords: Elements recovery; Membrane processes; Seawater brine; Desalination

Proposal for collaborative work between various research groups from Senegal and Spain to enhance innovative capacities in the integral water cycle to favor the mitigation of climate change in the ultraperipheral regions

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This proposal aims to show the possible results and benefits resulting from future collaboration through the MITIMAC project (MAC2/1.1a/263) where the following collaborate, among others: Direction de la Gestion et de la Planification des Ressources en Eau (Senegal) , the University of Gastone Berger (Senegal) and the University of Las Palmas de Gran Canaria (Spain), within the framework of the Interreg VA Spain-Portugal Cooperation Program (Woodwork – Azores

– Canary Islands) 2014 – 2020 and co-financed by the European Regional Development Fund (ERDF), which in its axis 1.A aims to pursue promoting research by improving research and innovation (R&I) infrastructures and the capacity to develop excellence in R&I and promotion of centers of competence, especially those of European interest in the outermost regions, though, in addition, the collaboration of third African countries that have shown interest in participating in the Program, such as: Senegal, Cape Verde, and Mauritania, which on the other hand have expressed their interest in the areas of agricultural activities, renewable energies and water. The aim is to obtain, through the MITIMAC project, the collaboration between the aforementioned research groups, to strengthen the innovative potential of mutual capacities related to the integral water cycle in both regions to contribute to the mitigation of climate change, focusing on the aspects related to the carbon footprint of the different processes related to the integral water cycle, as well as the energy used in it and its origin, with the purpose of contributing to the mitigation of climate change.

Keywords: Water cycle; Mitigation; Climate change; Carbon footprint

Plasma technology and functionalization treatments for membranes

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This work is a contribution to the platform *NewSkin* that is financed by European Union's Horizon 2020 (Innovation Eco-system to Accelerate the Industrial Uptake of Advanced Surface Nano-Technologies). Our main objective in the *NewSkin* project is to investigate innovative and sustainable treatments based on plasma technology and functionalization treatments for membranes required in many sectors such as water treatment, transport, medical devices and photonics. More specifically the contribution of this work can be divided in two research lines: 1) surface pre-treatments by plasma technology, and 2) functionalization by wet finishing processes of membranes for increasing membrane efficiency (fouling prevention)[1] and durability. Nowadays, plasma technology [2] has been established in various applications in the industry including but not limited to the automotive, composite and filtration membrane sectors. Properties of plasma treatments such as fast reaction time, waste-free processes, and high versatility make it suitable as alternative to replace conventional methods of surface activation and functionalization of polymeric membranes, being considered and environmentally friendlier technology [3,4]. Conventional wet finishing such as padding process, commonly used for textile finishing processes, allows impregnation of the membranes with a wide variety of functional solutions without altering the pore size of the membrane.

This work presents plasma surface treatments and wet functionalization processes of three different membranes, a nano/micro filtration membrane for water purification and mining applications, an osmosis membrane for desalination processes. They have been plasma treated and functionalised with the aim of preventing fouling and increasing their efficiency and durability.

The EU-funded *NewSkin* project is creating an open innovation test bed to provide companies and users access to the physical facilities, capabilities and services required for the development, testing and upscaling of industrial and consumer products exploiting nano- enabled surfaces and membranes. This work will provide a new insight in the use of plasma technology and wet functionalization processes for activation, functionalization and conformation of membranes.

Keywords: Plasma; Surface activation; Surface functionalization; Filtration membranes

Acknowledgment

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Water desalination using polyelectrolyte hydrogel. Gibbs ensemble modelling

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Recently polyelectrolyte hydrogels have been proposed as draw agents for reverse osmosis desalination techniques. Indeed, polyelectrolyte hydrogels have the ability to absorb a big amount of water across forward osmosis membrane as a result of their swelling pressure. The insoluble cross-linked network of the gel enables dewatering under the influence of stimuli (thermal and/or mechanical). On the other hand, the network structure of a polymer hydrogel from a thermodynamic perspective is already an osmotic membrane. So hydrogel microparticles may allow to completely avoid the osmotic membranes in forward osmosis and use microfiltration instead. By this article,we present our recent theoretical study of the use of polyelectrolyte hydrogel for water desalination. We modeled the thermodynamic equilibrium of coexistence of the gel and the aqueous salt solution in the so-called closed ensemble, in which the total amount of ions is assumed to be constant. We modeled compression of the gel and the associated with that release of the solution. We have shown that the squeezed out solution has a little lower salinity than that the gel was equilibrated with. Also, we performed a set of simulations modeling the process of continuous decrease of water salinity up to freshwater concentrations.

