Desalination for the Environment
Clean Water and Energy

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Fluoride,copper and combined fluoride-copper removals from semiconductor wastewater by electrocoagulation

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Treatments of fluoride (F), copper (Cu) and F-Cu from semiconductor-based silicon etching rinse baths by electrocoagulation (EC) using aluminum plate electrodes were investigated in this study. The effects of important process variables such as current intensity, initial pH and initial concentration on the removal efficiencies of F and Cu were evaluated. Removal efficiencies for F and Cu in the single system were found at about 99% at optimum operating conditions. The highest removal efficiencies were achieved at pH 3 for F and between pH 3 and 5 for Cu containing synthetic wastewaters. Experiments were conducted with different F/Cu ratio when Cu concentration was kept constant and F concentration was increased, the highest removal efficiency was observed at lower concentrations. EC study provided high removal efficiencies of F and Cu from semiconductor synthetic wastewater.

Keywords: Semiconductor wastewater, Copper, Fluoride, Electrocoagulation.

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A novel liquid pressure energy recovery device of high-efficiency for seawater reverse osmosis desalination

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Desalination is an effective measure easing freshwater scarcity. Seawater reverse osmosis (SWRO) is gaining rapidly acceptance among various desalination technologies and become a leading technology worldwide. The rapid development of SWRO benefits greatly from isobaric energy recovery devices (ERDs) that could significantly reduce specific energy consumption in desalination plants.

A novel high-efficiency ERD called 'fully-rotary valve energy recovery device (FRV-ERD)' is developed aiming at providing a high-efficiency energy recovery technology. The energy recovery process and device structure are different from current ERDs. The FRV-ERD which is simple in structure only consists of two identical FRVs and pipelines. Two phases repeat periodically in the energy recovery process by switching the two FRVs simultaneously. High pressure brine and low-pressure sea flow into one FRV, while low pressure brine and high-pressure seawater flow out from the other FRV.

As the key component of FRV-ERD, the fully-rotary valve (FRV) mainly consists of a rotor and a

stator. The stator is a cylinder with some inlets and outlets. The rotor which is composed of two symmetrical semi-cylinders with flow channels can rotate freely inside the stator. Two cavities are formed inside the FRV after the rotor and the stator are assembled together. The inlets/outlets on the stator will be open or closed according to the location of the semi-cylinders: if it is at the opening, then it acts as a sluice gate plate and the inlets/outlets are closed, otherwise they are open. In this way, the rotor can supply the pressure exchanging pipes with seawater and brine alternately depending on its phase positions.

As the main seal technology in current isobaric ERDs, clearance seal suffers some problems, such as high machining requirement, low seal tightness, scraping and abrasion between key components, etc. For the FRV, there is no reciprocating motion in the FRV and the rotor is the only moving part. For the FRV-ERD, the sealing is not from close contact between the rotor and the stator, so the abrasion and wear are successfully eliminated. Special seal structure has been designed to achieve higher seal performance instead of hard wear-resisting materials and precision machining, easing machining difficulty and capital costs greatly. Once the seal performance could not meet the operation requirement after long-term running, the only part that needs to be replaced is its sealing elements. The replacement is as easy as changing an O-ring.

According our test, the FRV-ERD can obtain high and stable seal performance. The leakage in this ERD is not detectable by flow meter with the accuracy of 0.5%. The efficiency is over 98%. Besides, the FRV-ERD is reliable in operation due to the cancel of physical piston which is used to separate brine and sea. The control system of FRV-ERD is hence simplified greatly. The switching period of FRV-ERD can be adjusted to control the device mixing in a reasonable range. The overall performance of this device is competitive among current ERDs.

Keywords: Energy recovery device; Liquid pressure; Positive displacement; Desalination; Fully-rotary valves

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Desalination by forward osmosis: failure, success, and future research focus

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Water scarcity is an emerging problem, which has affected most countries worldwide due to population growth, contamination of groundwaters, and increasing demands on freshwater resources. Desalination becomes the alternative source for freshwater supply using thermal and membrane technologies. Most of the current desalination technologies are unable to meet future sustainable development of modern societies. Energy-efficiency is one aspect that has been taken against thermal and membrane technologies besides the growing concerns about the environmental pollution. Reverse Osmosis, the most common desalination method, has been criticized for being an energy intensive process and desalination energy should be reduced in future for sustainable water supply. Forward Osmosis has been identified as an emerging energy-efficient technology that has the potential for scale-up and commercialization. The process has been under intensive investigation in the last 10 years or more, but yet there is not a commercial plant for seawater desalination. Pilot plant tests to demonstrate the feasibility and effectiveness of forward osmosis process have

failed to highlight the significance of the process. Some of the drawbacks of forward osmosis desalination studies are i) lack of comprehensive technoeconomic field studies that can be used for comparison purpose with current technologies ii) coordination between academic and industries iii) overestimation the potential of the forward osmosis process that have not backed up by field results and/or failure to understand the market demands iv) stereotyping instead of critique studies.

The current study tries to identify a number of past experiences in forward osmosis desalination and their academic and industrial impacts and evaluates potential applications. It also provides some data on energy efficiency of forward osmosis-reverse osmosis system for desalination and its potential use. Finally, it provides some information about commercial FO membranes that are readily available for technology testing.

Keywords: Desalination, Forward osmosis, Desalination energy

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The role of desalination in water-energy-food nexus: an opportunity for Algeria

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In Algeria, water resources are limited and often of low quality, fragile and unevenly distributed in space and time. Industrial development, population growth, and irrigation requirements are exasperating pressure on water resources by generating competition for water between agriculture, drinking water, and other uses. As for the future impact of climate change on the water-energy-food (WEF) nexus, the climate change is placing increasing stress on this nexus. Desalination technologies could play an increasing role in the country's linkages between water, food, and energy and contribute to the national economy. Demand for desalination will likely grow in the country due to limiting water resources and even changing preferences for food and consumption in general. The water reuse and desalination in agriculture also offer an opportunity to expand significantly implementing WEF nexus integration when meeting health standards, thus providing access to healthy foods and a subsequent way allowing stakeholders to optimize their water supply resources. Even though desalination can ensure efficiency and sustainability of the water, food, and energy nexus and mitigate the impact of climate change.

Keywords: Desalination, Mitigation, Climate change, Sustainable Development Goals (SDG's)

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Water-energy-food nexus approach: motivations, challenges and policies in Algeria

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The water energy food (WEF) nexus approach seeks to assess relevant and consistent strategies to address challenges to the development of the three sectors, to meet the demand and achieve sustainable development. They are the most indispensable elements for life and development respectively. Besides that, the production and cost of one depend highly on the performance of each other. Not any country could attain a sustainable development without first developing the three sectors and satisfy the demand. Most of developing countries face the challenges in handling the management of these resources due to different reasons. Among those reasons, the most predominant are high population growth, lack of skills in water management, low use efficiency and energy resources management and impact of climate change. This research seeks to find out the best ways to handle barriers to WEF nexus development with the target to satisfy the need in a sustainable way.

Keywords: Water – Energy Food Nexus; Nexus strategy; Policies; Sustainable development

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Adsorption, catalytic and membrane distillation processes for refinery wastewater treatment

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A three-step combination of adsorption, catalytic degradation, and membrane distillation has been applied for the refinery wastewater treatment. The copper ferrites ($CuFe_2O_4$) was used as a heterogeneous catalyst for the degradation of phenol in the water. The graphene-based materials have been used for the adsorption of phenols and heavy metal ions removal. As prepared graphene sheets have been used for the phenol removal from the wastewater and the removal efficiency and recyclability were studied. In order to improve the recyclability, mechanical stability and further adsorption of soluble heavy metal ions from the wastewater, the graphene oxide (GO) has been embedded in the sodium alginate biopolymer matrix. The GO has been further functionalized with

polyamines for the effective crosslinking and further improvements in the adsorption of metal ions. The functionalized GO-alginate beads showed high adsorption for Cd, Hg, and Pb ions. As a final tertiary water polishing step, a new superhydrophobic membrane was developed and used for the membrane distillation (MD). The detailed MD studies, utilizing the superhydrophobic nature of the surface, proved that the newly developed membrane is capable of desalinating high saline water (more than 200,000 ppm of NaCl) and continues operation of MD for more than one week showed stable water vapor flux with excellent salt rejection. The results are compared with conventional membrane and found to be highly superior in terms of water vapor flux and salt rejection.

Keywords: Membrane distillation, Catalytic degradation, Adsorption, Refinery, Wastewater

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Dual stage pressure retarded osmosis: potential and feasibility

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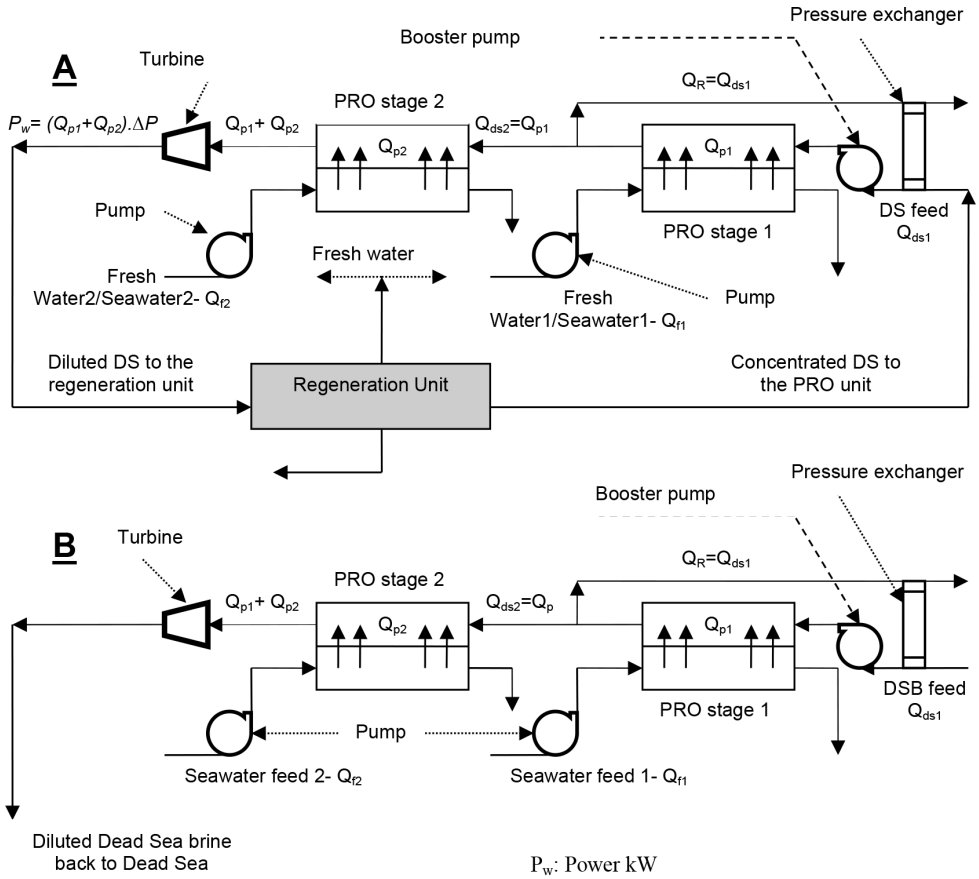
A dual stage PRO process has been proposed for power generation from a salinity gradient across a semi-permeable membrane. Both closed-loop and open-loop dual stage PRO system were evaluated using 2 M NaCl and Dead Sea as draw solutions, whereas the feed solution was either fresh water or seawater. The impact of feed salinity gradient resource and feed pressure on the net power generation and water flux were evaluated. The results showed that power density in stage one reached a maximum amount at $\Delta P = \pi/2$, but the maximum net power generation occurred at $\Delta P = \pi/2$. This result was mainly attributed to the variation of net driving pressure in stage one and two of the PRO process. The dual stage PRO process was found to perform better at high osmotic pressure gradient across the PRO membrane, for example when Dead Sea brine or highly concentrated NaCl was the draw solution. Total power generation in the dual stage PRO process was up to 40% higher than that in the conventional PRO process. This outcome was achieved through harvesting the rest of the energy remaining in the diluted draw solution. Therefore, a dual stage PRO process has the potential of maximizing power generation from a salinity gradient resource by 20%.

DSPRO can be combined with desalination plant using seawater brine as the draw solution either in closed-loop or open-loop. This hybridization has multiple applications such as reducing the impact of discharging concentrated brine to sea, energy storage, and increase the recovery rate of the desalination. Power generation by DSPRO will reduce the energy consumption by the desalination processes. Waste heat from power plants can be used for the regeneration of the draw solution in the closed-loop DSPRO. Process modelling has been performed and shown promising results for DSPRO application for power generation. The impact of module configuration, area and length, with relation to draw solution concentration have shown to have significant impact on osmotically driven processes and should be counted for.



P_w: Power kW
Q_{ds}: Draw solution flow rate m^3/h
Q_R: Recycle flow to PX m^3/h
V_1: Permeate flow rate in first stage m^3/h
V_2: Permeate flow rate in second stage m^3/h
$Q_{f\text{-}in}$: Feed flow rate m^3/h
Q_p: Permeate flow m^3/h
DSB: Draw solution brine
DS: Draw solution

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Sequence of optimized predictive models for forecast of global wastewater treatment plant performance

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The process control of wastewater treatment plants (WWTP) using data analytics is one of the research focus areas to improve the process efficiency and economics. According to literature, machine-learning models such as neural network models (ANN) were developed for WWTP process control. The models simulated plant performance, predicted water quality parameters such biological oxygen demand (BOD) and chemical oxygen demand (COD) and provided predictive control on process parameters such as coagulant dosage. Other machine learning models such as

fuzzy networks and self-organizing maps (SOM) used in conjunction with ANN predicted plant performance in terms of organic matter removal. Ensemble models such as bagging and rotation forest have shown to be more stable than single classifiers (like ANN) with lower tendency for overfitting. The ensemble models have not been used widely to simulate or predict wastewater treatment plant performance. This paper highlights the development of a sequence of predictive models to provide forecasts on global plant performance. The predictive models will be a mixture of data mining models such as bagging, ANN or SVM. Each individual model in the sequence will predict the performance of a unit (such as primary clarifier or secondary clarifier) based on basic input quality parameters. The prediction of global performance will employ the combination of individual unit performance forecasts. Thereby the global model will be providing a feedback control model based on current input quality parameters and estimated performances.

Keywords: Wastewater treatment, Plant performance prediction, Ensemble model, Data mining

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Improved desalination using a three-layer OTMS based superhydrophobic membrane for a membrane distillation process

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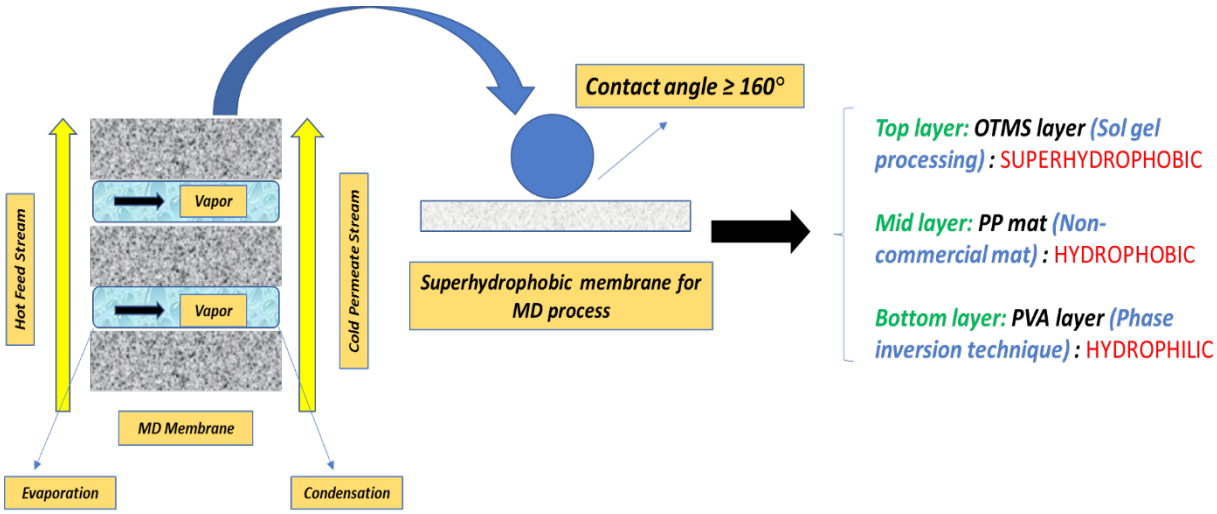
Graphical Abstract



Abstract

Superhydrophobic membranes are essential for improved seawater desalination. This study presents the successful casting of a three-layered membrane composed of a top superhydrophobic coating onto a polypropylene (PP) mat through simple sol–gel processing of Octadecyltrimethoxysilane (OTMS), and the bottom layer was casted with hydrophilic poly(vinyl alcohol) (PVA) by using a knife casting technique; this membrane represents a novel class of improved-performance membranes consisting of a top superhydrophobic coating onto a hydrophobic PP mat and hydrophilic

layer (PVA) at the bottom. OTMSs are well known low-surface-energy materials that enhance superhydrophobicity, and they were observed to be the ideal chemical group for increasing the hydrophobicity of the PP mat. The PVA layer acted as base layer absorbing the condensed vapor and thus enhancing the vapor flux across the membrane. The hybrid three-layered membrane exhibited superhydrophobicity, with an average contact angle of more than 160°, and demonstrated high performance in terms of rejection and water flux. This study also examined the pore size distribution, surface roughness, surface area, tensile strength, water flux, and salt rejection of the fabricated membrane. The salt rejection level was calculated to be 99.7%, and a high permeate flux of approximately 6.7 LMH was maintained for 16 h.

Keywords: Polypropylene; Octadecyltrimethoxysilane; Superhydrophobic; Desalination; Membrane distillation

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Metagenomic analysis of microbial communities in seawater reverse osmosis plant

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Biofouling of RO membrane is a huge problem for water treatment industry. In this study we applied a culture-independent metagenomic approach to characterize the microbial community composition and its functional potential in a full-scale RO plant. Samples of intake seawater (raw seawater), fouled RO membranes (leading and middle RO module) and brine were acquired. We found that *Proteobacteria* is the most dominant bacterial phyla in all the samples. *Bacteroidetes* were the second most abundant phyla in raw seawater followed by brine. However, for leading RO module (seven years old) *Planctomycetes* was the second most abundant bacterial phyla while in middle RO module (five years old) its abundance was approximately same as *Proteobacteria*. The genetic potential of RO membrane microbial community showed the enrichment of genes involved in biofilm formation, representing the selective pressure of biofilm formation process. Many genes in metagenome, especially for RO biofilm, showed low similarity to currently sequenced genes/ genome underscoring the need for sequencing more reference genomes from biofilm community on RO membranes. In total we reconstructed 31 metagenomes assembled genomes (MAGs), of which 25 of the MAGs were extracted from biofilm samples (leading and middle RO module). Of all the MAGs from biofilm samples 36% belong to *Planctomycetes*. We curated the MAGs for genes (pili, flagella, quorum sensing, quorum quenching) that play an important role in biofilm formation. We identified that *Planctomycetes* contain genes for flagella and pili formation and nitrate reduction. Although, no genes for quorum sensing were detected in biofilm MAGs, genes involved in quorum quenching were identified. Furthermore, archaeal species that might play a role in ammonia oxi-

dation were identified. These results show that *Planctomycetes* along with other microbes play an important role in formation and sustenance of biofilms on seawater RO membranes.

Keywords: Metagenomics, Reverse osmosis, Seawater desalination, Membrane biofouling, Membrane based water treatment

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The pollution load of wastewater and the performances of the sewage treatment plant of Skhirat city in Morocco

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The Skhirat city is characterized by a sewage treatment plant (STEP) which receives a very important volume of wastewater about 66473 m^3 with a flow about 2173.56 m^3/d. The aim of this research was to evaluate the pollutant load of wastewater and the performances of the sewage treatment plant of Skhirat city in treating domestic wastewater.

Sampling was carried out on the level of the entry of sewage treatment plant with a monthly rate. The analyses were carried at the laboratory with the cubic measure of wastewater

received by the sewage treatment plant.

The performances of the sewage treatment plant in treating domestic wastewater of Skhirat city was investigated. The results showed that the rate of the biochemical oxygen demand (BOD_5) chemical oxygen demand (COD) and the suspended matter (SM) respectively it's of the order 90.68%, 87.4% and 79.50%. The got results show that the COD(entry)/BOD_5(entry) ratio of 2.08, is lower then 3, which makes it possible to confirm the normal state of the station in biological treatment.

Globally, the results of the investigation revealed by the test unilateral Student, the test confirms this difference between the entry and the exit of this station which significant by p-value calculated is lower than the level of significance alpha= 0.05.

Keywords: Domestic wastewater, Pollutant load, Performance, STEP

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Nanofiltration membrane autopsy of decentralized desalination plant

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In 2014 the first decentralized desalination plant, using Nanofiltration (NF) membrane coupled with renewable energies (Photovoltaic and wind energies) was realized at Al Annouar high school of Sidi Taibi, Kenitra, Morocco. This project was designed to supply the 1200 students of the school with potable water, with a production capacity of 500 L/h (3L/d/student). The local underground water, which is slightly brackish, was treated by Nanofiltration, using an hybrid renewable energy system, photovoltaic and wind.

Sidi Taibi desalination plant has revealed difficulties related to the loss of membrane performances (increase of pressure, decrease of flux, poor product quality and increase of energy consumption). In the aim to solve this problem, foulant layer were analyzed to determine the reason of membrane fouling, and three cleaning solutions (hydrochloric acid, nitric acid and sulfuric acid) were tested and compared to find the suitable one for the fouled membrane, to regain its initial permeability. The membrane autopsy has achieved by two different methods, such as diffraction by X-ray and optical microscope, and the permeability of the cleaned membrane was calculated. The experimental results show that the foulant layer composed mostly of calcite (calcium carbonate) and quartz (silicon dioxide); these are the sources of fouling problem and the permeability is ameliorated by using both hydrochloric acid (pH 1-2) and nitric acid (pH 1-2) cleaners.

Keywords: Nanofiltration, Desalination plant, Fouling, Autopsy, Demineralization

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The first experience of brackish surface water reverse osmosis demineralization in Morocco

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The desalination plants situated in the south Moroccan provinces progress towards the North. In addition, seawater desalination is spreading out more and more toward the surface water. This is the case of Khenifra demineralization station in phase of exploitation by the ONEE (National Office of Water and Electricity). The brackish water reverse osmosis desalination plant has operated successfully from the second half of 2013 and is designed to produce 36.290 m^3/d of drinking water at the horizon of the year 2030. The plant consists of unconventional treatment and reverse osmosis section, containing three trains, each one with two stages and with a production capacity

of 9850 m^3/d. The aim of this paper is to highlight both the design and the performances of the reverse osmosis unit after nearly one year of operation.

Keywords: Surface water; Brackish water; Reverse osmosis; Desalination

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Decentralized emerging solar desalination technologies as a feasible replacement of medium and large plants: Saudi Arabia as a case study

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Expansion of conventional desalination technologies faces unavoidable economical, technical and environmental challenges such as high production costs, intensive energy consumption and environmental impact on the air, water and land. In addition to that, the centralization of water production and transmition of fresh water to the in land cities amplify more these challenges. Kingdom of Saudi Arabia (KSA) has built more than 7000 Km of transmission systems with pumping stations which erodes any attempt to optimize the water production cost. However, decentralization of water production using emerging desalination technologies with solar energy had not been investigated and compared with Business As Usual (BAU). In this work, decentralized adsorption desorption desalination (ADD) as an emerging desalination technology coupled with solar energy has been studied and compared economically and environmentally with BAU of a proposed seawater reverse osmosis (SWRO)plant in KSA. The study revealed that, the reduction of the specific energy consumption (SEC) from 4 kWh/m^3 of BAU to 1.38 kWh/m^3 of ADD will reduce the desalinated water production cost and CO_2 emission by around 40% and 70% respective.

Keywords: Decentralized desalination technologies; Solar Adsorption desorption desalination (ADD); Kingdom of Saudi Arabia (KSA); Specific energy consumption; Desalination CO_2 emission; Desalinated water production cost

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A novel high-efficiency energy recovery device for seawater reverse osmosis desalination

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Desalination is an effective measure easing freshwater scarcity. Seawater reverse osmosis (SWRO) is gaining rapidly acceptance among various desalination technologies and become a leading technology worldwide. The rapid development of SWRO benefits greatly from isobaric energy recovery devices (ERDs) that could significantly reduce specific energy consumption in desalination plants.

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Keywords: Energy recovery device; Efficient; Seawater reverse osmosis

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Integration of vacuum multi effect membrane distillation driven by solar linear Fresnel collector with adsorption/cooling system

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This paper addresses the solar driven of integration of vacuum multi effect distillation (VMEMD) with adsorption/cooling unit using metal organic frameworks (MOFs) adsorbent material to produce potable and cooling water. In the solar system, the linear Fresnel collector (LFC) unit will be equipped with cooling loop to cool the LFC unit and to recover its thermal energy.

Adsorption is a heat driven technology that can be used to generate potable water and cool-

ing through adsorption/desorption of water vapor by a porous adsorbent material. Metal organic framework (MOF) is a new class of porous material with high surface area (5500 m^2/g), superior adsorption characteristics and large porosity. MIL101Cr is an MOF material that was shown to have water vapor adsorption characteristics superior to those of silica gel and zeolite with up to 1.5 kg_{water}/kg.

VMEMD is a vacuumed membrane distillation technology where permeate side is vacuumed yielding lower vapor pressure than in the feed side thus generating the distillation process, such technology can effectively exploit the vacuum conditions associated with the adsorption process yielding higher potable water production rate.

The main excepted and calculated results of this project can be summarized as following:

- The pilot plant recovery ratio can be reached to more 50%.
- The power consumption can be lowered to 3.9 kWh/m^3
- Cooling water for towers.
- Environmentally friendly, no CO_2 emission and no harm upon ecosystems or the environment.

Keywords: Vacuum membrane distillation, Adsorption, Solar linear Fresnel collector

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Integration of multiple effect distillation and membrane distillation desalination processes

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Conventional desalination processes have been used in several countries particularly in the Gulf region to provide potable water requirements. Although the concept of hybrid processes is not new, its implementation is giving more attention in the last period. Compared to the standalone configuration, it has several important technical and economic advantages. The environmental impacts would be also be reduced. This work focuses specifically on the integration of multiple effect distillation (MED) and membrane distillation (MD) processes. Different possible configurations of integration will be assessed and discussed. The results of a theoretical model on the performance of the hybrid MED-MD unit will be presented and analyzed. The main performance parameters such as the performance ratio, recovery ratio and specific energy consumption will be investigated. The benefits and limitations of such an integrated system will also be highlighted.

Keywords: Multiple effect distillation, Membrane distillation, Integrated processes, Performance ratio

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Comparison between experimental and theoretical data for the design of atmospheric limestone contactors for permeate post treatment

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Atmospheric limestone contactors are more and more widely used for reverse osmosis permeate post treatment. The design approach is in general experimental and derives from data collected during the limestone contactors operation. Using a classical theoretical approach is possible to define a universal design criterion to size the filters in correct way taking into account different media characteristics. In the paper, the different approaches are compared and the theoretical calculation model is described.

Keywords: Remineralization plant; CO_2; Kinetic constants; EBCT; Carbonate system; Atmospheric contactors; Reverse osmosis

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Performance of an ultrafiltration membrane bioreactor (UMBR) in wastewater treatment

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In this study, the performance of an ultrafiltration membrane bioreactor (UMBR) in treating domestic wastewater was investigated using laboratory-scale experimental setup at different operation modes. During the experiments, biological oxygen demand of <11 mg/L and chemical oxygen demand of <15 mg/L were found in the permeate. No suspended solids were detected in the effluent during this period. With the domestic wastewater at low carbon/nitrogen ratio, the influence of hydraulic retention time in the bioreactor on phosphorus and nitrogen removal was observed. The treated water was fully nitrified and the phosphorus was used wholly in the bioreactor for biological growth. Bacteria and viruses were completely retained by the membrane system, reducing the extent of the final disinfection required. Metals such as Fe, Zn, and Cu were retained and accumulated in the system by filtration. In general, the results of the investigation revealed that external membrane bioreactors are potential alternative wastewater treatment processes, particularly, when the reuse of wastewater is considered as a vital option.

Keywords: Ultrafiltration membrane bioreactor; Domestic wastewater treatment; Pollution removal.

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A feasibility study and optimization of energy-efficient reverse osmosis (EERO) process: numerical modeling and simulation

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Chong et al. recently proposed a promising membrane system design, named an energy-efficient reverse osmosis (EERO) process (Fig. 1). The EERO process was configured as multiple stages that incorporate a single-stage reverse osmosis (SSRO) stage and a countercurrent membrane cascade with recycle (CMCR). This is an optimization strategy for multistage processing with recycling of one or both counter-currently flowing streams. A key feature of CMCR is to lower the osmotic pressure differential (OPD) across membrane by interstage recycling of permeate and retentate, and thus improve energy efficiency of the system.

The previous studies succeeded to conceptually prove the feasibility of the EERO system, but there is a controversial issue regarding the system's applicability for seawater desalination. The reason is that their analytical models used has limitations that need to be addressed, due to impractical assumptions: thermodynamic limit operation ($\Delta p = \Delta \pi$) and no frictional losses in membrane modules. Their disregard is more likely to highly overestimate the performance of systems with higher recovery and larger scale such as multistage processes, because of the higher degree of concentration polarization (CP) and pressure drop.

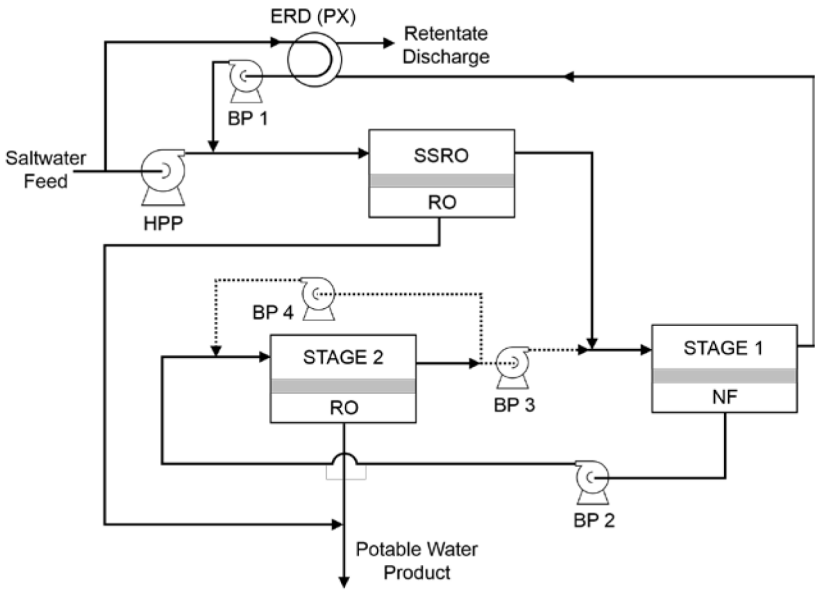

Fig. 1. A schematic of a 1-2 energy-efficient reverse osmosis (EERO) process where a single-stage reverse osmosis (SSRO) is combined with a countercurrent membrane cascade with recycle (CMCR) of two stages: one NF stage + one RO stage. Dotted lines indicate recycle streams of Stage 2.

The primary aims of this study, therefore, are to practically assess energy efficiency of the

EERO process, and finally determine optimal conditions for such multi-stage process. To this end, we developed a numerical model for a 1-2 EERO process, and then validated it using performance data obtained from commercial reverse osmosis (RO) projection software. In simulations, the 1-2 EERO, optimized in this study, exhibited not only greater energy efficiency, but lower potentials of membrane fouling and concentration polarization (CP) than a standalone SSRO at the overall water recovery rate greater than 55%. These findings can thus provide insight into optimal design and operation of the EERO process and guidance of successful practical implementation.

Keywords: Reverse osmosis; Seawater desalination; Energy-efficient; Multistage processing; Specific energy consumption

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Dynamic modelling and analysis of the coupling between CSP and MED plant

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Multi-effect distillation (MED) is a mature desalination process with high energetic performances and a lot of potential. Its main disadvantage is due to the high consumption of thermal energy that comes from, for instance, fossil fuels. One way to improve the process and make it more sustainable would be to associate a MED plant with a Concentrated Solar Power plant (CSP). This means that the MED plant would be operated under dynamic conditions, therefore it is major to predict the reaction and the operability of the MED plant when it is submitted to sudden changes of the operating conditions. Moreover, a control strategy has to be developed in order to counteract the effects of the input changes that otherwise, lead to great instabilities. Indeed, the brine pool level in each effect is the main variable driving the plant stability and the smallest incoming perturbation can have a hudge impact on its variations. Therefore, it is important to find a way to stabilize it if one wants to operate the MED plant under dynamic conditions. In this work, a CSP simplified model is associated with a dynamic model of a 12-effect MED desalination plant and the results of the simulations have been analyzed to prove the potential and feasibility of such a coupling.

Keywords: MED, CSP, Dynamic, Transient, Model

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Development of sustainable development of decision support framework for assessing the sustainability of different seawater desalination technologies: United Arab Emirates case study

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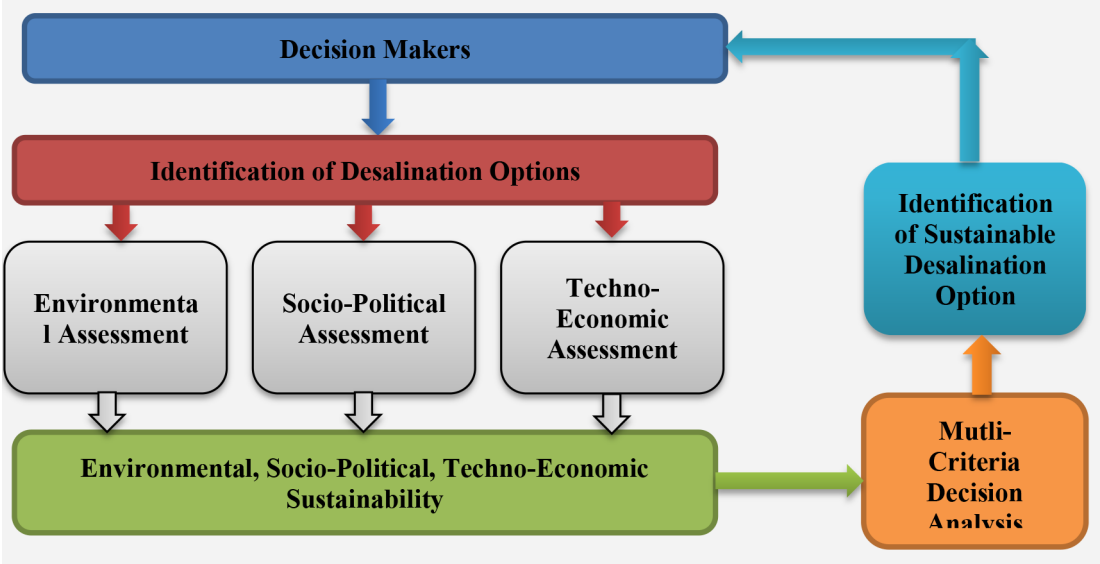
A full sustainability appraisal of all desalination options is necessary to determine which technologies perform best. Nevertheless, it is widely recognized and accepted that sustainability assessments should take a life cycle approach, taking into account all relevant sustainability issues. Therefore, a framework for assessing the sustainability of desalination in United Arab Emirates will be presented in this study. This framework integrates the three pillars of sustainability, techno-economic, environmental and socio-political using different tools of mixed integer linear programming, life cycle assessment and multi-attribute value theory (MAVT), which will be used for the multi-criterial decision analysis (MCDA). Moreover, each pillar of the sustainability will be assigned different set of indicators. The techno-economic framework has been assigned 15 indicators that will allow the cost assessment to be carried out. Furthermore, the environmental aspect will be assessed through SimaPro software using TRACI and Eco-Indicator 99 impact categories as the main indicators.



Regarding the socio-political framework, some indicators are accounted quantitatively (for example, employment opportunities indicator), others are based on individuals' perceptions and behavior and will be measured on a qualitative scale. Both expert stakeholders and public will be engaged in this study using MCDA survey to determine the relative weights of three main sustainability pillars as well as the indicators assigned to each. The usage of MCDA allows to model expert stakeholder, public opinion and to compare how differing perspectives may affect the choice of desalination option. Moreover, the decision hierarchy tree will be produced using the Web-HIPRE that allows the assessment of desalination sustainability based on the basis of each alternative's

performance under each sustainability indicator. This framework will be developed primarily to assess the sustainability of the three main desalination methods (MSF, MED, and RO) in the UAE, but is going to be applicable to other desalination technologies as well as to other countries.

Keywords: Sustainability, Desalination, UAE

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Recycling municipal wastewater for industrial applications – The MULTI-ReUse research project

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The decrease in quantity and quality of groundwater or surface water resources is not only leading countries in semi-arid and arid countries, where demand for agricultural and industrial water is increasing, to focus on recycling municipal wastewater or to process seawater. Even certain areas in countries with above average annual rainfall need to consider the reuse of municipal wastewater for industrial and agricultural applications, or groundwater recharge. The increasing water demand by the industry in lower Saxony in Germany, forces municipalities to consider those reuse options as well. Funded by Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung BMBF) of Germany, the MULTI-ReUse Research Project was initiated. The MULTIReUse Research project has four main objectives: 1/ Provisioning and adaption of innovative, modular process chains for the production of defined water qualities and volumes, based on regular treated wastewater, 2/ Monitoring procedures for the quality of the service water regarding health protection and plant protection, 3/ Evaluation of action alternatives on an economic and ecologic level, as well as evaluation of socio-cultural acceptance, 4/ Development of exemplary and marketable solutions for typical fields of application worldwide. The project involves nine partners and the city of Nordenham, Germany, where a pilot unit is located. Each partner brings his expertise. The interface to the industrial and agricultural sector is covered by the partners DECHEMA and the Leibniz Centre for Agricultural Landscape Research (ZALF). The waterboard of Oldenburg works together with the research partners IWW Water Centre, the Biofilm Centre of the University Duisburg-Essen (UDE) and the supplying companies inge GmbH, IAB Ionenaustauscher GmbH Bitterfeld and De.EnCon GmbH. The Institute for Social-Ecological Research (ISOE) mainly focuses on the knowledge transfer of the results. This paper presents the MULTI-ReUse Research Project and its current and future actions. It also presents the preliminary experimental results of the ultrafiltration performance and filtrate quality with respect to different requirements from the industry.

Keywords: MULTI-ReUse; Ultrafiltration, Wastewater

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Coating of ultrafiltration membranes the solution to improve the efficiency of the pretreatment

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Water scarcity, water pollution, climate change and environmental requirements pose an increasing challenge in many countries, particularly in countries in semiarid or arid zones where agricultural and industrial water demands are ever increasing. Nowadays, ultrafiltration plays a major role in water treatment in completely removing particles and microorganisms including protozoa, bacteria and even viruses. Depending on the quality of the feed water in regard of potential membrane foulants (e.g. dissolved or colloidal organic substances), operating parameters and required chemicals for the pre-treatment (e.g. coagulants) and different cleaning processes can have a significant impact on the design and on the capital and operational costs. In some applications, coagulation upstream ultrafiltration happens to be an unavoidable solution to prevent the threat of pore blockage from colloidal suspensions. It also helps in removing organic compounds to decrease the biofouling on reverse osmosis membranes. Although reduction in coagulant consumption was achievable through guidance from several studies on optimization of dosage, a huge potential still exists in composing an optimal coagulation procedure to reap further reduction. The procedure "membrane coating", developed by inge GmbH, is aimed to improve the efficiency of the pre-treatment step. In this process, the coagulant will not be added continuously during the complete filtration time. Instead of, the dosing pump starts operating with beginning of the filtration time and stops few minutes later when the membranes' surface is coated with the metal-hydroxide layer. The paper presents results from several pilot tests and full-scale experiences in different countries, as well as a comparison between intermittent and continuous coagulant dosing during the filtration cycle is included. The paper proves that the operational costs can be significantly reduced when applying intermittent inline coagulation as coating process.

Keywords: Coagulation; Coating; In-out filtration; Pilot Plant Test; Ultrafiltration

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Membrane distillation biofouling: Impact of feed water temperature on biofilm characteristics and membrane performance

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Reclamation of highly contaminated water has prompted the need for novel sustainable membrane technologies, such as membrane distillation (MD). The greatest challenge for membrane-based wastewater reclamation is microbial fouling (biofouling), the establishment of a bacterial consortium

within self-produced extracellular substances (EPS) on membrane and spacer surfaces. The goal of this study is to determine the effect of feed water temperature on biofilm characteristics and MD system performance. Dynamic biofouling experiments with thermophilic Anoxybacillus gonensis, isolated from municipal wastewater, were conducted in a bench-scale system with a cross-flow membrane cell. Feed water temperature was set to 47, 55 or 65°C, while distillate temperature was adapted to reach an initial distillate water flux of 23±1Lm-2h-1. System performance was continuously monitored via distillate water flux and conductivity. Biofilm was analyzed after three days of biofouling using total organic carbon, flow cytometry, confocal laser scanning microscopy and transmission electron microscopy. MD system performance was moderately affected at 47°C, but biofouling caused a drastic distillate water flux decline of up to 90% at 55°C, which coincided with the highest accumulation of biomass. At 65°C severe wetting was observed via optical coherence tomography accompanied by a 90-fold increase in distillate conductivity and penetration of membrane pores by bacteria. Our results indicate that feed water temperature is a determining factor for MD system performance. The impact of other parameters, such as flow conditions and bacterial community composition remain to be determined in future studies in order to maximize the potential of MD for wastewater reclamation.

Keywords: Membrane distillation, Biofouling, wetting, Feed water temperature, Biofilm characteristics

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Expansion of product range of spiral wound filtering elements production for desalination of seawater and brackish water

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Over the period of practical operation of reverse osmosis elements a number of problems have been revealed with properties of manufactured products with regard to rejection by specific components, contained in seawater (boron) and pretreated water at power engineering facilities (silicon). Besides this, taking into account increased temperatures of elements' operation at water treatment plants at central heating and powers plants, regional power stations etc. (up to 35°C) and desalination plants in Arabic countries (up to 40°C), R&D works have been required in order to increase thermal stability of membrane flatsheet.

The selective polyamide layer of reverse osmosis membranes contains free amino- and carboxy groups forming so called "nanodefects", though which pass molecules of Boron acid, having smaller size (4Å) than hydrated Sodium ions (6Å). Besides, the said nanodefects lead to increased agility of polyamide units at increased temperature, which decreases the membrane's rejection.

In order to eliminate such negative effects it is required to complete the additional cross-linking of selective layer.

Solution of the additional cross-linking agent was applied on the surface of selective layer by the membrane surface's contact with polyvinyl alcohol mixture and carbo-diimide based cross-linking agent followed by drying.

As the result of modification of selective layer of a standard reverse osmosis membrane for seawater desalination new spiral wound membrane elements were developed that can be applied in regions with increased temperature of desalinations plants' operation.

Water treatment at power engineering facilities calls for very strict control of Silicon content in permeate. The experience of using standard KC series elements, designed for desalination of feed waters with salinity of up to 5 g/l at such facilities has shown that despite high NaCl rejection, products of JSC "RM Nanotech" is inferior to similar competitive products in terms of Silicon rejection. At temperatures increased up to 35°C this difference significantly increased.

Silicon rejection value must be higher than NaCl rejection in all range of temperatures.

All this required creation of a new ultrafiltration substrate, production of which is the first stage of manufacturing of composite reverse osmosis membranes.

A key feature of this process is introduction of regulated gaseous environment in the zone of casting solution application on non-woven support in production of ultrafiltration (UF) membrane flatsheet. By doing so a fixed volumetric air flow with stable regulated humidity is fed to the application zone.

Absence of defects of UF substrate for reverse osmosis membranes is in direct dependence of dissolved gases content (mainly oxygen and carbon dioxide) in the water supplied to the precipitation bath during its manufacture.

Therefore, despite the fact that the equilibrium value of dissolved oxygen in water under normal conditions is 8 – 9 mg/l, its content in water for production of ultrafiltration polymeric membranes by wet method must be lowered down to the level of below 1 mg/l.

The system of degasation of demineralized water allows to de-aerate it and regulate its temperature.

Using the new UF substrate a process of inter-phase polycondensation was developed ensuring the required structure of the selective layer and required flow rate.

As a result of the works performed new generation membranes were created with increased properties of rejection, which have more stable values at high temperatures.

Currently our company manufactures spiral wound elements fully corresponding to the best foreign analogues for seawater desalination and those used in reverse osmosis plants in water treatment at power engineering.

Keywords: Spiral wound filtering elements, Desalination, Seawater, Brackish water, Reverse osmosis, Reverse osmosis membranes

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Experimental study on the performance of modified double slope solar still

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Abstract: Productivity of distilled water from conventional solar stilled is very limited. Improvement of the conventional solar still is essential to increase its productivity. This study focuses on an experimental work to improve the productivity of the conventional solar still. This was done by using three improvement methods namely, increase in the condensation surface, integrated with the collector/storage solar water heater and reflective panels, and integrated with fins at the basin plate. For this purpose, two solar stills models were fabricated and these were conventional solar still and the modified solar still. The models were tested during the period from February to July 2017 under different weather conditions in Baghdad city, Iraq (latitude of 33.33 and longitude of 44.43). The results show that the productivity was increase by 48%, 35% and 43% when the methods of increase in the condensation surface, integrated with collector/storage and reflective panels, and integrated with fins at the basin plate were used respectively.