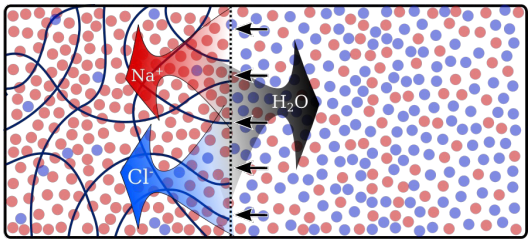

Fig.1. The compression of the gel affects the salinity of the solution

Keywords: Desalination; Hydrogel; Polyelectrolyte; Simulation

Acknowledgements

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Fluctuant and intermittent operation affecting membrane integrity in batteryless solar energy-powered membrane desalination systems

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Batteryless directly coupled solar energy-powered nanofiltration/reverse osmosis (NF/RO) membrane desalination systems arise interests since batteries are problematic in the field [1]. The operation of such systems with solar energy fluctuations causes unstable system hydrodynamics (variable applied pressure and feed flow) and water production, and induces osmotic backwash (OB) that could remove partial scalants and foulants from membrane surface [2]. However, the system start-up process, repeated spontaneous OB process during shutdown events (large cloud coverage causing pump-off) and enhanced OB via additional permeate pressure may cause the loss of membrane integrity, implying changes in membrane's selectivity and permeability as well as product water quality [3].

In this study, the impact of pressure increasing speed (0.17–2 bar/s) during start-up, cycles of OB (namely the number of shutdown events, up to 1000), enhanced OB via additional permeate pressure (up to 3 bar) on membrane integrity were investigated using a bench-scale crossflow NF/RO system powered by a solar array simulator (SAS). The flux and electrical conductivity (EC) of permeate were monitored during experiments. Both flux and permeate EC increased out of the initial status of the membrane, implying a loss of membrane integrity.

The results show membrane performance after 1000 shutdown events (namely 1000 spontaneous OB cycles) was similar to the initial performance (see Fig. 1), demonstrating the reliability and robustness of OB in bench-scale crossflow membrane systems. The speeds to increase feed pressure from 0.17 to 2 bar/s during start-up did not appear to cause the integrity loss, but in the extreme case where the pressure control valve 100% was closed, the membrane integrity loss occurred. Additional permeate pressure (~3 bar) to enhance OB caused the membrane integrity loss due to the high backpressure-induced imprints of the membrane surface. Hence, additional permeate pressure is not recommended to apply for enhancing the OB cleaning process. This work provides guidance for the fluctuant and intermittent operation of batteryless solar energy-powered NF/RO membranes.

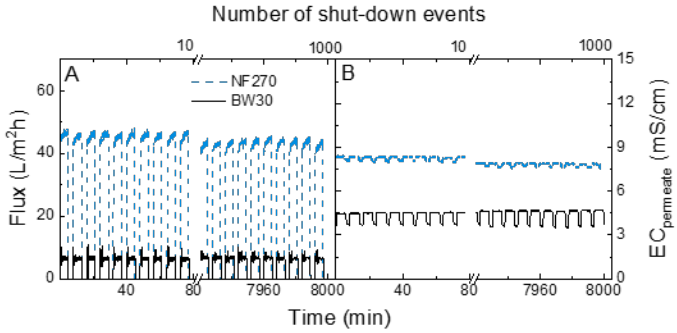

Fig. 1. Membrane performance (A) flux and (B) electrical conductivity of permeate as a function of time with 1000 shutdown events. Feed solution: 10 g/L NaCl with 1 mM $NaHCO_3$, 24 ± 1°C. Each cycle: high-level solar irradiance 800 W/m² (namely 10 bar operating pressure) for 5 min dropping to zero (namely pump-off) for 3 min.