Keywords: Distilled water productivity; solar still; new design

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Superhydrophobic co-axial electrospun nanofiber membranes for the treatment of seawater desalination by membrane distillation

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Membrane distillation (MD) is a thermally-driven membrane separation process. Currently, the membranes used for MD studies are usually microfiltration (MF) membranes. However, MF membranes are not ideally designed for MD process. Thus, there is a need to design new membranes with structures fit for MD. Electrospinning is one of the alternative techniques to fabricate MD membrane. Electrospun nanofiber membranes (ENMs) have several advantages such as high surface area, high hydrophobicity and porosity, and controllable pore size and membrane thickness. However, despite these advantages, the ENMs still suffer from wetting problems. Co-axial electrospinning technique is one of the electrospinning approaches to fabricate suitable membranes for MD with improved wetting resistance. Co-axial electrospinning utilizes dual tube nozzles, one central tube situated in the center of the annular tube. Two different polymer solutions, one composes the core, and the

other one composes the sheath, are separately injected into the co-axial nozzle, and when voltage is applied, they are ejected simultaneously to produce coaxially-layered ENMs. In the present study, we aim to investigate PVDF-co-HFP (PH) as core and PH/silica aerogel (SiA) as sheath for co-axial composite ENMs to obtain superhydrophobic property on the membrane surface.

Results of surface characterization showed that the active layer (i.e., PH) of all co-axial ENMs exhibited a rough, highly porous (>80%), and superhydrophobic surface (CA>160°). Co-axial ENMs possess small pore sizes (<0.39 μm) and suitable liquid entry pressure (>1.72 bar). Upon application in direct contact MD (DCMD) test (feed: 60.0°C; permeate: 20.0°C) for 72 h operation using 3.5wt% NaCl solution as feed, a high water vapor flux and salt rejection of 12.1 L/m^{2}h and 100% were achieved, respectively, when optimal SiA loading of 0.4 wt% solution was applied at the sheath (compared to 10.2 L/m^{2}h and 96.67% for single-nozzle PH ENM). The present ENMs containing SiA by versatile co-axial electrospinning fabrication shows great potential for DCMD desalination application.

Keywords: Membrane distillation, Seawater desalination, Membrane fabrication, Electrospinning, Co-axial electrospun nanofiber membrane

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Study on the fouling crystallization characteristics of hypersaline seawater

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Taking concentrated seawater as the research object, the deposition of the fouling on the metallic surface and the bottom of the container are studied by static deposition method. These are compared with the deposited fouling on the metallic surface under the flowing state. The results demonstrate that the fouling is mainly $Mg(OH)_2$ on the metallic surface under different working conditions. Under the condition of liquid flow, magnesium hydroxide crystals are thin flaky due to the shear action. The morphologies of magnesium hydroxide crystals are different under different working conditions. The higher temperature is, the easier producing the petal-like crystals of agglomerates for magnesium hydroxide is. Under the condition of static deposition, when pH value is 8.0, the temperature is 80°C, the salinity increases to 100 (g.kg^{-1}), the magnesium hydroxide crystals play the role of crystal seeds on the metallic surface. The quantity of precipitation is reduced with the increase of salinity; when the temperature is 90°C, the salinity is 100 (g.kg^{-1}), the surface fouling of titanium tube is the least. When the salinity increases to 120 (g.kg^{-1}), the supersaturation of magnesium hydroxide crystals is large and the large amount precipitate attaches to the surface of titanium tube which increases the fouling adhesion amount. Calcium sulfate crystals are precipitated by secondary nucleation and suspended in solution. Eventually most of calcium sulfate crystals deposit at the bottom of the container.

Keywords: Magnesium hydroxide, Calcium sulfate, Crystal seed, Hypersaline seawater, Fouling

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Use of marble and iron waste additives for enhancing structure and water filtering capacity of salty clay ceramics

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The paper elaborates manufacture and performance analysis of new clay ceramic water filtration materials. The clay ceramic is manufactured from salty clay and sawdust mix. Waste marble powder and machined iron fines are used as additives to the mix for manufacturing the new modified materials. Equal volume of salty clay and sawdust were used to manufacture the control clay ceramic (CC). Another ceramic, M-CC, was manufactured with distinct volume fractions of salty clay, sawdust and marble (40:40:10). Third ceramic, F-CC, was manufactured from equal volume of clay and sawdust and five percent by volume of iron fines.

F-CC showcased better arsenic (As (V)) contaminant removal from water at acidic pH while M-CC showcased best As(V) removal around pH of 8. Average flexural strength of M-CC ceramics was comparatively better than F-CC and CC ceramics. The modified materials showcased similar percolation rates at par with control CC ceramics. M-CC ceramic showcased comparatively better E.Coli removal capabilities than F-CC and CC ceramics. Only limited volumetric addition of marble powder and iron fines were found to positively affect compressive strength. The results demonstrate new low cost ways of modifying strength and specific water treatment characteristics of clay ceramics using waste materials from local marble processing and iron machining industries.

Keywords: Ceramic, Salty, Marble, Iron, E. Coli, Arsenic, Strength, Waste

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Preparation and characterization of polyvinylidene fluoride (PVDF) polymer/chitosan polymer membrane for water applications

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The present study deals with the preparation of novel nanofibers (NFs) from Thermoplastic polymers such as (Polyvinylidene fluoride (PVDF), coated by Chitosan (CH) to improve major membrane properties such as: hydrophilicity, surface roughness, Increase the water flux and (Salt) rejection.

Supporting layer is produced from thermoplastics using electrospinning then coated by chitosan using either electrospinning or immersion method. The Literature for methods of production of NFs from various of thermoplastics via electrospinning and from chitosan via electrospinning have

been thoroughly surveyed. In this study, NFs we produced for the first time using phase inversion a thermoplastic layer (PVDF) then make the second layer (coating) from chitosan via electrospinning and immersion method. Produced two type of membrane with different method for coating we characterized and tested for physical and chemical performance with Scanning Electron Microscopy (SEM), tensile machine test (tensile strength), permeation Tests (water flux and salt/pollutant rejection), contact angle meter (CA) to determine hydrophobicity. We found optimum membrane produced by phase inversion for support (PVDF) and coating chitosan by electrospinng method with The salt rejection of the membrane up to 70% for $MgSO_4$ and contact angle (52°).

Keywords: Membrane, Desalination, Water treatment, Nanofiltration

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Arabian Gulf seawater desalination using forward osmosis membrane technology and polyelectrolyte draw solution: a pilot scale study

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The current study assesses and validates the technical feasibility of using forward osmosis (FO) technology for desalinating Arabian Gulf seawater (AGS) on a pilot scale level using commercially available hollow fiber (HF) membrane. The main objective of this paper is to explore the feasibility of using thermo-responsive polyelectrolytes as draw solution in FO pilot system. The FO pilot plant test unit with a capacity of 10 m^3/d was constructed by Trevi Systems Inc., USA for desalinating AGS and was successfully installed and operated at Desalination Research Plant of Kuwait Institute for Scientific Research. The FO pilot plant consists of an integrated thermal and membrane separation system utilizing a coalescer and Nanofiltration (NF) membrane processes as draw solution recovery components. The pilot plant consisted of four stages: (1) pre-treatment system (2) osmotically driven transport of water molecules across a hollow fiber membrane resulting in concentration of feed and dilution of the polymer draw solution, (3) regeneration of polymer draw solution using a coalescer, and (4) NF post treatment system. A single element of commercially available HF FO membrane with bore diameter of 230 µm developed by TOYOBO was used in this study. The polymer draw solution used was ethylene oxide-propylene oxide copolymer. The feed used was AGS obtained directly from the beach well. The continuous operation of the FO pilot plant over a longer time at stable operating conditions using a single hollow fiber FO membrane element was able to produce product water with total dissolved solids of 180 ppm at water recovery of 30%. Simulation studies were performed to analyze the distribution of feed and polyelectrolyte draw solution throughout the membrane module and its effect on membrane performance. The osmotic pressure distribution of polyelectrolyte DS at different sections of the HF module was greatly influenced by DS flow rate. The study revealed that the DS had great potential to generate the high osmotic pressure ($\Delta\pi$) difference at the various compartments of the HF module. Consequently, the high $\Delta\pi$, which is considered as driving force of the FO process, resulted in high water flux of the HF membrane over long run experiments. Overall, this study provided encouraging results for

the investigated polyelectrolyte DS in terms of flux, rejection, long term stability, and high water recovery.

Keywords: Forward Osmosis, Thermo-responsive polyelectrolytes, Hollow fiber membrane, Bore diameter, Water recovery.

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A pilot scale study on reverse osmosis brine concentration using falling film crystallisation process

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This paper is aimed at evaluating and validating the technical feasibility of falling film crystallisation technology developed by Sulzer as a pre-concentration system for concentrating reverse osmosis brine. Several parameters influencing the separation performance of crystallisation and sweating processes, including cooling and heating rates, were investigated in a pilot plant operating in batch mode. The Sulzer falling film crystalliser differs from conventional falling film crystallisers in that it distributes the flowing melt and heat transfer medium (HTM) evenly as a falling film over the inside and outside surfaces of the tubes, respectively. This means that neither the shell side nor the inside of the tubes is filled with HTM or melt. This technique enhances the refrigeration method by maintaining a constant temperature distribution along the length of the inside and outside surfaces of crystallizers, leading eventually to obtaining a more homogeneous thicknesses of ice. The operation of the Sulzer falling film crystallisation plant included six successive processes, namely: filling, pre-cooling, nucleation, crystallisation, partial melting (sweating), and melting. These processes were applied in a non-adiabatic environment and operated under atmospheric pressure. The experimental results showed that the crystallisation experiments using feed stage (without the sweating process) and at operating end-point HTM temperatures of -6°C achieved salt rejection ratio and water recovery ratios of 56.6 and 49.8%, respectively, whereas at end-point HTM temperatures of -24°C the salt rejection ratio and water recovery ratios were 24.5 and 84.6%, respectively The multi-stage process experiments using feed and rectification stages (without sweating process) achieved salt rejection and product water recovery ratios of 46.89% and 64.24%, respectively. By using multi-stage process including feed, rectification and stripping stages (with sweating process), the salt rejection and product water recovery ratios reached 70.68 and 50.15%, respectively. In general, the experimental results showed that feed concentration, crystallisation temperature, cooling and sweating rate, and average growth rate, had a significant influence on the separation performance of the treatment system.

The experimental results showed that the falling film crystallisation technology, using a single freezing stage and without the sweating process, would be an ideal treatment system for concentrating RO brine and to produce saline water to near seawater quality that can be used directly as feed water for a RO plant. A scale-up of this pre-treatment process was performed based on the results obtained. The study proved that the investigated falling film Crystallisation process can

be *considered as a great solution* available *for brine concentration and as an alternative for reducing the environmental impact of the large volume of waste stream from inland desalination plants.*

Keywords: Freezing desalination technologies, Falling film crystallisation, Melt crystallisation, Brine concentration, Freeze-melting process

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Impact of the geometric parameters on the thermal performance of a large-scale falling film evaporator for desalination

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Based on a validated distributed parameter model, the thermal performance of a large-scale falling film evaporator were simulated under different geometric parameters including the tube length and the row-column ratio of the tube bundle. The distributions of the local heat transfer coefficient were exhibited and the average heat transfer coefficient was analyzed under different geometric parameters. On consideration that the falling film evaporators applied in the multi-effect evaporation are operated under small temperature difference and sensitive to the temperature variation inside the evaporator, the variation range of the seawater temperature is presented. Results show that the average heat transfer coefficient exhibits an increasing trend with the increment of the total tube length while a decreasing trend with the increment of the row-column ratio. The maximum variation range of the seawater temperature decreases with the increment of the total tube length. However, it shows a decreasing trend followed by an increasing trend with increment of row-column ratio and its minimum value is found when row-column ratio is between 2.5 and 3.0.

Keywords: Falling film evaporator, Horizontal tube bundle, Distributed parameter model, Geometric parameters, Thermal performance

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Technoeconomic analysis of advanced multi-effect distillation technology for seawater desalination plants: novel evaporator design

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alination including multi-stage flash (MSF) and multi-effect distillation (MED) desalination plants are dominantly used in the GCC countries and especially in Qatar due to their maturity and reliability in dealing with the harsh seawater conditions of high (TDS, Seawater feed

temperature, SDI, and HAB). Realizing the benefits and challenges of thermal desalination, the authors identified a room of improvement to reduce energy consumption. Qatar Environment and Energy Research Institute (QEERI) and Qatar Electricity and Water Corporation (QEWC) took initiative to improve the performance of thermal desalination plants in Qatar through building pilot plants for developing field demonstration of novel ideas.

This work presents a techno-economic analysis of an improved MED design based patented idea GCC2016-31325 patent [1]. The new design creates a vapor route to avoid shear losses, frictions, and breakdown of film liquid around the tubes (dry zones) which will reduce brine carry over. A prototype model of the novel design is based on both process and CFD simulation. A process Visual Simulation Program (VSP) is used to perform process design and comparison between commercial MED desalination plant (63 MIGD, Rass Laffan, Qatar) and proposed novel design. The capital cost of the desalination plant is calculated using recent bidding of commercial desalination projects and the updated market material price. 3D-CFD simulation is performed to visualize the vapor uniformity within the tube bundle and determine the thermal losses encountered in the vapor route.

Thermal losses analysis shows that the bundle losses present almost 90% of the total losses which totally excluded by the novel design. Process simulation shows that the calculated heat transfer area of the novel evaporator is 20% lower than of existing evaporator due to thermal losses reduction. Furthermore, removal of demister in novel MED evaporator decreases evaporator width by 65%. Therefore, the footprint of the novel evaporator is 70% lower than the conventional design. The novel evaporator capital cost is 30% less than that of the conventional evaporator due to a significant reduction of the evaporator width and vapor box.

The 3D-CFD simulation of the vapor route inside the evaporator at different process recovery ratio shows that the novel design is superior to the conventional design in creating a uniform vapor velocity at the entrance of the tube bundle. This uniform vapor approach assures a uniform heat flux over the whole tube bundle to avoid overheating or scale deposition grown up. Moreover, the novel design minimized the thermal losses encountered in the vapor route. The possibility of entrainment is also significantly would be reduced due to avoid intersection between the vapor route and the seawater falling film.

Keywords: Thermal desalination, MED, Simulation, Techno-economics

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Long-term operating data of a full-scale SWRO desalination plant. Performance analysis

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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 (Toray™ SU820) 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

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Water production by RO for the manufacture of paint 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 feedwater 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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Forward osmosis for wastewater treatment and energy recovery: a techno-economic analysis

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A novel wastewater treatment system was investigated using forward osmosis membranes to treat municipal wastewater. Treatment by forward osmosis was determined to cost $10 million per million gallons per day (MGD) of wastewater capacity over a 20- year lifetime, with an energy consumption of 870 kWh per million gallons. A case study at the Arcata Wastewater Treatment Plant was conducted to investigate a treatment system that combines energy recovery from algae biomass with forward osmosis membrane treatment using local seawater as a draw solution. Total system cost was calculated to be $29.7 million over a 20-year lifetime with a 2.3 MGD capacity. Energy recovery was found to offset the parasitic energy requirements of the system and produce an excess of 1,200 MWh annually. This research demonstrates a proof-of-concept study on the techno-economic feasibility of forward osmosis membranes to (1) treat municipal wastewater and (2) concentrate wastewater for energy recovery via anaerobic digestion of algae biomass.

Keywords: Forward osmosis, Wastewater treatment, Algae, Biomass

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Sustainability of water resources management in Gaza Strip, Palestine

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At present, the ground water in the Gaza Strip is the only source of water for its rapidly growing population, which is currently around two million, yet is unsuitable for drinking by any international standard, owing to high levels of salinity and nitrate pollution. The supply of good quality drinking water is vital for the future of the Gaza Strip and stability in the Middle East. Lack of adequate water in the Gaza Strip might hinder future peace negotiations and development policy in the region. This paper presents possible management solution to ameliorate the water quality and quantity crisis depriving residents of drinkable water in the Gaza Strip.

Keywords: Water demand, Resources, Management, Desalination, Water supply

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An experimental study on performance and quality aspects of solar domestic wastewater distillation for reuse and resource conservation

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Water is essential for all livelihood applications of mankind and animals. Reduced rainfall and continuous pollution of limited fresh water reserves by industrial and domestic wastewaters has caused increased water stress in developing countries. Strict regulations are available for safe disposal of wastewater from industries into water bodies. On the other hand, most of the domestic wastewater generated from households is dumped into water bodies without any treatment. Moreover, available biological treatment units are not so effective in treating wastewater in a single step. In case of India, only 10.0% of generated domestic sewage is treated while remaining part is sold to farmers to carry out agriculture. Continuous usage of untreated wastewater causes infertility of soil and health risks for humans. In order to tackle this problem suitable alternate effective and cheap technology suitable for energy and water scarce locations of developing countries is necessary. Solar energy can be used for treating wastewater as it is abundantly available in water scarce zones of the globe.

In this work, suitability of solar distillation unit for domestic wastewater treatment has been studied experimentally and reported. Experiments are conducted under the climatic conditions of Chennai (13.08° N, 80.27° E) in wick solar still of aperture area 1.18 m^2 with sewage water from Indian Institute of Technology Madras (IITM) campus as feed. Feed water and treated water quality analysis are carried out as per American Public Health Association (APHA) standards. Experimental days are sunny with intermittent cloud passage and experiments are conducted from 7:00 am to 18:00 pm each day.

Sewage water used for experiment contains tiny suspended particles and the adopted filtration process is not so effective in removing the tiny suspended particles. Cumulative solar radiation is found to vary between 16.3 to 21.3 MJ/m2-d during the experimental days. Average temperatures of the components of solar still are found to be higher for days with high solar intensity. Air- vapor mixture temperature is found be lower than wetted wick temperature. Maximum treated water production of 4.5 L/d at an energy efficiency of 45.2% is observed during the experimental day with 19.9 MJ/m^2-d cumulative solar intensity. Clogging of wick by tiny suspended particles of sewage water is observed and it also affects the performance of the unit. Quality of treated water obtained by solar distillation is superior to the safe disposal standards proposed by Central Pollution Control Board of India (CPCB). Biological oxygen demand (BOD), chemical oxygen demand (COD), Total organic carbon (TOC) removal efficiency by the unit is around 98.0, 95.8 and 97.3%, respectively. Total coliform and fecal coliform removal efficiency is around 99.9 and 100.0%, respectively. Expect BOD and COD all other quality parameters of treated water are well within the standards for safe drinking water proposed by World Health Organization (WHO). Solar distillation unit is capable of

providing clear, odor and bacterial free treated water in a single step with high removal efficiency. Hence, solar distillation is confirmed to be an effective option for treating sewage water in remote, rural regions of developing countries. Clogging problem can be avoided by incorporating partition basins instead of wicks.

Keywords: Sewage water; Solar energy; Distillation; Performance; Quality analysis; Reuse

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Commercial reality of pressure-assisted forward osmosis (PAFO) - reverse osmosis (RO) hybrid process: economics and applications

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Practical applicability of forward osmosis and reverse osmosis (FO-RO) hybrid process has been widely studied yet there are unknown hurdles in implementing FO membrane elements in the field. It has been reported that the FO element performance (i.e. water flux and draw stream dilution) is strongly dependent on hydraulic pressure. As such, the presence of hydraulic pressure is inevitable when operating the FO elements and this becomes a critical economic aspect for the commercial reality of the hybrid process. Due to the improved dilution of draw streams, employing pressure-assisted forward osmosis (PAFO) to the hybrid desalination system to replace FO in this scheme has been expected to reduce the overall economics. However, replacing FO with PAFO causes an additional energy cost in the seawater dilution step which inevitably leads to a question that PAFO-RO hybrid is truly an economically beneficial option. More importantly, though serial connection of FO elements improves the dilution of initial draw water, this economic benefit is also compensated with the additional membrane. To rationalize its overall performance and economic benefit, thorough performance and economic evaluations were conducted based on actual pilot-scale PAFO operations for serial connection of up to three 8040 FO elements. The results showed the FO-RO hybrid is not an economically feasible option unless a significant unit FO element cost cut-down is guaranteed. Meanwhile, PAFO-RO showed benefits with regards to target RO recovery and unit FO element cost, particularly when two FO elements are serially connected. It was found that PAFO-RO, indeed, has higher economic potential than FO-RO. Considering the major hurdle in real life that utilizing the final product as potable water is not plausible due to an aesthetic reluctance, the PAFO-RO hybrid process can be a practically feasible tool for producing product water for agriculture and industrial uses in the current stage.

Keywords: Hybrid process, Pressure-assisted forward osmosis, Reverse osmosis, Water reuse, Desalination, Pilot, Economics

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Biofouling control by membrane and feed spacer surface modifications

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The influence of polydopamine- and polydopamine-graft-poly(ethylene glycol)-coated feed spacers and membranes, and commercially-available biostatic feed spacers on biofouling has been studied in membrane fouling simulators. Feed spacers and membranes applied in practical membrane filtration systems were used; biofouling development was monitored by feed channel pressure drop increase and biomass accumulation. Polydopamine and polydopamine-g-PEG are hydrophilic surface modification agents expected to resist protein and bacterial adhesion, while copper feed spacer coatings and biocides infused in feed spacers are expected to restrict biological growth. Our studies showed that polydopamine and polydopamine-g-PEG coatings on feed spacers and membranes, copper coatings on feed spacers, and a commercial biostatic feed spacer did not have a significant impact on feed channel pressure drop increase and biofilm accumulation as measured by ATP and TOC content. The studied spacer and membrane modifications were not effective for biofouling control; it is doubtful that feed spacer and membrane modification, in general, may be effective for biofouling control regardless of the type of applied coating.

Keywords: Ultrafiltration (UF); Nanofiltration (NF); Reverse osmosis (RO); Membrane fouling simulator (MFS); Adenosine tri phosphate (TOC); Total organic carbon

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Health risks with drinking desalinated water

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Numerous publications from the 1950's until 2005, and some later than that, clearly show that intake of hard water, with optimum mineral levels is protective against diseases, especially cardiovascular diseases, osteoporosis, diabetes, decreased cognitive function in elderly, low birth weight, and even some forms of cancer. Such water is in general ground water from areas with readily weathered bedrock like e.g. limestone and shales.

Minerals are more readily absorbed from drinking water than from food, since they are in ionic form.

Presently, hundreds of millions of people around the world are provided with de-mineralized water as their tap water or bottled water. Thus, there are more than 21000 desalination plants in the world, providing more than 350 million people with their drinking water in 150 countries, especially in coastal areas, and more and more bottled water is produced from RO treated water. RO water is comparable to distilled water or rain water. Even pH-adjusted or re-mineralized RO water is poor in minerals.

Reduced mineral intake, due to drinking de-mineralized water, is not automatically corrected by one's diet. "Water intoxication", or delirium, may occur following intense physical efforts, like a marathon or working hard, and ingestion of several litres of low-mineral water. The cause is low electrolyte levels, Na and K. Early symptoms include tiredness, weakness, headache, brain oedema, convulsions, and in severe cases coma and finally death. Higher mortality in acute myocardial infarction patients was found in regions where the drinking water was desalinated water, attributed by reduced magnesium intake. Drinking low-mineral water in the long run will increase the risk of acidosis, acidified tissues, as indicated by decreasing pH in urine. Thus, metabolic acidosis was reported in infants whose drinks were prepared on distilled or low-mineral bottled water. There is an increased risk of cardiovascular diseases, osteoporoses, diabetes, and cancer etc., acidosis being one of cancer precursors. Food cooked in RO water loses up to 60% of Ca and Mg , Cu: 66%, Mn: 70% and Co: 86%. Minerals in the drinking water are also needed to prevent from corrosion and dissolution of pipe material, making the water unhealthy by toxic elements like e.g. lead (Pb) and uranium (U).

We are facing a worldwide experiment on humans and animals providing them with de-mineralized water. This has not been done before, since already as children we were taught not to drink rain water or distilled water. There is need for a discussion on how to re-mineralize RO water to a health bringing mineral level and balance. There are scientific studies to use to start with.

Keywords: De-mineralized water, Water minerals, Health, Acidosis, Electrolytes

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Development and analysis of a floating solar distillation device

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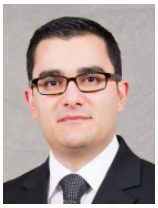

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The availability of safe drinking water is one of the most serious causes of health problems in the third world and in communities struck by natural disasters. Moreover, it is estimated that by 2025, two-thirds of the world's population (circa 5 billion people) would be living under water stressed conditions. With the existing climate change scenario, by 2030, half the world's population will be living in high water stress regions (75 million to 250 million people of which live in Africa and a number of island states in the region).

This paper presents the development of an inexpensive and simple floating solar distillation device which is being tested under natural weather conditions in Malta. The distillation performance of the prototype is correlated to the micro-climatic conditions which are monitored using an in-situ weather station.

Keywords: Solar distillation, Floating

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Development of a high-efficiency, pressure-resistant, and large-capacity cartridge filter module for low energy SWRO plant

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In order to protect reverse osmosis (RO) membrane, cartridge filter units are generally used to remove large particles and foulants existed in the outflow of pretreatment process. Removing these particles can prevent rapid fouling of RO membranes, which are the most important and expensive component in SWRO plant. Longer membrane life means reduced system cleaning and maintenance expenses as well as lower replacement costs over the life of the system.

In this study, the development of highly efficient cartridge filter for SWRO plant was demonstrated by improving the materials and inner structure of filter modules. In order to comprehensively understand better performance of cartridge filter module, several analytical methods including experimental and computer-based simulation methods were employed. Compared to other com-

mercial cartridge filters, improved performance (higher flowrate and low algae attachment with same membrane area) were measured. In addition, better water flow regime (much lower dead zone and equal distribution) inside cartridge filter module was also observed by CFD simulation. Through this study, a high-efficiency, pressure-resistant, and large-capacity cartridge filter module was developed and it could reduce EPC and O&M costs by preventing the fouling of RO membranes.

Keywords: Cartridge filter, Pressure-resistant, Large capacity, Low energy, Seawater reverse osmosis (SWRO)

Acknowledgement

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Membrane desalination of mine water

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Exploitation of coal is accompanied outflows of groundwater to the surface of the Earth, resulting in negative impacts on biocenosis of the rivers. High content of divalent ions causes membrane scaling which decreases membrane efficiency. Scaling may be controlled by the addition of antiscalants or application of nanofiltration (NF) before reverse osmosis (RO) in water desalination, which allow to obtain a concentrate with concentrations of salt, much bigger than for desalination only by RO.

The aim of the study is based onto assumption that introduction of NF to mine water desalination RO, will allow to obtain in the concentrate (brine) salt concentrations higher than in desalination only by RO, and in addition, this will allow obtaining desalinated water and concentrate in advance assuming content.

Research was carried out using natural mine waters coming from Desalination Plant „Dębieńsko" (southern Poland), characterized by relatively high levels of salinity and hardness. Samples of raw water were taken before RO instantiation, i.e. after standard pretreatment. Tests were conducted using the Osmonics Inc. Company's SEPA CF-HP type membrane module, in the high-pressure version in cross-flow mode and in some cases apparatus was used working in dead-end mode system. Commercial NF membranes produced by the Dow-Filmtec (NF-270 and NF-90) and RO membranes (BW30FR-400 and SW30-2521 from Dow-Filmtec, PA00416 HR from Lanxess and AD HR-90 from General Electric) were used in the test. The NF process was carried out at a

transmembrane pressure of 1.0 MPa and 1.5 MPa, and the RO process at a pressure of 2.0 - 3.0 MPa, depending on the system used (cross-flow or dead-end). Cross-flow velocity used in these measurements was 1 m/s and at temperature amounted to 23±2oC. A two-stage treatment system combining NF and RO for the desalination of mine water was used. At first, NF of the raw water was carried out and the permeate obtained was fed to the RO process. Both processes, NF and RO, were carried out to obtain 30-50% recovery of feed water. The desalination efficiency (flux and composition of permeate and concentrate) and toxicity of raw mine water and obtained streams were determined. For scaling phenomenon prognosis, the saturation indices for raw mine water (before NF), and permeate after the NF and before the RO, were calculated using the Phreeqc Interactive 3.3.3-10424 program (PHREEQCI) using the Wateq4f minerals database.

The experiments have shown that NF is an appropriate means for pre-treatment of mine water in the process of desalination with RO method. Such a solution increases the permeate flux of RO membranes, eliminating the scaling problem. That is why, that during the NF, the multivalent ions and to some extent sodium chloride removal occurs, and water going to RO process is characterized by much lower ionic strength than the raw water. The consequence is lower osmotic pressure and therefore we can apply lower transmembrane pressure, which leads to a reduction of the energy consumption and increase the degree of water recovery rate. Taking into account the results of the efficiency of the membrane and the prediction of scaling phenomenon, with two nanofiltration membranes (open NF-270 and compact NF-90), it was found that in the first stage of the desalination more compact nanofiltration membrane (NF-90 company Dow FilmTec) should be used. NF-90 membranes was characterized by high retention rates and lower performance compared to the membrane of the NF-270.

In the second stage of desalination, with the use of RO process, also two types of membrane were mused: for brackish and sea water desalination were used. In the first case (BW30FR-400 and PA00416 HR) received permeate has exceeded content of the sodium and chloride ions compared to the standards for drinking water. Taking into account the above results, for the desalination of mine water in a two-stage system, in the second case, a more compact RO membranes designed for desalination saline waters (sea) (SW30-2521-Dow-Filmtec and AD HR-90 General Electric) were used. The obtained permeate coming from integrated system corresponds to the standards of drinking water, and the resulting water is not toxic. It has been shown that in the second stage of desalination should be used the osmotic membranes for desalination of saline waters.

Analysis of the phenomenon of scaling phenomenon showed that there is a risk of precipitation on the NF membrane, first of all barium sulphate, but also $SrSO_4$ and $CaSO_4$, quartz and chalcedony.

Keywords: Mine water, Desalination, Integrated system, Nanofiltration, Reverse osmosis.

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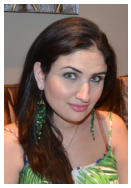
Effect of structural biofilm changes under different feed water substrate concentrations on RO performance parameters and cleanability



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Biofouling severely reduces operational performance of membrane systems increasing the cost of water production. Understanding the effect of critical feed water characteristics such as substrate concentration on the developed biofilm structure enables development of more effective biofouling control strategies.

In this study, the effect of different substrate concentrations on the developed biofilm structure was examined. A feed channel pressure drop (PD) increase of 200 mbar was used as a benchmark to stop the experiments (Fig. 1A). The amount and characteristics of the formed biofilm were analysed in relation to membrane performance indicators: feed channel pressure drop (Fig. 1A) and permeate flux (Fig. 1B). The effect of base/acid cleaning as applied in practice on the removal of the different biofilms was evaluated.

Results showed that higher substrate concentrations led to a higher accumulated biomass amount (Figs. 1C, D), a faster PD increase while a lower permeate flux decline (Fig. 1B) compared to the low substrate concentration that resulted in a lower accumulated biomass amount (Figs. 1C, D), a slower PD increase, and a higher permeate flux decline (Fig. 1B). The permeate flux decline was affected by the spatial location and the physical structure of the biofilm rather than the amount of the biofilm (Fig. 1E) where the biofilm at the lowest substrate concentration expanded more on the membrane leading to higher permeate flux decline (Fig. 1E). NaOH/HCL cleaning for the biofilm that developed at a low substrate concentration was less effective compared to the biofilm that developed at high substrate concentrations.

Effective biofilm removal rather than inactivation is essential to prevent a fast biofilm regrowth after cleaning. While substrate limitation is a generally excepted biofouling control strategy delaying biofouling occurrence, development of advanced cleaning methods to remove biofilms that form under substrate limited conditions is of paramount importance and should be based on the developed biofilm characteristics.

Keywords: Reverse osmosis performance; Extracellular polymeric substances (EPS); Chemical cleaning; Biofilm structure; Slowly growing biofilms.

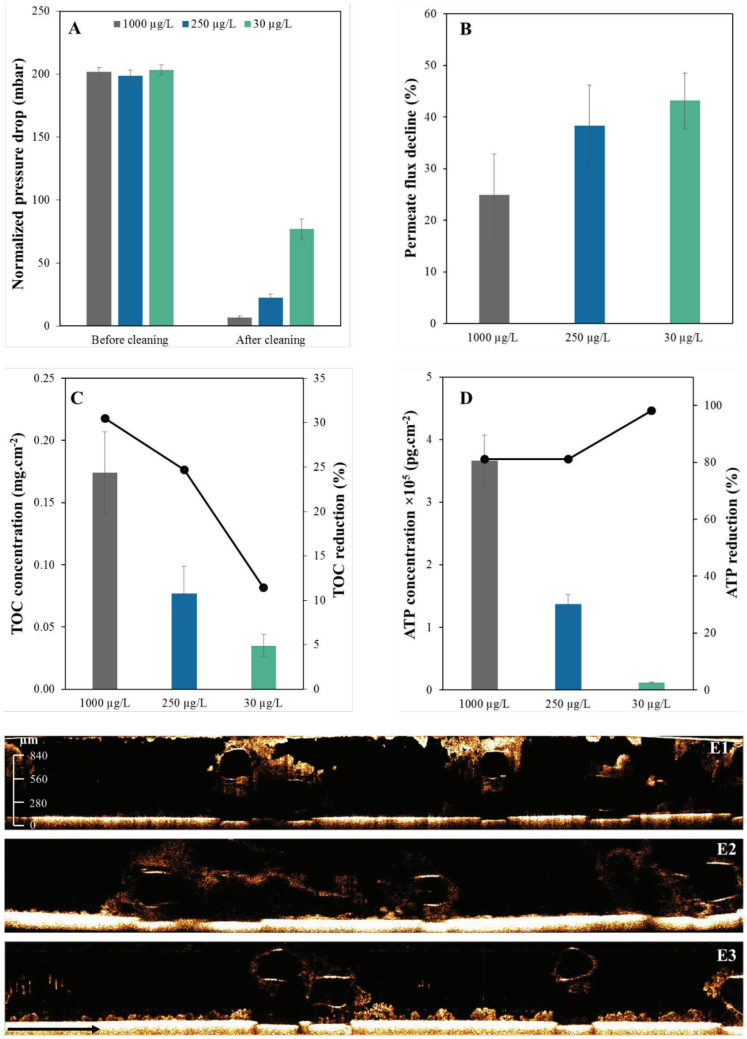

Fig. 1 – (A) Normalized pressure drop [mbar] at the end of the experiment once an increase of 200 mbar was reached and after cleaning with NaOH and HCL, (B) flux decline [%] at 200 mbar increase in normalized pressure drop, (C) Total organic carbon (TOC) (mg.cm^{-2}) and TOC reduction after cleaning, (D) Adenosine triphosphate (ATP) (pg.cm^{-2}) and ATP reduction after cleaning for the biofilms that developed at the different substrate concentrations once reaching a 200 mbar increase in normalized pressure drop. (E) 2D optical coherence tomography (OCT) images of the biofilms developing at different substrate concentrations (E1) 1000 µg-CL^{-1} (E2) 250 µg-CL^{-1} (E3) 30 µg-CL^{-1}.

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ZERO BRINE - Reusing resources from industrial wastewater

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Coordinated by TU Delft, ZERO BRINE advances circular economy business model solutions by re-designing the value chains of industrial wastewater. The objective of ZERO BRINE is to prove that minerals, such as magnesium, and clean water can be recuperated from industrial wastewater for reuse in other industries. The project aims to develop technological solutions and business models for wastewater/brine resource recovery, thus facilitating the implementation of the Circular Economy package and the SPIRE Roadmap.

The ZERO BRINE concept reduces industrial saline wastewater streams by recovering and reusing the minerals and water from the brine (saline impaired effluents) in other industries, thus 'closing the loop' and improving the environmental impacts of production. The project integrates innovative technologies to recover water and minerals of sufficient purity and quality for good market value.

ZERO BRINE includes 22 partners from research institutes, SMEs, process industries, and end-users from 10 countries. Over 4 years, ZERO BRINE is developing pilot plants in 4 process industries such as a demonstration water plant in the Netherlands, a coal mine in Poland, a silica factory in Spain, and a textile factory in Turkey. These provide massive potential to replicate and deploy circular economy solutions in the field of industrial wastewater treatment.

The presentation at the EDS conference "Desalination for the Environment: Clean Water and Energy" will give insights into the ZERO BRINE concept, its pilot projects, brine excellence centres around Europe and the Online Brine Platform.

Keywords: Circular economy, Desalination, Industrial wastewater, Water reuse

Measuring the bacterial growth potential of drinking water after reverse osmosis and remineralization

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Keywords: Bacterial growth potential (BGP); Reverse osmosis (RO); Remineralization; Flow cytometry (FCM).

Introduction

Limiting bacterial growth in public water supply systems can be achieved by: (i) addition of disinfectant residuals as practiced in many countries, which is associated with the formation of disinfection by-products (DBPs) and potential taste and odour complaints (Gopal et al., 2007; Hrudey, 2009), and/or (ii) improving water treatment to remove the bacterial growth-promoting nutrients such as assimilable organic carbon (AOC) and biodegradable dissolved organic carbon (BDOC) (van der Kooij *et al.*, 1982; Hu *et al.*, 1999). Reverse osmosis (RO) filtration is a promising technology to produce high quality water where AOC concentrations can be lowered to 10 µg-C/L or less (Park *et al.*, 2010). However, RO permeate needs reconditioning to meet the guidelines of drinking water quality including health, taste and chemical stability aspects (Withers, 2005; El Azhar et al., 2012).

Several methods are available to measure the bacterial growth potential (BGP) of drinking water by incubating batches of water samples at certain conditions and measuring bacterial abundance on different time intervals. Those methods are mainly developed for conventionally treated water (e.g., after sand filters and bio-filtration) and thus application of such methods for drinking water produced by RO and post-treatment might be challenging in terms of the methods sensitivity at lower BGP levels (i.e., the blank), where the existing blanks may be high. Moreover, there are a number of variations between those methods including mainly samples pre-treatment (pasteurization, filtration and none) and type of inoculum used (pure strains versus natural bacterial consortium).

The main objective of this study is to develop and apply the BGP method to assess the BGP of drinking water produced by reverse osmosis and post-treatment.

Material and methods

Treatment processes: This research is conducted at one of the water treatment plants in The Netherlands where anaerobic groundwater is treated by conventional means (3 Mm3/year) comprising aeration, rapid sand filtration, softening, granular activated carbon (GAC) filtration and UV disinfection. Moreover, the same groundwater is treated by a pilot-scale treatment unit comprising RO filtration, ion exchange, remineralization with calcite contactors and tower aeration.

Sampling: Finished drinking water of both treatment lines was collected (CTW and RO-TW, respectively) in AOC-free glassware (Hammes et al., 2005). In addition, RO permeate before post-

treatment was collected and remineralized (addition of calcium, magnesium, bicarbonate and CTW inoculum) at the laboratory to be used as a new blank for the method (RO-blank).

BGP method: Water samples were pasteurized (at 70°C) and inoculated (with natural bacteria of CTW) before distributing into 3 AOC-free glass vials. Thereafter, vials were incubated at 30°C in dark under static conditions. Total and intact cell counts were measured using flow cytometry (FCM, BD Accuri C6®) as described by Prest et al. (2014) for a total test period of 3 weeks. BGP is expressed as the maximum cell count obtained during incubation.

Results

A significant reduction in bacterial growth potential (BGP) of drinking water is achieved with reverse osmosis (RO) and post-treatment (RO-TW, 90k (±20) cells/mL) compared with the conventional processes (CTW, 650k (±70) cells/mL) where BGP is reduced by more than 6-fold. However, this low BGP level in RO-TW cannot be affirmed with the existing blanks used for this method which have BGP in excess of 100k cells/mL. Therefore, the new blank (RO-blank, 50k (±20) cells/mL) was used.

The lower BGP of RO-TW indicates a better quality compared with CTW where water quality analysis shows that dissolved organic carbon (DOC) and phosphorus dropped from >5 to <0.2 mg-C/L and from 11 to ≤1 µg-P/L, respectively.

A detailed study on the pilot-scale RO system showed that the remineralization of RO permeate by the traditional calcite contactors filled with fresh calcite grains has a significant impact of the BGP of the original RO permeate due to wash out of bacterial cells and organic nutrients during the first few hours of operation. This impact was clearly observed in the elevated dissolved organic carbon (DOC) concentrations in the instant samples collected after stating the operation with the fresh calcite grains, where 3.1 mg/L were detected in the effluent. The DOC dropped to > 0.3 mg/L (detection limit) after 3 h of filtration. The bacterial cell counts dropped as well from 300×10^3 to 20×10^3 intact cells/mL. As a result of that, BGP of the RO-TW was significantly high in the beginning of the operation at 500×10^3 intact cells/mL, which dropped 100×10^3 to with time.

As a conclusion, the developed BGP method can be applied to assess the BGP of ultra-low-nutrient drinking water such as RO-treated water. Moreover, operational conditions might negatively affect RO permeate, and thus, more precautions should be considered.

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Modelling thermal and geometric effects on non-condensable gas desorption in horizontal-tube bundles of falling film evaporation

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Non-condensable gas (NCG) produced in multi-effect distillation (MED) seriously deteriorates the heat transfer efficiency of falling film evaporation. Due to the complex coupled nature between NCG desorption and heat transfer process in falling film evaporation, little attention has been paid to local conditions of NCG desorption which contribute to improving geometrical design of MED. A mathematic model of CO_2 desorption in horizontal-tube bundles of falling film evaporation, which considers heat and mass transfer, flow dynamics and chemical reactions in seawater, was established. The numerical model predicted the local CO_2 desorption element size, carbonate concentration, evaporation rate and CO_2 desorption in seawater for varying thermal and geometric parameters. The predicted CO_2 desorption rates are in a good agreement with the running data of a reference MED desalination plant, which validates the accuracy of the developed model. An increasing evaporation temperature, which results in a decrease in chemical reaction time and element size, contributes to decreasing specific CO_2 desorption rate. With an increase in inlet heating steam velocity, the specific CO_2 desorption rate decreases due to the increasing element volume and decreasing specific evaporation rate. The effect of increasing tube pitch on the increasing CO_2 desorption rate decreases from the top tube to the bottom due to the opposite actions of increasing film flow rate and heat transfer coefficient. The specific CO_2 desorption rate increases with an increase in tube diameter which leads to decreasing heat transfer rate and increasing phase interface area of CO_2 desorption.

Keywords: CO_2 desorption, Element size, Thermal and geometric effects, Non-condensable gas, Falling film evaporation

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Ultrafiltration performance in seawater industrial cooling towers for biofouling control

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The demand for seawater as an alternative make-up water in cooling tower systems has rapidly increased over the past decades. In Saudi Arabia a huge amount of seawater is used in operation of cooling towers due to a lack of freshwater and groundwater resources. Seawater is mainly used as a cooling medium in heavy industries, oil refineries, petrochemical plants and thermal power stations and the most feasible (low-cost and unlimited).

Operating challenges such as scaling, corrosion, and biofouling hitherto plagues conventional cooling towers available and the latter is one of the major issues in seawater cooling towers. Nevertheless, biofouling is a serious problem in industrial cooling tower processes. It damages equipment through bio-corrosion, causes blockages, and increased energy consumption through decreased heat transfer. Seawater cooling towers have higher challenges because it is an open system as well as the concentration of nutrients (organic carbon, nitrate, nitrite, phosphates and etc.) due to evaporation where biofouling and bio-corrosion occurring within the fillers and piping of recirculation systems can greatly mitigate their performances.

The research strategy is focusing on the control of biofouling the in seawater cooling towers by using alternative approaches ultrafiltration membrane to prevent the growth of biofouling by removing the microorganisms. Ultrafiltration can remove the viruses and algae from seawater, that is particles larger than their largest pore size. Recently the use of ultrafiltration (UF) in the treatment of the drinking water becomes a more significant technology as an alternative to the conventional clarification. Also, the UF has been applied as a pretreatment in the reverse osmosis (RO) of fouling removal. This can be applying for the treatment of the seawater cooling tower process. The test results indicate that the ultrafiltration membrane achieved 95 % removal of the microorganisms in seawater feed were effective in keeping the microbial growth to the minimum.

Furthermore, hybrid system (UF/GAC) pretreatment was also applied to improve the ultrafiltration process performance by adding biofilter such as granular activated carbon (GAC) in the pretreatment process. GAC biofilter has a possibility of reducing biofouling potential in the pretreatment of seawater feed by removing AOC. The hybrid AC/UF process is very effective removing the organic matter from seawater and the UF can achieve a complete removal of microcystis aeruginosa cells. By adding the activated carbon to UF process treatment significantly improved the removal of DOC to 80% and 99% removal of microorganisms were achieved. The applications of the combination of AC and membrane filtration are a useful process for seawater cooling tower treatment. The measured results from this study enable designers of seawater cooling towers to manage the biofouling problems when such cooling towers are extrapolated to a pilot scale.