Keywords: Decentralised water desalination systems; Operation and maintenance; Osmotic backwash; Delamination; Membrane damage

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New ceramic membrane for wastewater treatment: phosphate and oil removal

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A novel hybrid ceramic membrane incorporated with activated carbon (AC) was prepared and tested for two distinct end uses: a) phosphate removal from treated sewage effluent (TSE), and b) oil removal from saline water. The membrane was prepared by incorporating the cheap and high surface area powdered AC (10 wt.%) within an alumina (Al_2O_3) framework. AC incorporation enhances the adsorptive properties of the hybrid membranes and create a tortuous matrix of micro- and nano-channels, that eventually improved the overall porosity and total pore area of the membrane by 90% when compared with unmodified alumina membrane. Moreover, the modified ceramic membrane showed an increase of 71% in its hydrophilicity and an increase of 45% in its oleophobicity when compared to unmodified alumina membranes. Due to the enhancement in the porosity and hydrophilicity, the hybrid Al_2O_3/AC membrane showed a higher permeate flux in comparison with the unmodified membrane. The phosphate removal capacity of the modified membranes was evaluated by the treatment both of model solutions and real TSE. The novel Al_2O_3/AC membranes exhibited almost complete phosphate removal at 30 ppm phosphate concentration in the TSE while maintaining a high permeate flux of 18.9 L/m².h (LMH) compared to 2.8 LMH for the unmodified alumina membranes. The prepared Al_2O_3/AC membrane has demonstrated oil removal efficiency between 91% to 99% at emulsified oil concentrations ranging between 500 and

5000 parts per million (ppm). The modified membrane showed improved anti-fouling behavior during the filtration of oil and real TSE when compared with unmodified membrane. During the fouling resistance tests with emulsified oil, the Al_2O_3 membrane showed a noticeable normalized flux drop of about 60% after the sixth filtration cycle while only a slight decline in the normalized flux was found for Al_2O_3/AC membrane. The results of this work showed that the novel Al_2O_3/AC membrane can be used for the efficient removal of phosphate residue from TSE, and pretreatment of oil-containing wastewater.

Keywords: Ceramic membrane; Activated carbon; Phosphate; Oil removal

NewSkin services portfolio for desalination and water treatment — from pumps to membranes and filtering media

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NewSkin is a H2020 funded Open Innovation Test Bed that offers the water treatment sector (research labs, SMEs and industry) access to a set of upscaling and testing facilities and expertise to accelerate the uptake of advanced surface technologies and membranes.

NewSkin offers a full set of facilities to increase the Technology Readiness Level (TRL) of lab scale developed technologies and build the necessary supply chains to advance nanotechnologies and advanced materials to prototypes in industrial environments (TRL 7+). NewSkin facilities offer unique facilities for the continuous production of advanced surfaces, coatings and membranes. NewSkin facilities enable:

- The continuous production of **nanocarbon-membranes** with controlled pore size and density for MD, UF, RO and NF applications.
- The continuous production of **ceramic and polymeric nanocoated and textured surfaces**
- to prevent **scaling**, **fouling** and **increase media selectivity**.
- The formation of continuous multi-stacked media to produce **highly efficient active surfaces and filtering media**.
- A set of advanced coatings and textures **for pumping equipment to increase equipment performance and durability**.
- A set of **state-of-the-art testing facilities** to demonstrate the performance of the new developments in relevant environments.

The NewSkin services portfolio is not only limited to technical but also offers key activities in the translation of research into products:

- Corporate **Funding**.
- **Supply chain** Management.
- **Networking** with end-users.

Access to our EU funded NewSkin physical facilities, capabilities and services is provide through a single-entry point under fair conditions, reducing cost and investment risk while accelerating technologies to market. Services are available to research labs, SMEs and industry under fair pricing conditions, and **free of charge** in four competitive Open Calls. Open call applicants can request an NDA before filling the open call application.

Keywords: Nano-enabled surfaces and membranes; Energy efficiency; Fouling; Corrosion; Performance

NewSkin: Open calls and the role of EU funded open innovation test beds to accelerate the transfer for KET to key industries

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NewSkin is an Open Innovation Test Bed that offers the water treatment sector (research labs, SMEs and industry) access to a set of upscaling and testing facilities as well as route to market services to accelerate the uptake of nano-enabled

surfaces and membranes in different applications. NewSkin provides the Innovation Ecosystem with 360º Services to bridge the gap between research and industry, including: cutting-edge prototyping, upscaling and testing facilities, and access to corporate funding and route to market support.