Keywords: Ultrafiltration; Microorganisms; Biofouling control; Seawater cooling towers

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CO_2 mineralization as a method for reducing the salinity of brine and the emission of CO_2 from seawater desalination

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Seawater desalination discharges highly saline brine into the ocean, which exerts detrimental effects on the marine lives such as sea grasses, planktonic algae and invertebrate larva by breaking the electrolyte balances between the cells and the environment. In addition seawater desalination emits large amount of CO_2 because this consumes large energy for the operation. Abundant amount of Ca and Mg in brine are useful for the reaction with CO_2, CO_2 mineralization, to reduce CO_2 emission. The purpose of this study was to show CO_2 mineralization as a method for reducing salinity of brine and CO_2 emission. We compared the efficiencies of CO_2 mineralization by the different CO_2 concentrations and bubble sizes. In addition, individual or co-existence of Ca and Mg in brine also was examined. $CaCO_3$ and $Mg_5(CO_3)_4(OH)_2 \cdot 4H_2O$ were successfully precipitated as the reaction products. Mineralization of Mg was responsive to the injection way of CO_2 than that of Ca. This study can help to reduce the emission of CO_2 and the salinity of brine from seawater desalination.

Keywords: Brine, CO_2 mineralization, Seawater desalination

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An innovative hollow fiber air gap membrane distillation (AGMD) process with internal heat recovery and reduced footprint

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Due to depletion of fossil fuels reserves and adverse environmental effects caused by the emission of greenhouse gases, the global trend is shifting towards developing more energy-efficient desalination technologies. In this regard, membrane distillation (MD) can be viewed as an attractive alternative to conventional seawater desalination processes like reverse osmosis and multi stage flush with respect to process performance and product quality. Moreover, an introduction of the air gap between the membrane and condensation surface allows to improve the thermal efficiency of the process due to decrease in heat conduction from the feed side to condensation side of membrane.

In our study, we developed and comprehensively exanimated an innovative air gap MD (AGMD) process which combined hollow fiber membranes and heat exchangers in a single module to achieve internal heat exchange and reduce process footprint. We further evaluated the effect of fiber type and packing density to attain an optimal module design with respect to two different feeds, Red Sea water and reverse osmosis brine. A higher efficiency of the AGMD was observed in the case

of capillary membranes as compared to tubular membranes due to reduced wall thickness which facilitated better thermal efficiency. At a feed temperature of 85°C, the vapor flux increased from 11 to 17 kg/m^{2}h with the increase in heat exchangers packing density from 9 to 28%, and then decreased to 13 kg/m^{2}h when packing density was increased to 36% due to condensing surface constrain inside the lumen.

The effect of operating conditions and temperature difference between the feed and coolant solutions on process performance was also investigated. The increase in the feed flow rate had significant effect on vapor flux comparing to that of coolant for all tested AGMD configurations. This effect was more pronounced at high feed temperatures comparing to low feed temperatures.

Keywords: Desalination, Seawater, Membrane distillation, Air gap, Capillary membrane

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Thermodynamic model for a reversible desalination cycle using weak polyelectrolyte hydrogels

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We propose a novel desalination scheme which employs the hydrogels as a tool to draw salt ions from a brine with low salinity to a brine with high salinity. As a driving force we use the fact that the volume of polyelectrolyte gel does depend on the surrounding salinity. While the salinity defines the gel volume in open system, i.e. in equilibrium with big bath, in closed system salinity is defined by the gel volume. The compression and swelling in open and closed system processes are combined into four stages thermodynamic cycle working between two bathes of different salinities. The cycle implies reversibility at any stage, so, in principle, the method can achieve the maximum thermodynamic efficiency. We have shown that for weak polyelectrolyte gels the dependence between the salinity and gel volume appears to be non-monotonic. Depending on the model parameters the surrounding salinity may increase or decrease during compression. In both cases we consider the possible use of this relation in desalination cycle.

Keywords: Forward osmosis, Polyelectrolyte hydrogels, Mean-field theory

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Forward osmosis with upper critical solution temperature-like inorganic salt as draw solute

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During the past decade, forward osmosis (FO) has attracted considerable attention and seen as an innovation membrane-based separation process for potential applications in various fields including saline desalination, water purification, power generation, food processing, and drug delivery. FO is an osmotic pressure driving process that water in the feed side would pass through the semi-permeable membrane to the draw solution side due to osmosis pressure gradient. One of the critical barriers for a sustainable FO in a full-scale application is the selection of an appropriate draw solute with high osmotic pressure, low salt leakage, easy regeneration of the diluted draw solution, minimal toxicity with economic feasibility and environmental friendliness. In this study, upper critical solution temperature-like (UCST-like) Na_2SO_4 was selected as draw solute with required criteria in FO. The experiments were performed for D. I. water and 0.6 M of NaCl as feed and $Na_2SO_{4(aq)}$ as draw solution. The results showed that the flux were 12.9 and 3.5 LMH, respectively. The diluted Na_2SO_4 solution could be separated into water-rich phase and Na_2SO_4 crystal-rich phase by decreasing temperature. For 0.6 M of NaCl as feed, the water-rich phase could be further concentrated and produce water by nanofiltration (NF) with operating pressure of 29 kg/cm^2. Moreover, FO with $Na_2SO_{4(aq)}$ as draw solution was also applied in RO reject (ROR) concentration evaluation for the purpose of near zero-liquid discharge. The results showed that the ROR from steel Industry could be concentrated with concentration ratio of ~5.5. Furthermore, the diluted Na_2SO_4 solution could be separated and recovery by temperature control and NF for long term operation.

Keywords: Forward osmosis; Upper critical solution temperature; Draw solute; Desalination; Concentration

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Isolation and identification of antiscalant degrading seawater microorganisms and investigation of their interactions within RO membrane systems

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Identification of microorganisms from environmental samples still rely on expensive and time-consuming molecular techniques. In this research, matrix-assisted laser desorption ionization – time of flight mass spectrometry (MALDI-TOF MS) technique was used as a rapid and cost-effective proteomic technique to identify various microorganisms from Qatar's seawater. These microorganisms were then investigated for their ability to biodegrade different antiscalants which are used to reduce membrane scaling in seawater reverse osmosis (SWRO). The objective of this research was to investigate the interaction between these antiscalants with sea water microbial community. Since, the biodegradation of these chemicals will reduce their efficiency to suppress membrane scaling, thereby, promoting microbial growth and biofouling in SWRO.

Total of seven samples from different locations across Qatar's marine environment were collected from both offshore and onshore areas. Using MALDI-TOF MS, the isolated strains were identified as *H. aquamarina, H. elongata, P. fragi, P. stutzeri, V. alginolyticus,* and others. These microorganisms were further differentiated through their protein profiles. Most of the isolated strains showed ability to grow in media supplied with acrylic acid, poly acrylic acid and maleic acid as the only carbon source. The microbial growth was monitored through optical density and plate count method and complete growth curve showing exponential phase, lag phase and death phase was obtained. This implies that the wide biodiversity of microorganisms possesses the ability to biodegrade these commonly used antiscalants in SWRO and as a result, the efficiency of these chemicals to reduce membrane scaling will be reduced.

To further investigate the effect of antiscalants on biofouling of SWRO membranes; Fourier transform infrared spectroscopy (FTIR) and other conventional microbiological techniques (colony forming unit measurements) were used. Results of FTIR (Fig. 1) showed that the biofilm on RO membrane was formed after the addition of antiscalants.

Thus, it can be concluded that the presence of microorganisms such as *H. aquamarina* isolated during this research and is commonly found in marine environment may biodegrade the antiscalants, thereby reducing their efficiency to minimize membrane scaling and increasing biofouling potential in SWRO. The results of this research have opened relatively a new area of research in which biodegradation characteristics of such commonly used chemicals in desalination industry needs to be studied and investigated before their application at industrial level. It is highly expected that the outcome of this research will help to fill several knowledge gaps and answer several research questions within the field of SWRO.

Keywords: Antiscalant, RO, Microorganisms, Biodegradation, FTIR

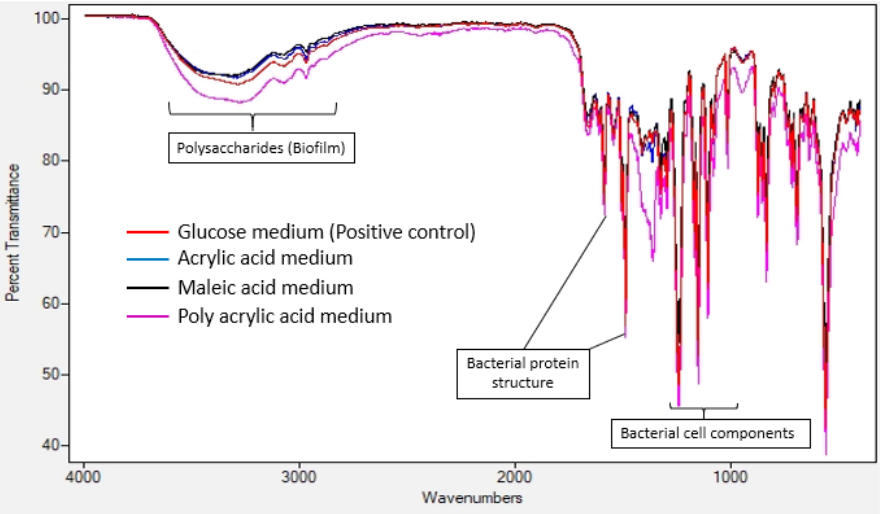

Fig. 1. FTIR spectra of Biofilm growth on RO membrane in the presence of antiscalants

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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, namely algal organic matter (AOM), bacterial organic matter (BOM), and humic organic matter (HOM). These organics are different in properties and chemical composition. Therefore, they were systematically studied to understand whether they behave differently or similarly in reference to organic fouling of ceramic ultrafiltration (UF) membranes. (AOM), (BOM) and (HOM) were compared in terms of fouling behavior, removal efficiency, and divalent impact. UF experiments have been conducted at constant flux mode using 5 kDa and 50 kDa ceramic membranes. Six filtration cycles were tested in duplicates, with a cycle consisting of thirty minutes operation followed by hydraulic backwashing for one minute. AOM and BOM were extracted from marine algae, Chaetoceros affins (CA) and marine bacteria, Pseudidiomarina atlantica (P. atlantica) respectively in the lab, while commonly used (Suwannee River) humic acid was used as HOM. These organics have been spiked separately into synthetic seawater feed with a total TOC of (0.5 mg/L). Results showed that more TEP/organics were removed by the 5 kDa membranes compared to the 50 kDa membrane, which is accounted for by lower MWCO. The UF 5 kDa membrane also showed low fouling formation than 50 kDa membrane for all of three types of organic matter tested. Analysis of the fouled membranes by SEM images 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. The SEM images also revealed that a cake layer is formed for all types of organics tested; the flux was stable over the filtration periods for AOM and BOM, most probably due to the high porosity of the cake layer. For 50 kDa membranes, AOM and BOM organics presented a similar fouling behavior and mechanism. However, AOM was quite higher compared to BOM concerning of TEP concentrations and gel-like formation; this is probably attributed to high polysaccharides concentration in AOM. For 5 kDa membranes, AOM and BOM showed thinner cake layer during all filtration cycles using 5 kDa membranes as TEP particles derived from AOM and BOM have evolved this process by making the cake layer more compact and compressible which in turns enhances the fouling resistance and reduce the porosity of the cake layer. HOM cake layer was thicker than those for AOM and BOM. This cake layer was found to be more porous and less compact, and 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. The divalent cations such as calcium revealed a strong influence on membrane fouling. In this experiment, the HOM particles were most likely influenced than AOM and BOM, which bridge/adsorb more organic molecules when interacting with calcium ions making the membrane less negatively charged and enhancing the membrane fouling. However, this fouling was less severe compared to AOM and BOM fouling.

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

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Recent developments in desalination technology in Saudi Arabian context

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One of the basic and benign needs of human being is the availability of clean safe and healthy drinking water. Desalination is a technique to produce safe and clean drinking water from the water available in the sea. The Kingdom of Saudi Arabia (KSA) adopts the desalination technique to produce drinking water for its society and is honored as the biggest manufacturer of desalinated drinking water in the world. Desalination of sea water caters to around 50% of the total requirement of drinking water in the Kingdom. Recent trend is towards utilization of renewable energy for desalination of sea water. In this article the recent developments in the field of desalination technology is summarized with special reference to solar energy for desalination.

Keywords: Desalination, Solar energy, Recent developments.

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3D printed triply periodic minimal surfaces as spacers for enhanced heat and mass transfer in membrane distillation

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Feed spacers are an indispensable part of membrane systems. They increase the turbulence of the flow along the surface of the membrane, which enhances the mass transfer. However, several studies have shown that biofouling originates at the feed spacer filaments. Pressure drop and energy costs are also significantly affected by the spacer design. Great improvements can be made to the performance of a membrane process by modification of the spacer geometry. 3D Printing allows the fabrication of spacers with novel, complex geometries.

Novel feed spacers were developed in this study using 3D printing technology based on triply periodic minimal surface (TPMS) architectures. TPMS are minimal surfaces with an interconnected, maze-like structure that are perfectly curved at every point, minimizing fouling and enhancing flux. 3D printing is utilized to create different feed channel spacer designs aimed at enhancing the spacer performance specifically for membrane distillation (MD) application. The novelty is the use of mathematically developed triply periodic minimal surface (TPMS) as feed spacers. Five different TPMS based spacer designs were evaluated and benchmarked against the conventionally used net type spacer (Fig. 1). The best performing TPMS spacer topology exhibited 60% higher water flux and 63% higher overall film heat transfer coefficient than the commercial spacer. The TPMS spacer designs also had a significant advantage over the commercial spacer when treating feed with high fouling potential such as brine solution. The advantages of TPMS spacers were the high throughput combined with sustained flux performance over increasing TDS concentrations ranging from 75,000 ppm to 100,000 ppm. The best performing TPMS spacer design was identified to have the highest surface area to volume ratio along with a design structure that caused relatively higher turbulence by disrupting the feed flow. Particle deposition tests were done using microspheres to visualize the impact of TPMS spacer design on dead zone formation. Pearson correlation coefficient showed that particle deposition is strongly correlated to the spacer voidage and its membrane contact area.

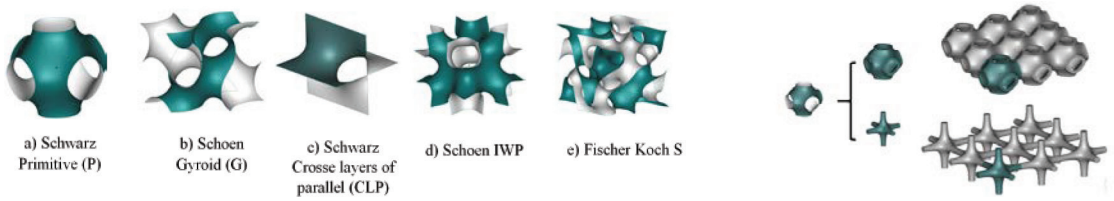

Fig. 1. a) Unit cells of TPMS types utilized in this study, b) spacer design from single TPMS unit cell

Keywords: Triply periodic minimal surfaces; 3D printing; Spacers; Membrane distillation; Fouling

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Improvement of a bio-inspired solar stills system for land regeneration in drylands

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Land degradation and water scarcity are global challenges compromising food security; they especially affect the livelihood of poor people who heavily depend on agriculture. Millions of them live in drylands. Bringing enough water in these areas, together with suitable land practices, could help regenerating the degraded soil and its productivity. The Mangrove Still is a bio-inspired solar still whose aim is to produce enough water at low cost to be used for soil regeneration projects and food production. In this paper improvements and variants of the design of the still are proposed which allow this technology to be highly adaptable to different contexts. Furthermore it is presented an initial pilot test for an integrated system â€“ called Mangrove Technology Platform â€“ which combines a saline water desalination system, organic incubators for seedlings and a customised IoT monitoring system. Emulating the capacity of Nature to address complex problems requires moving from individual solution to systems of solutions and cooperative multidisciplinary research and innovation is of utmost importance.

Keywords: Solar still, Desalination, Land regeneration, Decentralized processes, Biomimicry

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Experimental investigations of a solar operated HDH system with modified air heating layout

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Modified closed air open water solar air heated humidification and dehumidification (HDH) desalination system is designed, built and investigated experimentally. The effect of different water to air mass flowrate ratios (MR) of the HDH system in the performance is studied. A theoretical design procedure was followed for predicting the input heating energy, GOR, humidifier and dehumidifier areas and hence sizing the system. Then, the system is designed and constructed to produce fresh water through a modified (closed air -open water; CAOW) air heated HDH system as shown in Figure 1. In this layout, the air heater is placed in between the humidifier and the dehumidifier. Moreover, different setups of the modified solar air heated HDH system were built and tested in an outdoor (uncontrolled) climate.

Results show gained output ratio (GOR) increases with increasing inlet water temperature to humidifier, and with decreasing the inlet water temperature to dehumidifier system. However, it

decreases with increasing mass ratio greater than 1.2 (Optimum MR) and input solar energy. The high mass ratio of system is found to produce higher production rate while it is associated with higher energy consumption. The combined evacuated tube solar collectors are able to provide air up to 130°C in some cases for the HDH system while the maximum temperature of water inside system reaches almost 65°C.

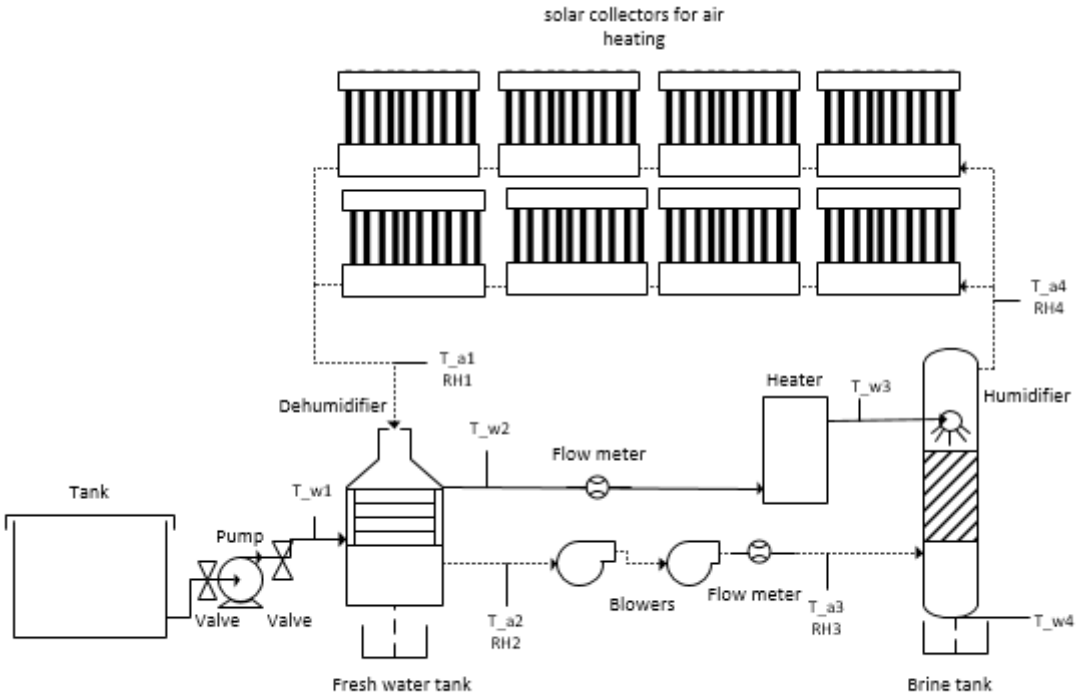

Fig. 1. Layout of the modified air heated HDH system

Keywords: Desalination, Solar energy, HDH system, Humidification, Dehumidification

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Numerical simulation of the convection and diffusion process of the discharge of hot concentrated brine in desalination

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Low temperature multi-effect distillation seawater desalination technology is used to produce high quality fresh water,however,it will produce hot concentrated brine at the same time.Whether the brine discharged into the sea will have an impact on the marine environment is urgent to study. In this paper, a numerical model is established by using the MIKE software to study the process of convection and diffusion,also heat and mass transfer process.The main research results are as follows:

1. The control equations of hydrodynamic,salinity and temperature convection and diffusion are established. Using the eddy viscosity model to describe the turbulent flow.The boundary conditions of the model and the numerical method of MIKE3 flow model are introduced.

2. The model of ideal flume is designed. The results show that the surface and vertical distribution of the salinity and temperature are periodically changed in a certain range. The distribution of them are very similar, indicating that convection plays a leading role. In the vertical direction, the salinity and temperature will increase synchronously with depth. But when the depth increases, velocity decreases.
3. A three-dimensional hydrodynamic model of the Liaodong Bay is established. The calculation of tidal level is compared with the measured data. The results show that they are in good agreement. The numerical simulation results could reflect the change of the tidal current in the Liaodong Bay. The model is suitable for study the process of convection and diffusion of the concentrated brine.
4. Then, the convection and diffusion law of concentrated brine is studied. The results show that the increase of salinity and temperature is mainly concentrated in the maximum range of 4.58 km from coastline, and most of the area in Liaodong Bay has not been affected. The surface distribution of salinity and temperature is greatly influenced by the tidal flow and periodically change with the flow. The surface distribution of temperature and salinity is very similar, indicating that convection plays a leading role. In the vertical direction, the salinity and temperature value of the same surface position will be increase along with the depth, and will accumulate at the bottom plane.

Keywords: Multiple effect desalination; MIKE3 flow model; Convection and diffusion; Temperature and salinity distribution

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Renewable energy for desalination process: efficiency and environmental impact in tropical island using numerical modeling

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Desalination is considered by many experts as the main solution to the lack of freshwater for small island developing states with low reserves of groundwater and high variability of their hydraulic system. Increase in the global population has urged for the need to find new, sustainable and high quality water resources.

Coastal areas of these islands offer a large surface of salt water that can be utilized. Climate change effects, such as increasing surface temperature and change in rainfall patterns will mean rainwater harvesting will be increasingly unpredictable and difficult method of obtaining freshwater. Therefore, desalination is seen as a feasible method of providing this.

Desalination still a high energy consumer, salt water reverse osmosis which is the higher pressure method requires a high amount of energy to run. Billions of liters of water are forced through the pressure treatments, consuming an average of 10-13 kWh per every 3.8 m^3. Small islands in most cases do not have sufficient fossil resources to provide conventional energy at a sufficient rate. However, tropical islands are well suited to use intermittent renewable energy sources such as solar, wind, geothermal or energy from waves.

A numerical combination of renewable energy sources implementing solar and wind energy sources is used to power desalination plant with energy necessary for operation. The type of plant modeled is a reverse osmosis plant due to its low need of energy and capital. For this paper, modeling of the dynamic hybrid system using a block diagram is carried out using the combination of efficiencies of a solar panel, wind turbine and desalination plant (reverse osmosis) to determine the overall efficiency of the system.

More than 15 years of data (i.e. water salinity, wind speed, solar irradiation, rainfall,...) obtained by direct or remote measure and simulation are used to model the system in real conditions. That allows to estimate the energy need, water cost and salt water discharge effect for smaller island of the Great Antilles.

The study shows that a cost of $US0.96m^3 - $US1/m^3 of fresh water is possible for a saltwater reverse osmosis (SWRO) desalination plant powering by hybrid renewable energy system applying adjustments in the management of the production.