NewSkin can provide services under paid contracts, and also offers **free of charge services** to the Innovation Ecosystem under competitive Open Calls. In the water sector, our aim is to accelerate the market uptake of new advanced filtration media, advanced treatments to prevent fouling and increase media selectivity, as well as functional textures and coatings to increase equipment performance and durability of pumps and systems. Join us in our session to know how to collaborate with us.

Keywords: Open innovation; Technology transfer; Upscaling; Commercialization; Nanomaterials

Investigation on magnesium hydroxide recovery from real bitterns

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Magnesium hydroxide, $Mg(OH)_2$, is a chemical compound of peculiar characteristics. It has been extensively employed in numerous applications as a flame retardant filler in polymeric materials, as an acid neutralizer in wastewater treatment and as the precursor for magnesium oxide catalysts [1]. Commercial $Mg(OH)_2$ powders are mainly produced from magnesium (Mg) rich rocks. However, the use of minerals leads to (i) a continuous depletion of landing mineral reservoirs; (ii) high energy consumption; (iii) geopolitical concerns due to the main presence of Mg ores in China, USA and Russia. As a matter of fact, in recent years, EU has listed Mg among the 30 critical raw materials for its economical and industrial sustainable development. In this context, the EU funded SEARcularMINE project proposes an innovative treatment chain aiming at valorising the spent bitterns of Mediterranean Sea saltworks through the extraction of high-value minerals and reagents in-loco production. Bitterns are highly concentrated saline solutions where ions reach concentration values considerably higher than in seawater.

The present work aims at investigating the possibility of recovery $Mg(OH)_2$ from saltworks bitterns thoroughly assessing, at the same time, the purity of the produced $Mg(OH)_2$ powders. An extensive experimental campaign was conducted treating two real bitterns collected from the Galia and Margi saltworks located in the district of Trapani (Sicily). Galia and Margi bitterns had a Mg concentration of ~23 g/L and ~60 g/L, respectively. The bitterns contained also a very low Calcium concentration of ~150 mg/L and ~60 mg/L. $Mg(OH)_2$ solids were precipitated using stoichiometric and over-stoichiometric sodium hydroxide (NaOH) solutions in a 2 mm diameter circular cross-sectional T-shaped mixer to ensure fast mixing of the reactants. The use of over-stoichiometric NaOH solutions allowed achieving a 100% magnesium recovery with high mass $Mg(OH)_2$ purity, >95%, and even higher cationic one, >99%. Results marked the possibility of employing saltworks bitterns as promising un-conventional sources for the production of $Mg(OH)_2$ powders with characteristics complying with market requirements.

Keywords: Magnesium hydroxide; Mineral recovery; Precipitation; Seawater brine

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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.

Acid and alkaline production from multi-ionic brines via electrodialysis with bipolar membranes

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In recent years, a great attention has grown towards the brine valorization through chemicals production and mineral recovery as an alternative to conventional disposal. Electrodialysis with Bipolar Membranes (EDBM) is an emerging process that can be used for the production of alkaline and acidic solutions from salt solutions. Within the SEArcularMINE project framework, the exploitation of saltworks bitterns (highly concentrated solutions generated during the sea-salt production process) is proposed for minerals recovery and NaOH and HCl solutions production.

In this work, an EDBM unit, equipped with commercial ion exchange membranes, was tested for the first time in closed-loop mode with: (i)single NaCl solutions as reference case (ii) synthetic brines including NaCl, Na_2SO_4, and KCl salts, and (iii) real saltwork brines, which contains traces of other minor elements. Different scenarios were assumed in terms of feed compositions to study the effect on process performance parameters as specific energy consumption (SEC), acid and base solutions purities, current efficiency, and yield.

Main results at laboratory-scale unit highlights the process feasibility to produce alkaline solutions at target concentrations exceeding 1M NaOH equivalent, while maintaining high product purities and current efficiencies.

Keywords: Electro-membrane process; Brine valorization; Multi-ion solution; Ion-exchange membrane.

Acknowlegements

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.