Keywords: Desalination, SWRO, BWRO, Hybrid renewable energy system

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Performance assessment of membrane distillation (MD) configurations using computational fluid dynamics (CFD) modeling tools

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Several types of membrane distillation (MD) configurations exist today, which have common performance bottlenecks. These include low permeate flux compared to other membrane-based separation technologies, like RO, wetting and fouling issues, and unpredictable membrane lifespan under MD operation. While direct contact MD (DCMD) is considered among the simplest and most known MD configuration (along with air gap MD), varying its design parameters, such as the selection of module type (flat-sheet (FS) or hollow-fiber (HF)) can make a significant performance difference. Similarly, the performance of permeate gap MD (PGMD) strongly depends on the module design parameters. In order to address the insistent issues and enhance the deployment of MD technology, it is critical to understand the hydrodynamic reasons behind the performance of a particular MD design and develop suitable mitigation strategies for any problem that arise from the said design. In this regard, computational fluid dynamics (CFD) modeling provides extensive information including the local effects of boundary layer on fluid flow and its influence on the overall heat and mass transport of a specific MD configuration. In this work, three dimensional CFD models were developed for two case studies, and the models were validated for different MD configurations.

Then, a two-level full factorial analysis was performed for each case to design the simulation runs and examine the effect of selected parameters on process performances based on the responses collected from the designed CFD simulation runs.

In the first case, the performance of PGMD configuration, which is a promising hybrid version of DCMD and air-gap MD configurations, was investigated. The validated PGMD model was used to examine the effect of selected parameters on permeate flux and thermal efficiency. The selected parameters for the PGMD configuration were permeate gap conductivity (k_{gap}), permeate gap thickness (δ_{gap}), membrane distillation coefficient (B_m) and module length (L_{module}). In the second case study, the validated CFD models of FS and HF MD modules were used to compare their performances under DCMD operating conditions. Additionally, the importance of key operating parameters and their interactions on the FS and HF modules performance were inspected in terms of permeate flux and temperature polarization phenomena under the same hydrodynamic conditions. The selected operating parameters for the DCMD configuration were feed inlet temperature (T_f), permeate inlet temperature (T_p), Reynolds number on the feed side (Re_f) and Reynolds number on the permeate side (Re_p). The effect of each factor and interactions between the factors were evaluated for each membrane configuration/module, and the observed trends were discussed.

Keywords: Membrane distillation; PGMD, Computational fluid dynamics (CFD); Heat and mass transfer

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WRDC approach for MSF distillers inspection

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The Ministry of Electricity and Water (MEW) depends on seawater for the production of drinking water. The water produced by Multi Stages Flash (MSF) comprises 89% of the total desalinated water produced by MEW (463.1 million imperial gallons per day). The Ministry, conducts periodic preventive maintenance on distillers in order to maintain its continuous performance efficiently, ensuring the availability of distillation units and reducing the material and moral losses resulting from faults and sudden shutdown. Inspection is a major and vital phase of the maintenance series of the distillers. Besides inspecting the internal distillation condition and checking the validity of its structure and parts, it includes recommendations and instructions for maintenance works that will maintain the level of production and help to avoid the sudden trips. The inspection of distillers operating in MEW is one of the main functions of the Water Resources Development Center (WRDC). These inspections carried out by a team of specialized engineers. The engineers inspect and evaluate the distillation state prior to the maintenance work in the so-called initial inspection and after the annual maintenance work, known as the final inspection or in other cases during the evaluation of chemicals or methods of operation. The inspection process went through developments in terms of procedures, parts, characterization, evaluation and documentation, and increased frequency of inspection due to the expansion of the construction of distillers witnessed by the Ministry until the number of inspections for the purpose of periodic maintenance more than 100 inspections annually. These years of practice in the inspection of distillers have resulted in considerable experience and reliability in the capabilities of WRDC and have helped improve the inspecting

system. This paper presents the inspection approach followed by WRDC to inspect MSF distillers including prats, observations, sequences and evaluation.

Keywords: Multi-stage flash distillation, Maintenance, Inspection, Ministry of Electricity and Water, Kuwait

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Neutral pH cleaner to remove metal fouling from membranes

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Membrane fouling is one of the major challenges for an efficient operation of water treatment facilities, including sea water and brackish desalination plants, industrial plants and waste water reuse/tertiary facilities (1,2,3). Main consequence of fouling phenomena on membrane systems is an increase in operational costs, mainly related to increased energy demand, additional labor for maintenance, chemical cleaning and reductions in membrane life (4).

The different fouling types affecting membrane systems are well known (5): these include biological fouling, particulate/colloidal matter, inorganic fouling/scaling, and organic fouling,

Although fouling by metals could be included in inorganic fouling category, it is important to distinguish them so as to identify their source and because in some cases they may cause some additional effects on membrane surface.

Elemental metals such as iron and manganese are quite common in water and can oxidize from soluble to insoluble forms within a membrane and precipitate on the surface. In other cases, the presence of metals can be related to operational practices such as the use of iron and aluminum salts when used as coagulants to pretreat RO feed water. Both ferric chloride and alum are sometimes overdosed and can carry over to post-precipitate and foul a membrane as a suspended solid (6).

There are also water treatment plants involved in industrial and mining processes in which presence of metals in the feed source is very significant.

The presence of metals at the membranes surface is not only important when they are the main fouling component. Both RO and UF membranes commonly show presence of metals as secondary component of fouling and this secondary component is in many cases the cause of a poor cleanings by conventional techniques (7). Additionally, when metallic particles from corrosion deposits (usually iron) from feed system metallurgy reach the membranes where they can affect membrane integrity by abrasion.

Apart from the problems related to fouling, the ability of the transition metals such as iron, manganese, copper, zinc, etc. to change the valence states catalyzing and increasing the oxidation potential of oxidizing agents has been reported by several authors (8, 9).

For these reasons an in-depth study of how metals on membranes surface may affect plant performance is considered of importance.

Genesys Membrane Products S.L. (GMP) laboratory has a wide experience in the development of autopsies, from the study of more than 1200 membrane autopsies. These autopsies are the main tool to determinate the cause of a membrane failure, to identify fouling nature and source and to establish if there is any possibility to recover membrane performance. During these autopsies, most of the analyzed membranes (both RO and UF) showed the presence of metals in most cases and approximately 10% showed these metals as a main composition of the fouling mass. Although most common metals detected during autopsies are iron, aluminium and manganese, in some cases, and mainly depending on the previous process, other metals could be also detected.

In this study, data from the autopsies developed in GMP laboratory will be used to show how the presence of metals on membranes surface can affect their performance and integrity.

During this study, metals fouling removal by cleaning procedures is reviewed and discussed. These cleaning procedures will include data obtained from a new neutral pH organic chelant cleaner recently developed by Genesys International Ltd. with suitable characteristics for metals removal.

Keywords: Metals, Fouling, Cleaners, Autopsy

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Drinking water from brackish groundwater without disposal (zero discharge)

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Background of research project

New sites for winning clean fresh groundwater are not unlimited available in the eastern part of the Netherlands. Due to human influences, the quality of groundwater gets worse and pesticides, herbicides and medicines are present in shallow groundwater at more locations.

Brackish ground water, which is old and still free of anthropogenic influences, can offer a possible outcome. In this case, only salts have to be removed.

Boundary condition of Vitens for this application is that the solution must be able to be deployed location independent, so without discharge of waste streams. Thus, no energy and time is required for the long term request for authorization of concentrate discharge.

The research question

Which process line can produce drinking water from brackish ground water, so that only off residual products are released?

Techniques may be selected if proven on pilot scale (> 1 m^3/h).

Goals of the project

- Quality drinking water produced meets the guidelines for drinking water. Total hardness is allowed to be < 1 mmol/l;
- Residual substances must have market potential, preferably of the highest quality;
- Balancing criteria between the process lines are efficiency, durability, TRL (technology readiness level) and costs;
- At the end of 2018 the pilot program for a pilot study will be set up, objective is to compare different process lines with each other;
- Capacity of the drinking water flow will be approximately 250 m3/h.

Approach of the project

During the inventory phase (until September 2018) partners asked for ideas for complete process lines or parts of it.

The processing of the inventory and asking of questions of explanation to applicants will take place in the autumn of 2018.

The choice of process lines that will be evaluated during the pilot study will be carried out in Q4 2018. The scenarios will be elaborated into a detailed pilot program that includes a plan of approach for the pilot research that takes place in 2019.

The pilot plant research to compare different scenarios will start in the beginning of 2019.

Keywords: Brackish ground water, New water resources, Zero discharge, Resource recovery from concentrate

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Desalination and renewable energy in Brazil

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In recent years, Brazil has been facing water and energy crises with great regularity, due to the lack of rainfall and structural problems, even though Brazil has 12% of the world's freshwater volume. The Brazilian power supply is essentially made up of hydroelectric dams and the main problem

with this strategy is the vulnerability of the system in periods of atypical droughts, which may lead to power interruptions (blackouts) and to force public measures of energy saving (rationing). In 2001, for example, the country experienced the greatest crisis in its history in this sector, when the risk of blackout was combated through intense rationing of energy, with the objective of reducing household expenses by 20%. After this period, plans for expanding the electricity and water supply network were introduced, allowing for advances in this sector. However, some deficiencies in terms of investments and project implementation have undermined the effectiveness of energy and water policy in the country. According to data from the Brazilian Association of Investors in Self-Production of Energy - ABIAPE, in 2013, 40% of the planned energy volume did not come into circulation due to delays in transmission projects and in bidding processes. The energy demand grew by 11% and the water reservoirs in the country have experienced notable decreases in the total volume of water, reaching critical levels. These falls were mainly due to a lack of rainfall (with the worst rates since 1954) and a record increase in energy consumption. In the state of São Paulo, in 2014, the Cantareira System reservoir - responsible for water supply throughout the São Paulo Metropolitan Region - reached one of its lowest levels in history, comparable only to the rationing season of 2001. The Operator National System recommended a 5% reduction of energy consumption throughout the region. In the rest of the country - including the Northeastern region, which is experiencing significant droughts and dwindling water reserves - the situation is very similar with water supply problems and the risk of an energy crisis. This situation requires a reordering of the issue of energy production and water distribution in Brazil, with measures to streamline the execution of projects in the sector and to expand the supply of new sources of supply, such as the construction of water desalination plants and the expansion of other energy sources, such as the construction of wind farms. The objective of this work is to propose the construction of a desalination plant on the coast of the São Paulo state, in Brazil, to supply the Cantareira system, which is responsible for supplying half the population of the greater São Paulo city and some neighboring cities which corresponds to 8.8 million people. The study considers the location of the desalination plant in a city at sea level whose production will supply the Jaguari/Jacareí dams belonging to the Cantareira system, located at 700 m high. The pumping should be done by wind power units. The idea is to contribute to the establishment of public policies for the effective supply of water that is economically, socially and environmentally accessible in one of the most populous and important regions of Brazil.

Keywords: Desalination, Renewable energy, Water and energy crises, Public policies

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A global analysis of five years management of slurry with natural treatment systems for wastewater (NTSW) in Gran Canaria using a pilot plant

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The objective of this article is to describe the experience on management, behavior and organic waste removal capacity in a pig farm over a 5 years period. In this farm there is a pilot plant with a singular design of Natural Treatment Systems for Wastewater (NTSW) composed of: rotary sieve, first generation multi-chamber biodigestor, two constructed wetlands (CW) with subsurface flow and a facultative pond between both CWs.

The pilot plant has operated for 5 years (2009-2015), after the first year of commissioning (2008). This plant, located in the Island of Gran Canaria, has allowed to verify the suitability of the solutions applied to livestock waste, adaptability to variations in concentration (incoming batches), organic load, flow and atmospheric conditions. Data, was collected through 30 variables distributed between dry and wet periods, and significant correlations have been found between them.

In general, NTSW have stable and cyclic elimination percentages according to the time of year. Noteworthy is the significant elimination of the total COD (91.84% on average), soluble COD (96.11% on average), total suspended solids (TSS) and fixed solids (FS) (more than 90%) and other micro-elements such as copper, iron, manganese, zinc, (above 80% reduction) or the virtual exhaustion of total nitrogen (93.77%) or phosphorus (98.80%). The process is delivered with minimum energy consumption, located in the rotary sieve system, as all movement is performed by gravity.

The biodigester stands out for decreasing soluble COD. The particulated COD which was not eliminated in the biodigester, is converted in soluble COD in CW n°1. The CW n°2 is better in organic load removal than the CW n°1 because CW n°2 improves the yield with respect to CW due to good work done by facultative pond placed in between then. NTSW show outstanding capacity of COD removal (total, particulate and soluble) above 90% and conductivity 50%

Globally, the NTSW system exhibits a stationary behavior during the entire study period, even when the system intake is given in batches, thus showing that the integration and combination of different equipment allows NTSW to obtain a remarkable elimination performance and stability to load and variations of flow. NTSW can be considered an alternative solution to the management of waste in livestock farms with similar sizes.

Keywords: Natural systems, Anaerobic digester, Slurry management, Wastewater treatment, Constructed wetlands, Ponds, COD removal, Low-cost treatment, Organic load removal

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Colloidal fouling mitigation and energy saving potentials of pulsating flows in osmotic membrane processes

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Fouling control and mitigation are the major challenges of membrane processes. In particular the deposition of colloidal particles depends on a range of parameters including hydraulic conditions, membrane properties and properties of the particles themselves. In this study a strategy for fouling mitigation by applying pulsating flows is investigated. Dynamic flows generate high wall shear stress on the membrane, which prevents the build-up of a cake layer. This allows to treat highly polluted water, reduce pretreatment, lower maintenance costs, reduce necessary chemicals, and decrease brine disposal. The shear stress profile depends on several factors including frequency, amplitude ratio and volume flow rate.

The studies are based on experiments of colloidal fouling in forward osmosis (FO), which allows to conduct the experiments under pulsating flows at ambient pressure conditions. In addition to these technical advantages, colloidal fouling plays a crucial role in the treatment of wastewater and pharmaceutical processes including feed water with a high Total Organic Carbon (TOC) content, where FO is preferable to other membrane processes (Ansari et al. 2018, Ge et al. 2017). Although fouling tends to be reversible (Tow et al. 2018), it significantly reduces the flux during continuous operation and extensive cleaning is necessary. Therefore, this study focuses on the effect of pulsating feed flows on the build-up of colloidal cake layers. It investigates the influence of frequency, volume flow rate, and amplitude (Strouhal and Keulegan-Carpenter Number) on fouling mitigation as well as the energy saving potential. The findings concerning underlying mechanisms are expected to be transferable to RO. Studies show that the cake layer formation is not depending on the feed pressure (Tow et al. 2018).

The experimental setup consists of three main components: A flat sheet FO test cell, a rotating disk in the feed cycle that generates pulsating flows and a measurement instrument for dynamic volume flow rates based on the studies of Doblhoff-Dier et al. (2011). The frequencies chosen were in the range of 0.1 to 20 Hz. The mean effective velocity inside the test cell varied from 0.1-0.3 m/s and the amplitude ratios from 0 to 1.3. Experiments were conducted for steady-state and transient conditions. The investigated feed solutions contained high colloid concentrations of 5 g/l of colloidal silica with a size of 200-300 nm. Fouling was monitored by measuring the flux decline and pressure loss in the module over a period of 5 hrs. Using the experimental results, a model that correlates the transient cross-flow velocity with the growth of the colloidal cake layer in FO and that predicts the influence on the energy requirements was derived.

In Figure 1a and 1b results for steady-state and dynamic measurements with an amplitude ratio of 1.3 and a mean volume flow rate of 40 l/h, resulting in a mean velocity of 0.2 m/s, are shown. Figure 1a shows the volume flow rate over time and Figure 1b the normalized flux through the membrane. It is an interesting result that the flux decreases more rapidly in the transient than in the steady-state case. It declines to 60% of the initial flux while it reaches 40% in the steady-state case.

Keywords: Pulsating flow, Colloids, Fouling, Membrane, Experiment, Forward osmosis

As it is shown in Figs. 1a and 1b, the growth of a colloidal cake layer in FO can be significantly reduced by inducing a transient feed flow. To identify fouling mitigation and energy saving potentials, a systematic investigation led to a predictive model. The presented results indicate that pulsating flows are an efficient operation strategy to decrease fouling while avoiding chemical treatment and extensive cleaning.

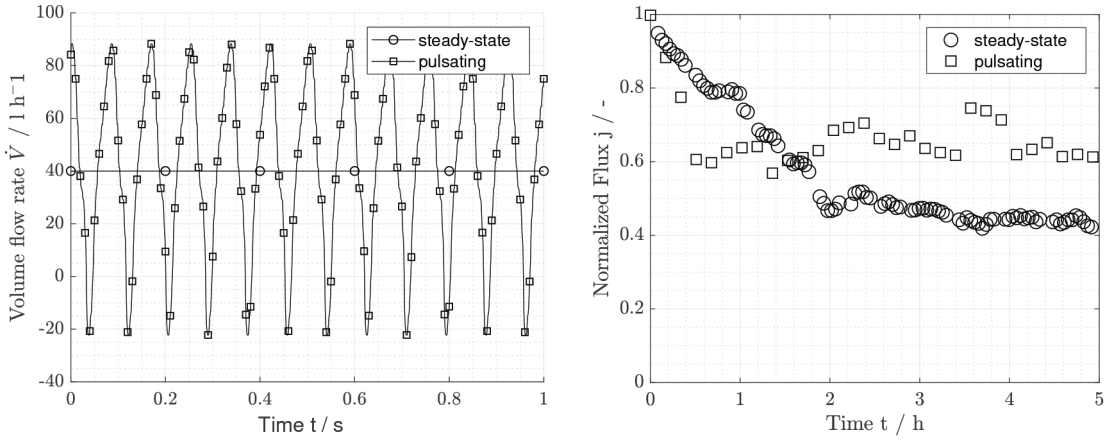

Fig. 1. Volume flow rate in feed channel (a) and comparison of normalized flux in steady-state and pulsating conditions at 12 Hz (b)

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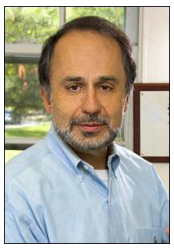
Opportunities for solar desalination: U.S. R&D status



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The water desalination industry is booming. Investment in new plants topped US$21 billion in 2015, and that amount is expected to double by 2020. However, almost all the world's 18,000-plus desalination plants are powered by fossil fuels which add to the greenhouse effect about 2-6 kg CO_2 for each m3 of fresh water produced. Water

desalination can be a sustainable solution to resolving water scarcity if it is affordable and safe for the environment.

Solar powered water desalination has the potential to dramatically increase availability of fresh water in arid locations which by virtue of their topography and climate have large solar resources. The main roadblock in the wide use of desalination is its upfront and operating cost. In most areas, reverse osmosis (RO) is the lowest cost technology both in terms of capital investment and operating costs. The capital costs of RO desalination plants are in the range of $600-$1600 per m^3/d of capacity (GWI, 2015), depending on the plant's size, the feedwater's quality and pre-treatment requirements, and its location. The cost of water produced by large (i.e., >50,000 m^3/d) SW RO desalination plants ranges from $0.53/$m^3$ to $1.65 /$m^3$, with the exception of several plants in Australia for which the costs are much higher (GWI, 2015). This cost strongly depends on the price of electricity, and pre-treatment requirements, in addition to capital costs. The operating costs of RO has been reduced over the last several years because of the usage of higher permeability membranes, pressure recovery devices, and more efficient pumps (Elimelech and Phillip, 2011). Such improvements tool place mainly during 1990-2005 and took the cost of RO desalination from ~$2/$m^3$ down to a low of $0.53/$m^3$. However the cost declines did not continue past 2005 as any benefits resulted from more efficient membranes were counterbalanced with higher energy and material costs (GWI, 2015). Currently, the operating pressure at SWRO plants is just 25% higher than the theoretical limit for overcoming the osmotic pressure, so little room for improvement is possible in further reducing energy requirements in the field. Opportunities for further reducing the cost of desalination are related to the use of 'free fuel' from renewable technologies, to longer lasting fouling-resistant and chlorine-resistant membranes, and to hybrid designs that can handle the fluctuations of solar energy.

Powering RO plants with electricity produced by photovoltaics is currently the lowest cost solar desalination option as the cost of PV electricity generation from high irradiation regions has been lowered to ~5 cent/kWh and is expected to continue decreasing. A main driver for the drastic system price reductions of PV have been the increase on module efficiencies and reduction of their prices. Every doubling of the cumulative capacity of PV module production during the last ten years, has resulted to a 22% reduction in module prices; this corresponds to a 'progress ratio', defined as the ratio of new price over the previous price, of 0.78). The price of battery electricity storage is being reduced at about the same progress ratio as that of PV modules. Cheaper storage is on the verge of massively expanding the markets enabled by PV, and this includes water desalination.

The price reductions of solar electricity catalyze R&D and Deployment in desalination according to two mechanisms: a) Energy cost is up to Â½ of the cost of water produces by desalination so reducing this cost increases the desalination market and correspondingly the PV market; b) larger desalination markets (due to lower solar electricity cost) creates the incentive for developing technology hybridization or new desalination technologies which can handle solar variability. In addition to cost, the desalination industry is looking to ways to reduce carbon dioxide emissions as it is scrutinized by stakeholders for their high carbon profile; this is the main incentive for the creation of the Global Clean Water Desalination Alliance (GCWDA), co-founded by Dr. Fthenakis, which was launched in Paris during the COP21, sponsored by the governments of the UAE and France.

Fthenakis will present the current status of solar desalination research at Columbia University including a flexible desalination design that won the US Department of Energy -Israel Ministry of Infrastructure Integrated Energy-Desalination Design Challenge in 2018.

Keywords: Solar desalination, Flexible, Reverse osmosis

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A numerical study on flow characteristics of horizontal tube falling film with column flow

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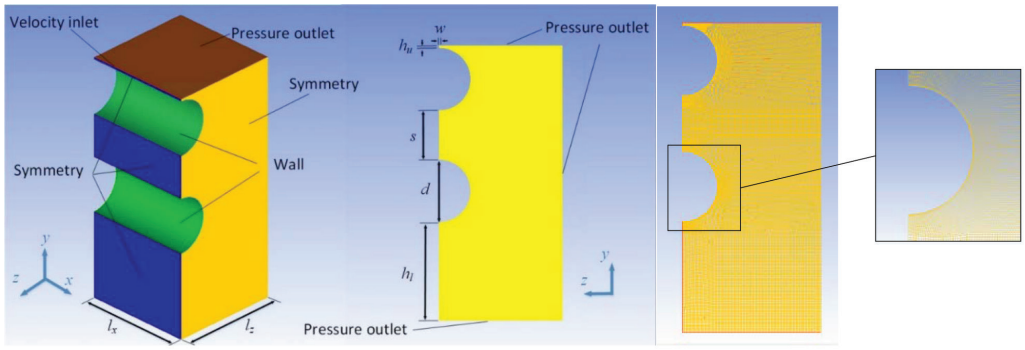
Horizontal tube falling film evaporation has been used in multi-effective distillation desalination due to high heat transfer rate and low temperature difference. The flow state of liquid film around the horizontal tube directly dominates the heat transfer. Therefore, a three-dimension numerical investigation of a liquid film falling around a horizontal tube was performed using VOF to study the flow characteristics with column flow, as shown in Fig. 1. The effects of inter-tube spacing and Reynolds number on flow characteristics involving the film thickness distribution along circumferential angle and axial length have been analyzed in detail. The numerical simulation results can accurately match the flow behavior captured in previous experiment under the same condition (Re = 258, s =20 mm), as shown in Fig. 2.