A feasibility study of table salt production from seawater reverse osmosis brine

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The term Critical Raw Materials has been created in 2011 to group a list of elements and compounds whose European reliance on external supply could constitute a threat to geopolitical stability of the Union. Conversely, Europe is surrounded by them, as they are all contained in seawater. The difficulties encountered in their extraction is mainly related to their low concentrations, spanning in the ppm to ppb region.

Many studies point out that a possible approach is the use of desalination brines as they represent a more concentrated seawater already treated to reduce biofouling. Additionally, the constant growth of the installed desalination capacity brings the brine disposal problem and the need for environmental sustainability.

For these reasons, the concept of Zero or Minimum Liquid Discharge is regarded as the tractor of the innovation in the desalination sector.

To allow for critical raw materials extraction, waste minimization strategies have to deal with the fact that more than 99% of total dissolved solids in the brines is made from Na, Cl, Mg, Ca, K, SO_4, Br, B and Sr and their extraction has to be feasible from both technical and the economic point of view.

The REWAISE project is an ambitious innovation action tackling the seawater-energy nexus with an holistic approach, aiming at bringing real value to the market. In this framework, an attempt is made to make use of the ancient tradition of fractionated crystallization accomplished in saltworks along with the advanced possibilities given by thermodynamic equilibria simulation tools.

This work reports the preliminary results obtained with laboratory tests, computer simulation and pilot plant design of evaporative basins for $CaCO_3$, $CaSO_4$ and NaCl fractionation from reverse osmosis brine. This is the first step towards the construction of a minimum liquid discharge pilot installation at Aqualia premises in Adeje, Santa Cruz de Tenerife, Spain.

Keywords: Desalination; Brine; Minerals; Table salt; Circular economy; Saltworks

Acknowledgments

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 869496 (REWAISE).

A pilot-scale investigation on magnesium and chemicals recovery from seawater desalination brines

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Nowadays, the increasing trend of freshwater production via desalination is unfortunately accompanied by a likewise increasing volume of waste brine discharged into natural water bodies, compromising the aquatic ecosystem. Such disposal not only leads to environmental issues but to economic ones too.To overcome contemporarily both matters, a novel integrated process at pilot scale was developed, recovering high valuable minerals and chemicals such as magnesium hydroxide, sodium hydroxide etc., from the seawater desalination brine of Lampedusa, Italy. The integrated process consists of three technologies: (i) nanofiltration NF, (ii) multiple feed – plug flow reactor MF-PFR and (iii) electrodialysis with bipolar membranes EDBM. The nanofiltration plant, developed by Lenntech BV, was fed by seawater brine and produced two different streams: (i) a retentate rich in bivalent ions such as magnesium and calcium and (ii) a permeate rich in monovalent ions such as sodium and chloride. The NF retentate is sent to the MF-PFR, an innovative reactive crystallizer developed by the University of Palermo, in which magnesium and calcium are selectively recovered in the form of hydroxides, employing an alkaline reactant (sodium hydroxide). The third and last unit, EDBM was able to produce acidic and alkaline chemicals starting from a saline solution (the NF permeate or the MF-PFR effluent). Initial experimental tests have been carried out and preliminary results have proven the stability of each pilot plant of the integrated process. Furthermore, the MF-PFR was able to recover all magnesium present in the seawater brine whereas the EDBM successfully produced chemicals with the specific concentrations required by the MF-PFR. Therefore, such "in-situ" production of chemicals made the process even more interesting from an economic point of view. Further experimental tests will be conducted, investigating different operational conditions for each pilot plant, in order to make the process the most efficient as possible. For the time being, the integrated process at pilot scale appears to be a promising solution to environmental and economic concerns of brine disposal, transforming such brine from a waste to a novel source for high valuable mineral and chemicals production.

Keywords: Desalination; Mineral recovery; Seawater brine; Magnesium hydroxide; Calcium hydroxide; Chemical production; Circular economy

Acknowledgments

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Double pass nanofiltration optimization for metal removal in brine mining valorization

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This paper presents a novel conceptual design for a double pass nanofiltration system where sulfate ions are added to the first pass permeate, either as a salt (e.g. sodium sulfate) or an acid (e.g. sulfuric acid), to enhance hardness removal in brine mining valorization opportunities. This novel design, with an optimally designed double pass, could increase hardness removal compared to a typical removal rate of 85% observed in a single pass design.