(a) (b)

Fig. 1 Dominant region and grid.

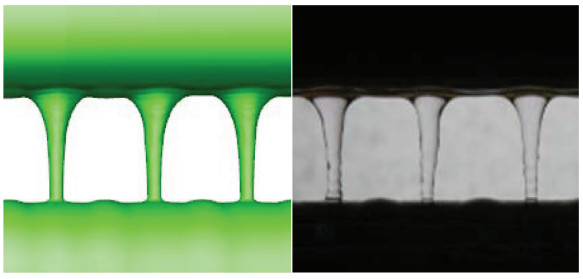


Fig. 2 Flow state of horizontal tube falling film: present simulated result (left) and previous experimental one with same condition (right).

The results indicated that horizontal tube falling film flow takes on strong three-dimensional features, the film thickness with l*=0 has a good agreement with Nusselt' solution, but the that with

l*=0.5 is much larger than Nusselt' solution. The enhancement in Reynolds number has a greater influence on film thickness near l*=0.5 rather than that near l*=0. Moreover, the comparisons between water and seawater were also presented.

Keywords Horizontal tube falling film, Film thickness, Three-dimension simulation, Tube spacing, Seawater

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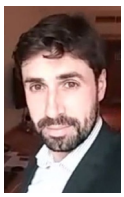
Long term boron rejection of thin-film nanocomposite membrane at Pembroke desalination plant in Malta: a case study



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Keywords: Desalination, Boron rejection, Thin-film nanocomposite, Reverse osmosis

Introduction

Boron is one of the important regulatory constituents for drinking and irrigation water. In irrigational use, while boron in small quantities is essential for the plant growth, an excessive amount of boron is known to be toxic to some plants. Because of that, even though the World Health Organization (WHO) raised the maximum boron concentration for drinking water to 2.4 mg/l in 2009, there are still some countries that have much tighter regulation than the WHO guideline. For example, many countries in the Mediterranean Sea area has the drinking water guidelines stipulating the maximum boron concentration in the range of 0.3 to 1.0 mg/l. Implementation of these stringent standards to the quality of water produced by reverse osmosis membranes creates a challenge to the seawater desalination industry.

In early 2016 LG Chem's NanoH_2O sea water RO membranes manufactured with the patented Thin-Film Nanocomposite (TFN) technology were installed in Pembroke desalination plant in Malta. The most challenging requirement of this project was to ensure the boron concentration in the permeate stream to remain below 0.9 mg/l after 5 years of operation. After more than 2 years of operation, the membranes maintain an excellent boron rejection performance without any further pH adjustment of the feed water which has relatively lower pH of around 6.7.

Highlights:

This case study will highlight the following points:

- Boron rejection mechanism by TFN membranes;
- Long term operation performance of TFN membranes;
- Boron rejection performance of TFN membranes without pH adjustment.

Project Background

Based on the operation data and performance for more than 2 years, the following points will be discussed:

- Boron in seawater can be found in two distinct forms: boric acid, the non-ionic form that dominates below pH of about 9; and borate, the ionic form that dominates above pH of about 9. While borate is usually well rejected by RO technology, the boric acid form tends to have a much higher passage through the membranes. At a typical seawater pH of about 8, the boron rejection tends to be much worse than that of sodium chloride and usually does not exceed 90-92% for the majority of commercially available RO membranes.
- To alleviate the problem of lower boron rejection by RO membranes, there are two common methods in the desalination industry: pH adjustment of the feed stream or use of two-pass RO systems. Pros and cons of each method including the cost estimates will be discussed.
- Pembroke desalination plant, one of the three desalination facilities in Malta, produces 54,000 m3/day of water on 12 single-pass trains at 45% recovery. During the pretreatment phase, the incoming seawater is treated with acid bringing the pH to about 6.7, which makes the boron removal an even more challenging task.
- TFN membranes with the nanomaterial in the active layer demonstrate a superior boron rejection compared to the conventional TFC membranes under the same operating conditions. It is speculated that the improved boron rejection is caused by the binding effect of the nanomaterial and the boron forms in the feed water. Based on the historic record of the TFN installation it will be shown that the required levels of boron in the product can be achieved without costly pH adjustment or a second RO pass.

Results/Outcomes

The results obtained in this study during more than 2 years of operation in the Pembroke desalination plant in Malta will highlight the following:

- Overall performance of TFN membranes: successful and reliable long-term performance of TFN membranes with respect to boron and salt removal with minimum membrane degradation;
- Boron rejection of TFN membranes without pH adjustment: impressive results of boron rejection by TFN membranes at low pH and the potential OPEX benefits that could be brought to a desalination facility by the TFN technology.

Conclusions

Low level of boron in permeate water is still a critical factor in seawater desalination in many countries in the Mediterranean region. A case study of Pembroke desalination plant in Malta with more than 2 years of operation data will showcase a successful implementation of TFN membranes to maintain boron concentration within the local guidelines without use of additional passes or pH adjustment.

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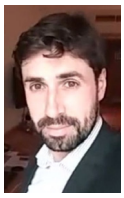
Advantages and disadvantages of reverse osmosis hybrid membrane configuration in seawater for different water treatment plant sizes



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Introduction

A seawater reverse osmosis (SWRO) system with a membrane hybrid configuration is a combination of two or more different membrane models within the same pressure vessel (PV). This type of design is usually used due to two possible reasons: A) to achieve a suitable design balancing the flux/recovery within a PV. B) To customize membrane performance to a specific need of a project in terms of quality and pressure requirements. Although they are commonly used in the water industry, particularly in large projects, there are still many professionals who are skeptical about the use of hybrids due to the possible inconveniences involved in installation, maintenance and membrane replacement. A comparison study of different size projects using membrane hybrid and non-hybrid design has been performed in order to evaluate the possible advantages and disadvantages in A and B scenarios.

Highlights

The following highlights will be shown in this study:

- Three different plant sizes will be studied using a hybrid and non-hybrid membrane configuration: 100,000 m^3/d, 10,000 m^3/d and 1,000 m^3/d
- A financial comparison evaluation will be performed for the first five year of operation of each case, including capital cost (CAPEX) and operational costs (OPEX).
- Additional points of discussion:
  - Replacement rates (RR) of different types of membranes
  - Different *Average Membrane Life Time* (AMLT) of each type of membranes
  - Different plant requirements due to fouling or scaling scenarios with two types of membranes

Methodology/Process

For each plant and configuration, two different scenarios will be analyzed:

A) Design Requirement: to achieve a suitable design balancing the flux/recovery within a PV to avoid exceeding the maximum element flux or/and recovery

B) Quality and/or Pressure requirements: to customize the membrane performance to a specific need of a project in terms of quality and pressure requirements

For each case, the following parameters will be studied:

- Energy consumption: annual energy consumption based on kW/h/m3 of water produced will be analyzed for each case for the first five years of operation.
- Labor hour requirement: An estimation of the number of hour required due to initial membrane installation, planning and maintenance including membrane replacement will be evaluated for the first 5 years of operation of each case.
- Consumables

Further general evaluation for both configurations will be shown for the following design parameters:

- RR for different type of membranes
- AMLT for different type of membranes and deviations from projections performed during the design phase
- Different replacements requirement due to fouling/scaling issues

Results/Outcomes

The results from this study will show the differences in term of CAPEX and OPEX cost for different RO plant sizes using hybrid and non-hybrid membrane configuration. Also, it will show other design parameters to be considered and their actual influence in the different plant size projects.

Conclusions

Despite membrane hybrid configuration being commonly used in the desalination water industry, it could have different advantages and disadvantages in terms of OPEX, CAPEX and maintenance procedures in comparison with membrane non-hybrid configuration. This study will expose and compare them to simplify and ease the decision making process at the design phase for reverse osmosis plants with different production sizes.

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Photovoltaic powered reverse osmosis desalination: Optimum technical and economic configuration of system components in autonomous operation mode

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Keywords: Sea water desalination, Variable load operation, Photovoltaics, Energy management system.
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The increase of the population and the climate change have led to one of most significant issues of the worldwide agenda, which is the water scarcity (Gosling and Arnell, 2016). There are many areas in the world, such as islands and coastal regions, that have significant shortage in potable water supply and more than 2 billion people do not have access to fresh water. An alternative sustainable solution to face water scarcity is water desalination (Dimitriou et al., 2014) and reverse osmosis (RO) has become the dominant desalination process today worldwide (Lee et al., 2011). Furthermore, the continuously increase of the fossil fuels prices and their environmental impact as compared to the advantages of the renewable energy systems (RES), makes the combination of RES with desalination units a sustainable and economically viable solution (Ghaffour et al., 2015).

Many Mediterranean countries suffer from water scarcity (Bdour et al., 2009) while the population growth and living standards increase the water supply problem in the whole Mediterranean basin (García-Ruiz et al., 2011). Specifically, many regions in Greece, such as Aegean islands (mainly

the Dodecanese and Cyclades island complexes), are characterized by low water availability (Zotalis et al., 2014). The water deficiency problem is more crucial in these islands during summertime, due to the higher water demand for tourists and crops' irrigation. The problem of water shortage is partially solved by transporting water which is subsidized by the Greek government (Mentis et al., 2016). The transportation of water is expensive and it has great environmental impact due to the carbon emissions of the ships that transport the water. Desalination units are being installed in the islands but they use the grid electricity which is mainly generated by fossil fuels. As a result, the desalination units increase the problems on grid frequency stability, a problem which the islands energy systems already face especially during the summer. Given the fact that the Aegean islands are characterised by high solar radiation potential, the combination of RES, with sea water reverse osmosis (SWRO) desalination units could be the most appropriate way to face the water shortages in these islands (Karavas and Papadakis, 2017).

The integration of desalination plants and the variable energy production of RES require a cost effective planning strategy in order to design the optimum energy supply system and water and solar electricity storages. In the current study, the optimum technical and economic configuration of a stand-alone small-scale SWRO desalination system powered by photovoltaics (PV) was investigated in order to tackle water scarcity in islands by producing fresh water of acceptable quality at all operating conditions.

The solar powered SWRO desalination system is considered to be installed in a small Aegean island at Cyclades complex. The stand-alone PV-SWRO desalination system should be able to cover a given daily water consumption profile and the SWRO desalination unit must satisfy the water demand at all times. In order to find the optimum SWRO desalination system, five different scenarios of PV-SWRO system configurations were considered. The objective was to determine the most feasible configuration at the lowest cost. In all scenarios, the PV array consists of a number of typical monocrystalline silicon PV modules and a programmable DC-to-DC converter able to find the maximum power point of the PV array (optimize PV's efficiency).

Initially, a targeted experimental investigation of a small-scale SWRO desalination unit equipped with an energy recovery device (Clark pump) (Karavas et al., 2018) was performed in order to develop its dynamic model. The SWRO desalination unit was studied operating at variable conditions and at various temperatures of the feed water. The various feed water temperatures affect the operation of the desalination unit. The objective was to study the performance of the desalination unit operating at a range of pressures imposed by varying the power input while producing fresh water with sufficient quality (electrical conductivity under of 1000 μS/cm). Three different feed water temperatures were selected in order to investigate the operation of the SWRO desalination unit under variable power input. In this study, the salt concentration of the test water was kept constant to 32000 ppm. The variables that were consider necessary to be investigated in order to evaluate the SWRO desalination unit performance, were the specific energy consumption, the pressure at the inlet of the membrane, the water recovery ratio and the electrical conductivity of the fresh water. The experimental results clearly indicate that the SWRO desalination unit can operate at various temperatures and it can produce fresh water with adequate quality in a wide range of power inputs. The operation range of the membrane was identified between 35 and 50 bar depending on the feed water salinity and temperature.

Subsequently in order to define optimum configuration options for PV-SWRO units five scenarios were examined: First scenario: the stand-alone PV-SWRO desalination system does not incorporate any energy storage device but it does incorporate water storage and the desalination unit operates at nominal load (constant feed flow rate and pressure). Also the DC-to-DC converter is an ON/OFF power controller. The desalination unit starts operating when the PV power is sufficient

to operate the SWRO unit at the nominal load (constant feed flow rate and pressure). Second scenario: the stand-alone PV-SWRO desalination system does not incorporate any energy storage device, it does incorporate water storage while it operates under variable power supply and variable conditions (variable feed flow rate and pressure). The desalination unit starts operating when the PV power reaches a specific limit and it stops when the PV power is not sufficient to operate the desalination motor. Third scenario: the stand-alone SWRO desalination system incorporates both energy storage device and water storage. An energy management system (EMS) based on a hysteresis control scheme is considered to be installed in the DC-to-DC converter. The hysteresis is used to activate or deactivate the desalination unit based on the State of Charge (SOC) of the battery bank. When the SOC is above a set high limit of SOC then the desalination unit is turned on and operates at nominal load until the SOC drops below a set low limit of SOC. In the forth and the fifth scenarios the components of the stand-alone SWRO desalination system are the same as those of the third scenario. The difference is that the energy management system and the desalination unit are allowed to operate at variable load (variable feed flow rate and pressure). In the fourth scenario, the energy management system is based on Fuzzy Logic and in the fifth scenario the energy management system is based on Fuzzy Cognitive Maps (FCM).

The five different scenarios were afterwards compared techno-economically. The economic analysis was performed according to the market prices of the components. The economic life of the system was considered to be 20 years. The depreciation of the capital investment in the same period is considered at an interest rate of 5% and the annuity factor of the depreciation was set equal to 8%. The design and the optimum sizing of the system in each scenario took place with the utilization of Particle Swarm Optimization (PSO). The PSO algorithm has been chosen because of the good results it has produced in energy systems optimizations. The purpose of optimization is to obtain the design that fulfils all technical constraints set and most appealing in terms of cost. The simulations of the scenarios were performed using a platform which consists of the TRNSYS, MATLAB, GenOPT and TRNOPT software packages.

The obtained results indicated that all the different configurations of stand-alone SWRO desalination system can cover 100% the water needs of 7 people. The comparison of the different scenarios showed that the PV-SWRO desalination system equipped with an energy management system based on FCM presented the lowest cost and the lowest specific energy consumption. In addition, as compared to water transportation, the stand-alone SWRO system can produce fresh drinkable water at a cost lower than about 60%.

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The management of desalination impacts in Spain

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Desalination plants can have an impact on the environment that may be minimised. In this study, a review has been carried out to analyse how the impact of the desalination industry in Spain has been managed. Researches carried out to date have allowed knowing the effects of hypersaline discharges on the benthic organisms and communities and how they can be mitigated. The application of this knowledge has allowed that the development of the desalination sector in Spain was done without producing significant impacts on the marine communities or, when some impact has been observed in monitoring programmes, they have been reversed. Moreover, the application of environmental management plans with the use of bioindicators have allowed to discriminate between the effects of desalination and others impacts with a spatial confluence, such as aquaculture, land reclamation or sewage.

The experience acquired to date may be applied to other countries where the desalination is developing in order to minimise its impacts on the environment.

Keywords: Seawater desalination; Environmental impacts; Brine discharge; Reverse osmosis; Environmental management plan

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Impacts of natural pore-water and offshore aquifer chemistry on the operation and economics of some subsurface intakes types for SWRO plants

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Horizontal and slant wells are being investigated as a means of obtaining feed water for seawater reverse osmosis desalination (SWRO) plants. These well types have been touted to produce higher quality seawater that will reduce the rate of membrane biofouling by removing algae, bacteria, transparent exopolymer particles, and other fractions of natural organic matter similar to onshore wells located on the beach. As these new well types are being considered for large-scale use, a careful evaluation of the biogeochemistry of seawater that occurs within the nearshore subsurface sediments is necessary to assess potential impacts to the SWRO process train. A high percentage of the coastlines of the world contain offshore sediments with seawater that is anoxic in nature with significant concentrations of hydrogen sulfide and dissolved organic matter, iron, manganese, and heavy metals. Where dissolved iron and/or manganese occur at concentrations greater than 1 mg/L in raw seawater, there can be problematical for direct treatment using the SWRO process. Membrane scaling and biofouling could become issues, which may necessitate pretreatment to reduce dissolved iron and manganese to acceptable concentrations prior to entry into the membrane process. The anoxic nature of the water could complicate the pretreatment process to remove the dissolved metals. Pretreatment requirements could significantly raise the capital and operational costs of SWRO negating the economic advantages of subsurface intakes. Six SWRO cost scenarios were evaluated to assess the impacts of slant wells on capital and operating costs based on the necessary to remove or not remove dissolved iron and manganese. The capital cost comparison to two open-ocean intake pretreatment systems to those in slant wells shows an increase of 6 to 20%. The difference in operating costs can range from 19% lower to 15% higher depending on the pretreatment required.

Keywords: Seawater reverse osmosis, Subsurface intake, Pretreatment, Dissolved iron, Dissolved manganese

Chitosan microparticles as a new filler for alginate mixed matrix membranes MMMs

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Composite alginate membranes (ALG) filled with bare chitosan particles CS, and glutaraldehyde modified chitosan particles CS-GA were prepared by the stepwise casting from solution and their effectiveness in pervaporative dehydration of water/ethanol mixture were investigated. Firstly, physico-chemical properties of all membranes were studied by measuring the swelling characteristic, contact angle, FTIR spectra, DSC thermograms and SEM images. The mean size D50 of CS and CS-GA particles were determined using Malvern Zetasizer and were equalled to 0.25 and 3 μm, respectively. The influence of both types of chitosan particles as well as their content on the transport properties of the MMMs were discussed. It was founded that the addition of the bare chitosan particles to the alginate matrix significantly alterates its transport properties leading to the improvement of separation parameters. In case of ALG_CS membrane with 5 wt% of bare CS filler the values of flux and separation factor was about 2.0 times higher, and the ***PSI*** was about 3.5 times bigger in comparison with the pristine ALG membrane (Fig. 1). The modification of chitosan particle impacts on the further improvement of experimentally estimated transport and effectiveness characteristic of such membrane (ALG_CS-GA). Filling with CS-GA particles, propertied decreased degree of crystallinity, results in an enhanced flux of MMMs alginate membrane. The best effectiveness of pervaporative dehydration of ethanol was founded for ALG_CS-GA membrane

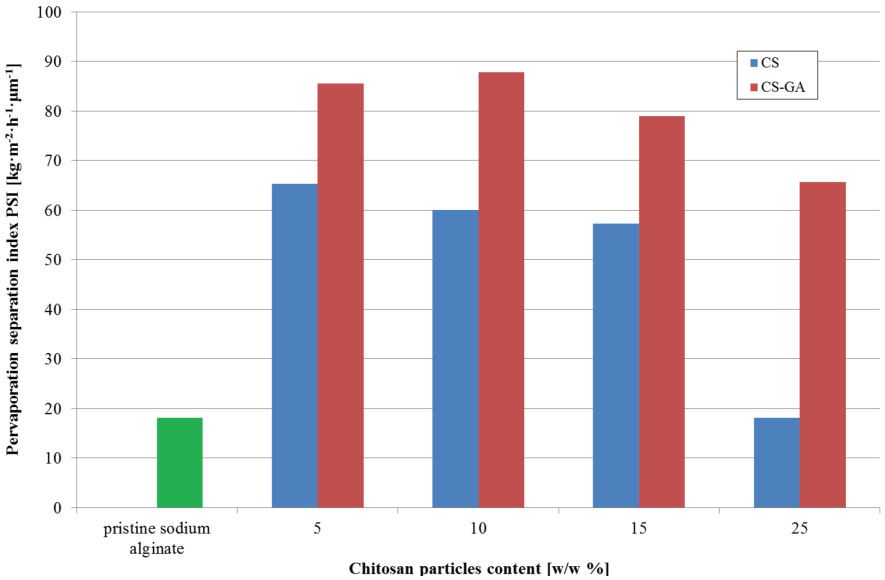

Fig. 1. Pervaporative separation index ***PSI*** of pristine ALG membrane (green) and filled with different amount of bare CS (blue) and modified CS-GA particles (red)

with 10 wt% of CS-GA particles. In this case, separation factor α and pervaporative separation index PSI were equalled to 48.7 and 87.8 kg·m^{-2}·h^{-1}, respectively, which is about 5 and about 1.5 times higher than of pristine ALG membrane and ALG_CS membrane with 5 wt% of bare CS filler, respectively (Fig. 1).

Keywords: Composite alginate membranes; Pervaporative dehydration of water/ethanol mixture

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Computational study on fluid behavior by inlet distributor within the inflow part of a pressurized module

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Keywords: Inlet distributor, Pressurized module design, Flow distribution, Flow velocity and pressure, Computational fluid dynamics

1. Introduction

The CFD could accurately interpret the flow distribution on the novel module design, i.e. the module configurations, distributors, module shapes, etc (Bucs et al. 2015; Lim et al. 2017). Therefore, the purpose of this study is to investigate the fluid behavior from velocity, pressure and flux, and explain an evenness of water distribution on the inflow part of a pressurized module to induce the non-uniformity coefficient and energy utilization using computational fluid dynamics. The originality of this study is to find the effect of the uniform fluid distribution by newly designed inlet distributors installed at the inflow part of a pressurized membrane module.

2. Methods

In this study, ANSYS CFX (version 18.0) was employed to simulate the fluid behavior such as velocity, pressure and flux. CFX is the most widely used CFD software tool because of an outstanding accuracy in its hydraulic analysis of membrane modules (Oh et al., 2015). The pressurized membrane module commonly has inflow, membrane, and outflow parts, in this study, only inflow part was simulated because inlet distributors installed at the this part. The inflow has a down-to-up flow that inlet plane is lower section and outlet plane is upper section, as shown in Fig. 1. The outlet plane was divided with nine sections to analyze the flux distribution.