The main markets or target applications that could benefit from this concept are ocean/seawater brine mining, lithium brine mining, sodium chloride brine purification, or metal mining in general.

This paper will also assess this novel design and compare it to other alternative technologies such as ion exchange, exploring their respective pros and cons, along with other design options that could further optimize the project feasibility.

Chemical products reduction in the ultrafiltration pretreatment of Maspalomas I reverse osmosis desalination plant

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SWRO desalination plants open-intake requires different strategies of pre-treatment to reduce the biofouling and scaling. The Ultrafiltration (UF) technology is a recently application to this process. Some alternatives to chemical products reducing in chemically enhanced backwash (CEB) and clean in place (CIP) of a UF rack have been studied in the MASPALOMAS I seawater desalination plant exploited by ELMASA in the framework of DESAL+ project (ERFD funds) thanks to the funding of ACIISI. The results were compared with the current mode of daily operation of the CEB. The results show that a reduction of up to 60% in the amount of sodium hypochlorite per cubic meter of water produced employed in UF CEB's, mini CIP's and CIP's can be achieved. However, the consumption of the rest of chemical dosing increased notably, and therefore the operating cost of UF also increased. In addition, there was an increase of desalted water consumption to the chemical products removed, up to almost 95,84 %, in comparison with the currently operational mode of CEB. On the other hand, operating the UF plant in the manner proposed requires a automatization of the process and expert staff to programme the control. Therefore, based on the results obtained, the alternatives proposed could reduce the chemical products in use but it is not conclusive in terms of exploitation operational costs.

Keywords: Ultrafiltration; Reverse osmosis; SW open-intake; Clean in place; Chemically enhanced backwash; Chemical products reduction; Biofouling; Pretreatment

Highly efficient high-pressure pumps and energy recovery devices for brine mining applications

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This presentation will describe the benefits of using high pressure positive displacement pumps and energy recovery devices from Danfoss for Brine concentration, brine mining, ZLD application with osmotically assisted reverse osmosis technology.

Water scarcity is increasing around the world, SWRO is one of the main technologies to produce fresh water. But what about brine?

Technology developers are looking to produce more water from brine. But more concentration means more power consumption, maybe not?

OARO technology provides one of the lowest power consumptions for brine concentration applications, lower OPEX lower CAPEX.

Keywords: Energy saving; Retrofit; Energy cost; Efficiency; Brine mining; ZLD; OARO

Oil spill contaminate removal by novel anti-fouling membrane to prevent desalination plants shutdown

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Accidental and intentional oil spills in marine environment are persistent threat to seawater desalination plant operation. The oil concentration in seawater intake for desalination is strictly regulated. There are a variety of oil/water separation technologies, such as, hydrocyclone, air flotation, gravity settlement, and membrane filtration, etc. Among them, membrane filtration is well-known for its good quality of the effluents after treatment. However, the issue facing current commercial membranes is their fouling propensity when treating oily wastewater. In this study, we present a novel anti-fouling membrane developed in our institute for oil/water separation. The membrane was made of inorganic nanofibers, which render some unique advantages including low fouling propensity, high water permeation flux and durability. This study outcome could contribute to practical applications of membranes filtration in oil/water separation industry.

Keywords: Oil/water separation; Membrane filtration; Anti-fouling; Water flux

AQUAMATCH — desalination and salt production

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Big desalination project presentation – this project is in Basrah and Basrah seawater is a very critical water source because Basrah Gulf is very polluted seawater as physical and bacteriological also there is changeble TDS value in a wide range

Salt production project presentation – this project includes pretreatment package and salt production package. The pretreatment package is including most efficient pumps and membrane selection. Also salt production package is the first large scale plant in the world

Our project partners in this project are Danfoss Pumps, Toyoba Membranes and Hyrec Engineering Company.

Keywords: Desalination; Mega desalination plants; Energy recovery; Salt production; Salt reuse; Brine mining

Sea-based desalination with renewable energy: turning challenges into solutions. A practical approach

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When islands want to construct desalination plants they are confronted with a significant number of challenges and risks. Land is scarce and expensive, and energy needs to be imported.

In addition the construction of desalination plants involves several risks including the construction of the plant infrastructure and the network of pipes transporting the feedwater to the plant over land, which may impact environmentally sensitive areas, and which becomes expensive if the plant location is remote. Also, handling the brine generated by land-based plants creates significant additional challenges.

Barinthus Technologies has developed a novel, patent pending, approach to desalination for island and coastal communities.

The concept, currently in functioning prototype modus, consists of using the sea not just as the provider of the water to be desalinated, but as the very place where the desalination takes place.

- Using a (nearshore) anchored barge allows for the desalination process to be much more flexible.
- It can be done near any coast without requiring space on land.
- It can be moved quickly at any time in case of emergencies to other locations, or other islands.
- It allows for use of only renewable energy, thereby massively increasing self-sufficiency of island communities, while actively combatting climate change.
- It allows for a non-standard and less invasive way of dealing with brine.
- It has much shorter lead times to production than any land-based facility.

Even so, this maritime approach creates unique technical challenges, which are addressed in the presentation.

Keywords: Self-sufficiency; Renewable; Zero CO_2 emission; Desalination; Floating; Barge; Flexible; Nopollution; Fast

DIVIDE & CONQUER: Closing the loop of water, nutrient and resource management for irrigation activities

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Over the 21th Century, drought events and water scarcity have become more frequent within the EU, with one third of the EU territory experiencing water stress. Water reuse has been evidenced as the most sustainable alternative to the use of freshwater sources in terms of cost and environmental impact. However, wastewater salinity is a challenge in wastewater treatment (WWTP) and reclamation (WRP) plants where collectors receive industrial brines, agricultural runoff waters and/or marine intrusion, thus, limiting water reuse and forcing consumption of freshwater sources for

nonpotable uses, as well as the discharge of effluents with nutrients to natural water bodies. This is the case of the city of Murcia (Spain), which is characterized by structural water stress together with a high agricultural activity. The city currently counts with an urban irrigation network (UIN) designed to cover the water needs of 405 ha of parks and green areas. This water demand of 1.750.000 m^3/y for irrigation is at the moment is totally covered with freshwater sources (55% of groundwater and 45% of potable water). There is a will to boost water reuse for parks irrigation through the reclamation of 500,000 m^3/y from the effluent of Zarandona WRP, operated by EMUASA, which will be injected to the UIN. Nevertheless, the current treatment train does not allow a salinity removal. Thus, a posttreatment is required in order to comply with regulation and adequate water for irrigation purposes. LIFE CONQUER project aims to demonstrate a WRP that enables reuse for irrigation purposes by reducing salinity concentrations, allowing the fixation of nutrients in plants instead of their discharge to eutrophication-prone water bodies, and brines transformation into valuable products. The main objective is to make available cost-effective alternatives to conventional desalination systems through a circular economy approach that changes salinity and nitrates removal paradigm from concentrate the problem (as brines) to maximize resources efficiency through their valorization.

Boron recovery from saltworks brines by ion exchange resins

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The availability of raw mineral resources containing elements included in the critical raw materials (CRM) list is a growing concern for the European Union (EU). CRMs are those of high importance for the EU economy and present a high supply risk due to a lack of mineral ores in the EU. In the case of B, which is widely used in glass and fibreglass, there is an absolute dependency on import since Türkiye provides the 98% of the EU borates. Seawater mining has been identified as a promising secondary source for recovering CRMs. In particular, brines obtained from solar saltworks (called bitterns) contain relevant amounts of valuable CRMs such as Mg, B, another alkaline/alkaline-earth metals (Rb, Cs, Sr) and transition/post-transition elements (Co, Ga, Ge) up to 40 times more concentrated than seawater. Within this context, the H2020 SEArcularMINE project (www.searcularmine.eu) aims to recover the above-mentioned CRMs from the bitterns generated in the solar sea saltworks. Due to the low concentration of these elements (e.g. B, Ga, Ge), they will be recovered by using pH-Swing Adsorption technology.

In this study, three commercial N-methylglucamine sorbents (S108, CRB03 and CRB05) are evaluated for the B recovery in packed bed columns using synthetic bitterns mimicking the SEArcularMINE process. In addition to B, N-methylglucamine sorbents were also able to retain Co, Ga and Ge. Similar behaviour is observed, independently of the bittern used for all sorbents. Among them, B reached concentration factors up to 10. The other elements sorbed presented concentration factors up to 6 (Co) and 32 (Ga, Ge).