3. Results and conclusions

3.1 Velocity and pressure at cross-sectional plane

As shown in Fig. 3a, the fluid velocity of case 2 at the cross-sectional plane was relatively uniform and then average velocity was the highest at 5.501 m/s among all conditions, because the fluid velocity

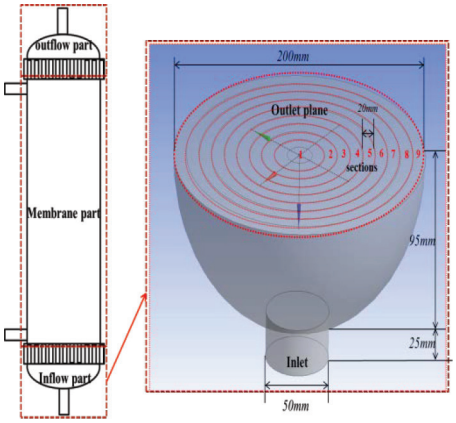

Fig. 1. Structure and specifications of the inflow part

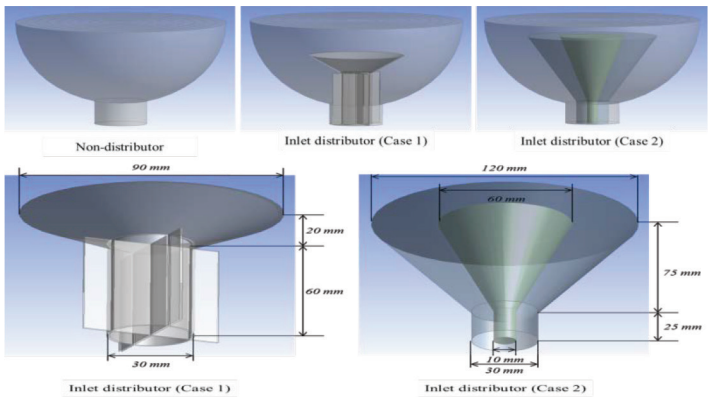

Fig. 2. Detailed specifications of the inlet distributors

Table 1. Module specification of effective area and volume on inlet distributors

Conditions	Items	inlet	outlet
Non-distributor	Area (cm2)	19.5	361.4
	Volume (cm3)	2,140	
Case 1	Area (cm2)	17.7	361.4
	Volume (cm3)	2,086	
Case 2	Area (cm2)	19.5	361.4
	Volume (cm3)	2,136	

Table 2. Boundary conditions for CFD simulations

Condition	Value
Dimension	3D
Flow mode	Turbulent
Inlet pressure (bar)	1
Outlet pressure (bar)	0
Fluid temperature (°C)	20

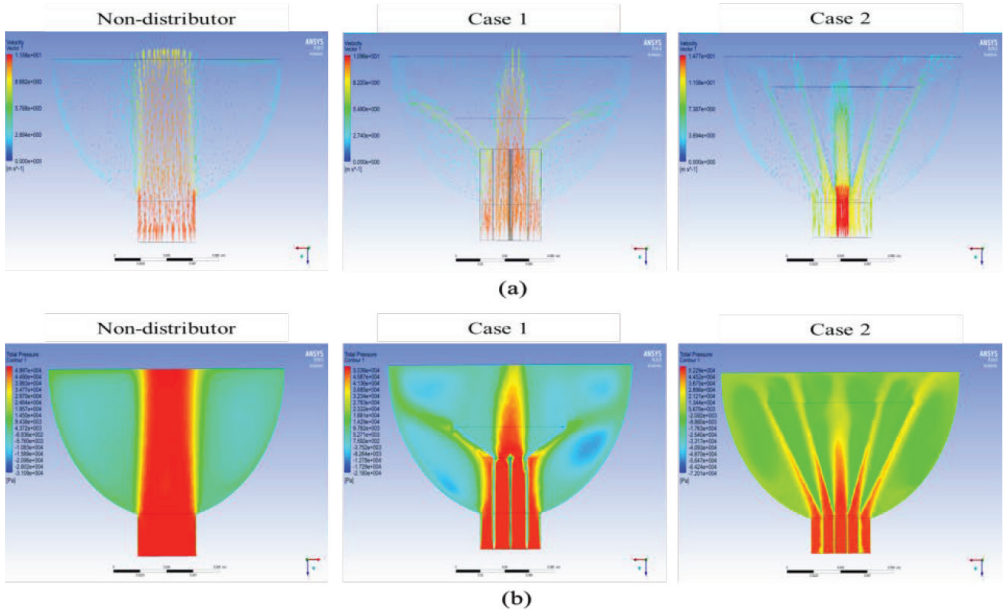

Fig. 3. Contours images of velocity vector and pressure on inlet distributors at cross-sectional planes: (a) velocity vector and (b) pressure.

is equally distributed in the flow part due that the shape of the inlet distributor could divided the fluid with three quarters. The average velocity of case 2 was higher than that of case 1, indicating that the ideal fluid flow was observed among three conditions. Also, in case 2, the red color at the center of inlet pipe was caused that the area of a center circle was smaller of 78.5 cm^2 than other circles showing that cross-sectional area of 2nd circle was 628 cm^2 and that of edge circle was 1,256 cm^2. Overall, the fluid velocity at the cross-sectional plane in the inflow part was high and showed the most even distribution in case 2, indicating the ideal flow. From the results of Fig. 3b, the water pressure distribution of case 2 was relatively uniform and the mean pressure value was low at 14.2 kPa, because the fluid was evenly distributed by the round-shaped inlet distributor in the inflow part. Thus, the lowest water pressure was observed in the cross-sectional plane with the fastest flow velocity from the results of chapter 3.2.1. From the above results, it is concluded that the water pressure at the cross-sectional plane showed the most uniform distribution and low water pressure in case 2 as the fluid velocity indicating the ideal fluid flow.

3.2 Flux variation at sections on the outlet

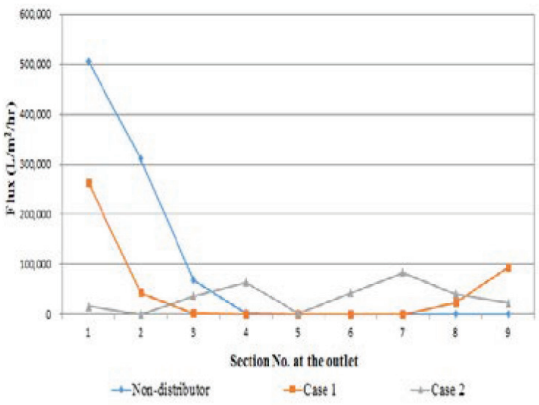

Fig. 4. Flux variations at sections on the outlet plane.

Fig. 4 displays the average flux values at 9 sections which are on the outlet plane with 20 cm interval. From the results of Fig. 4, it can be seen that every fluid passed through sections 1 to 3 in a non-distributor and case 1, on the other hand, no flux at other section. Case 2 shows that the fluid passed through all sections of the outlet plane except for a section 2, and standard deviation was the lowest at 27,599 $L/m^2/h$ (max. 83,687 L/m2/h at section 7 and min. 0 L/m2/h at sections 2), and it proved that fluid is relatively uniformly distributed in the inflow part due to the inlet distributor with two rounded shape of case 2.

3.3 Non-uniformity coefficient and energy utilization at each plane

Non-uniformity coefficient, *N*, is the standard deviation of the local fluxes at the specific plane, and means that an evenness of flow is higher when the value is smaller (Zhuang et al. 2015). Fig.5a shows the values of non-uniformity coefficient *N* at the five planes, i.e. inlet, and 2.8 cm, 9 cm, 11 cm and 12 cm (outlet) from inlet to identify the flow evenness within an inflow part. The *N* of a non-distributor were the largest in all planes compared to other conditions, and case 1 and 2 were relatively small, proving that the flow was uniform on each plane by inlet distributors.

A parameter of the energy utilization, η, means the pressure drop which is a fluid transport to the place, hence high η means low pressure drop and energy utilization of the module newly

designed (Zhuang et al. 2015). Fig. 5b shows the values of energy utilization at the four planes. The η at 2.8 cm based on the initial pressure at inlet was 0.0019 for non-distributor, 0.0046 for case 1 and 0.0033 for case 2, and η of case 1 was the highest and that of a non-distributor was the lowest. It was considered that the pressure drop decreased because the flow evenly distributed by inlet distributor.

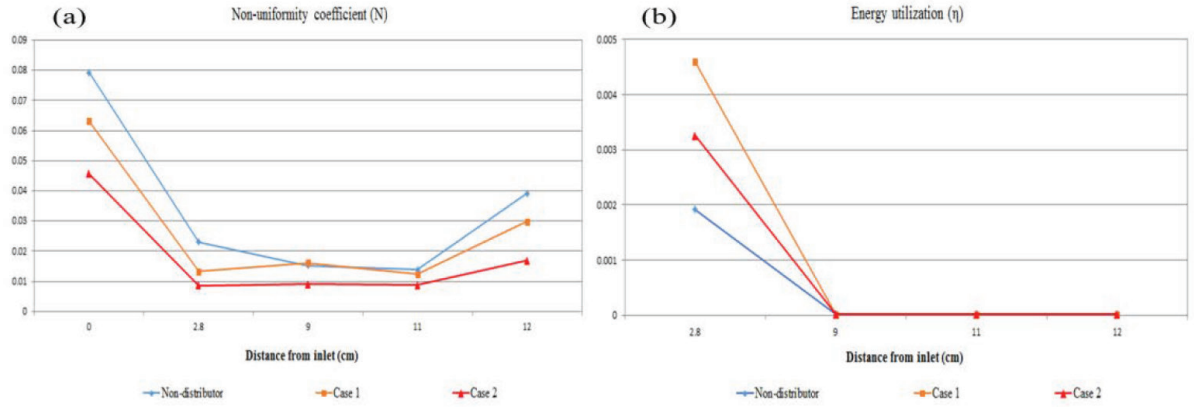

Fig. 5. Non-uniformity coefficients at five planes within an inflow part: (a) non-uniformity coefficient and (b) energy utilization.

4. Summary

In summary, from CFD simulation results on inlet distributors, the fluid flow of inlet distributor of case 2 was maintained the best even distribution within an inflow part of pressurized module when considered parameters of a velocity, pressure, flux, non-uniformity coefficient and energy utilization.

Acknowledgements

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Study on the seawater fouling during the horizontal-tube falling film evaporation under vacuum

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The fouling on heat transfer surfaces is a severe problem and a complex phenomenon in multiple-effect distillation plants with horizontal tube falling film evaporators for seawater desalination. This paper presents an experimental study on the seawater fouling during the falling film evaporation outside the horizontal tubes under vacuum. Experiments are performed under the seawater spray temperature of 70°C, 80°C and 90°C, the salinity of 80g/kg, 100g/kg and 120g/kg and the seawater spray density of 0.03 kg/(m s), 0.06 kg/(m·s) and 0.08 kg/(m·s). The titanium tubes were used inside an evaporator and Dalian local seawater selected as the working agent. The scale growing curves under different conditions are obtained through weighting the amount of the scale formed at different periods. The crystalline scale layers are analyzed by a scanning electron microscopy (SEM) and an energy dispersive X-ray spectroscopy (EDXS) to get the structural and chemical characteristics of the scale. The results show that the salinity plays an important role in the seawater fouling during the horizontal-tube falling film evaporation. When the spray seawater temperatures are 70°C and 80°C and the spray density of 0.06 kg/(m·s), the asymptotic value of scale increases with salinity, while at seawater temperature of 90°C and under the three different spray densities, the asymptotic value of scale reduces with salinity increasing. With the seawater spray temperature of 90°C, spray density of 0.06 kg/(m·s) and seawater salinity of 8%, 10% and 12%, the scanning electron microscopy images of the scale on the surface of the heat transfer tubes are given out. It is found that, with the increase of salinity, the morphology of the scale develops from the initially needle-shaped grown of magnesium hydroxide crystals to a more regular polygonal flaky crystal shape when the seawater salinity increases from 8% to 10%. When the salinity is 12%, clustered growth of flaky magnesium hydroxide crystals has appeared, indicating that the increase of seawater salinity promotes the growing of magnesium hydroxide crystals under this experimental condition. The major component of the scale is magnesium hydroxide under this experimental condition.

Keywords: Seawater fouling; Falling film evaporation; Spray temperature; Spray density; Salinity

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Cost analysis in SWRO desalination plants productions lines of 750, 1500 and 3000 m³/d: mathematical model and simulation

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At a national level, the Canary Islands are characterized for having a large amount of seawater desalination plants that use reverse osmosis within the range 500–5000 m³/d of production, where a significant number range from 750 to 3000 m³/d.

Our paper carries out an exhaustive study of the OI plants with productions of 750, 1500, and 3000 m^3/d, of which we know their most common expenses, such as investment-amortization, consumption of reagents, replenishment of cartridge filters, replacement of membranes, personnel, maintenance, environmental cost and energy consumption.

Through the study of previous costs, we worked on obtaining a cost function with which to identify the production range based on the multivariate analysis, the factorial analysis and the Kolmogórov-Smirnov and Shapiro-Wilk tests. Also, we performed a univariate variance analysis and the weighted least squares analysis model that regulate the total expenses of these plants.

We will calculate the deviations that appear between the real data and the study of cost function by using the real data obtained from plants in the Canary Islands that work regularly for the productions previously mentioned.

Finally, our conclusions broadly present a cost function characteristic of said ranges and possible options to reduce their cost.

Keywords: Reverse osmosis, Unit costs, Canary Islands, Desalination, Operating parameters

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Energy consumption assessment of 5000 m^3/d SWRO desalination plants

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Within the desalination of seawater by reverse osmosis in the Canary Islands (Spain), one of the most characteristic productions is 5000 m^3/day and the most relevant cost is the energy cost.

In this article, a study of this cost in 3 fully operational plants over 4 years was made. Initially, each of the plants was analyzed and an exhaustive study of the operative data was carried out, then a comparative study between them was made.

The initial analysis was conducted through ROSA program then a study of the energy recovery systems to obtain the type of data distribution and its deviations was carried out.

This article highlights the efficiency of energy recovery system, obtaining and concluding the necessary basis for a reduction of the cost for this type of plants and production.

Keywords: Seawater, Reverse osmosis, Desalination plants, Operating data

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Energy consumption assessment of 300 m³/d SWRO desalination plants. Comparison with production 600, 4000 and 5000 m³/d

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The Canary Islands have been the first to desalinate water through reverse osmosis in Spain. As a consequence of the size of the territory of the islands, the great majority present very small productions but it also implies that the islands have a great experience in this type of plants.

In this article we study the monthly energy cost in two reverse osmosis desalination plants over two operating years.

We analyze the deviations between them and the energy recovery systems used. This cost was compare with small plants of 600 m³/d and slightly larger plants than 4000 and 5000 m³/d.

This work reflects the deviations of the energy cost in such plants compared to other larger productions and distribution data demonstrating the necessary basis for a reduction of the cost for this type of plant and production.

Keywords: Seawater, Reverse osmosis, Desalination plants, Operating data

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Energy cost analysis in SWRO desalination plants.productions lines of 2500, 7500 and 15000 m³/d

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The Canary Islands have more than one hundred installations of seawater desalination by reverse osmosis. As a consequence of this quantity, there are different productions and sizes, as well as different production lines that installed in parallel produce the volumes of desalinated water.

In various publications we have done it shows that the most profitable production line is 7500 m³/d.

In this article we study the monthly energy cost in 3 plants, the total production being multiples of the aforementioned production, 2500, 7500 and 15000 m³/d, respectively, over 8 operating years. We analyze the deviations between them and compare the 3 production lines with and without energy recovery system.

This paper presents findings on deviations energy costs in these plants regarding the most effective production line specifying in each case necessary to obtain a reduction of the cost for this type of plant and production activities.

Keywords: Seawater. Reverse osmosis, Desalination plants, Operating data

Biological and membrane-based pretreatment processes

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MIDES Project is a novel concept that integrates reverse osmosis (RO) with an innovative technology for simultaneous wastewater treatment and desalination called a microbial desalination cell (MDC). Microbial desalination cell merges biolectrochemical systems (BESs) and electrodyalisis (ED) with the aim of developing a sustainable process to provide low-energy drinking water without external energy input. Current desalination technologies require high-energy input, being reverse osmosis (RO) the most-widely used technology for seawater desalination with an energy consumption of at least 3 kWh/m^3. The idea of the integration of MDC technology with RO post-treatment of partially desalinated seawater allows desalination with an energy consumption below 0.5 kWh/m^3, an energy saving of more than 80% compared to the leading commercial desalination process currently implemented in industrial plants.

The rationale of the MDC relies on the use of the energy provided by electroactive bacteria through the oxidation of organic matter contained in wastewater (up to 1.8 kWh of bioelectricity per m^3 of wastewater). This energy is utilized directly to lower salt content in seawater from 35 to 5 g/L (brackish water) without external energy input, while further salinity reduction to achieve drinking water quality is performed in the subsequent RO step. Therefore, this novel technology enables the simultaneous treatment two steams, saline and wastewater, by obtaining new and re-generated water sources.

Figure 1 shows the main scheme in MIDES process treatment.

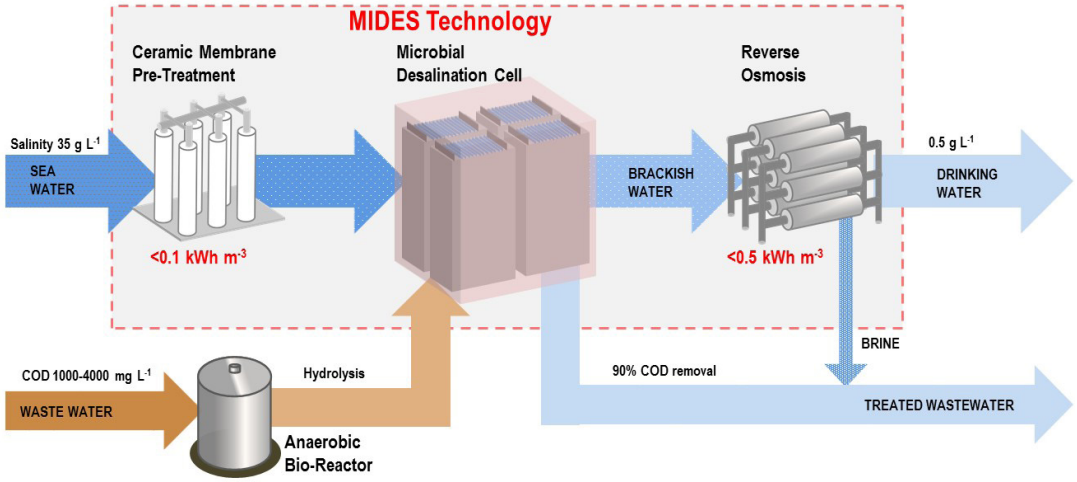

Fig. 1. MIDES process scheme.

Both saline and wastewater streams need to be pre-treated before entering the MDC. On one hand, foulants usually present in natural salted water (inorganic suspended solids, organic matter, colloidal particles…) are removed from the saline stream. The proper selection of the pre-treatment

stage is a vital step to guarantee a stable operation in desalination plants. In this project, the pre-treatment proposed for the saline stream is based on micro and ultrafiltration membranes, where ceramic membranes were compared to polymeric submerged membranes in terms of membrane performance, chemical reagent requirements, water quality and cleaning strategies. This research have been carried out in the MIDES Demo Site 1 (Racons BWDP) in Denia (Spain), working with superficial brackish water from the river Racons. This river presents special features, with high variability in flow and composition, marine intrusion and a high concentration of natural organic matter (NOM), representing a clear source of fouling. Suspended solids (SS) ranged from 1.2 to 44.6 mg/L and turbidity from 0.8 to more than 100 NTU, with sudden fluctuations even hourly. Because of the river water characteristics, this location states as the worst-case scenario and represents a major challenge in membrane pre-treatment.

On the other hand, wastewater has to be enriched in volatile fatty acids (VFAs) to become a suitable feed for the MDC, since the energy required in the MDC for the ions migration comes from the oxidation of acetate of some other VFAs present in wastewater carried out by bioelectrogenic bacteria attached to the anode of the MDC. Thus, the anaerobic pre-digestion can be seen as a key element for the MIDES system, since it provides the energy required for the desalination step.

Different wastewater sources were evaluated as the optimal feed to the MDC. Three different types of wastewater (municipal wastewater, municipal wastewater doped with molasses and industrial wastewater (brewery)) were treated in four different anaerobic reactors to evaluate its potential use as MDC feed in terms of VFAs concentration and water quality after the anaerobic treatment.

Industrial wastewater (brewery) has been identified as the optimal feed to enhance the activity of bioelectrogenic bacteria in the MDC, considering its VFAs concentration, its high buffer capacity and water availability.

Keywords: Desalination, Pre-treatment, Anaerobic digestion, Ultrafiltration

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Determination of the optimal intake points for a PRO power plant in the Magdalena River based on experimental and simulated data

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Renewable electrical energy can be produced through the controlled mix of two water streams with different salt content (salinity gradient energy, SGE). Those two required water sources with high salinity gradient across them exist naturally at river mouths.

In this study we consider the system formed at the Magdalena River mouth in the Caribbean Sea, to assess its potential for electrical production via salinity gradient technology, specifically considering pressure retarded osmosis (PRO). The Magdalena River mouth is a highly stratified estuary, which means it presents a salt wedge penetrating the river channel from the sea, which in this particular case is quite variable throughout the seasons. Experimental on-site data has been acquired and used to obtain a model to predict the salinity along the distance to the sea. A methodology here is proposed to pinpoint the optimal location of the river water intake, given a fixed position for the hypothetical power plant.

Methodology proposed

The Magdalena River mouth presents a promising opportunity for SGE processes due to its unique morphology. Its last kilometers before reaching the sea were artificially modified to enable navigation, by the construction of an artificial barrier, which grants the availability of sea and river water at a small distance. Temperature and salinity data have been gathered along the final stretch of the river and sea, along with seasonal flowrates historic data to formulate a hydrodynamic tridimensional model to simulate the salt profile along the river under several climatic circumstances.

The simulation results of the hydrodynamic model show that this system is adequate for SGE generation, due to its high stratification, which enables the availability of fresh water and salt water at a short distance, which is very beneficial.

Different pairs of data location-salinity can be used to calculate the potential power extractable in those points, through a simulation method using a realistic practical approach. Afterwards, the pumping costs, among other energetic losses, will be deducted to calculate the effective net power extractable on each location.

Establishing a methodology to determine optimal locations related to the design of a PRO plant in a concrete natural system can be very helpful in developing this growing technology.

Keywords: Salinity gradient energy, Pressure retarded osmosis, River mouths, Estuary dynamics

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Hexavalent chromium removal from tunneling wastewater using chemical and electrochemical techniques

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Hexavalent chromium (Cr^{+6}) is of particular environmental concern due to its toxicity and mobility and is challenging to remove from industrial wastewater. The present investigation deals with the removal of Cr^{+6} (~140ppb) of tunneling wastewater, which has a very basic pH (11-12). For this purpose, batch experiments with wastewater samples were conducted to determine whether sub-ppb concentrations of dissolved Cr^{+6} could be achieved by chemical (using ferrous sulphate) or electrochemical reduction (iron electrodes). Cr^{+6} is chemically reduced to less soluble Cr^{+3} species by Fe^{+2}. The influence of pH, temperature, suspended solids, concentration of ferrous sulphate, current density and reaction time were evaluated in the removal of Cr^{+6}. Further, predictive equations were developed within the studied ranges. The results showed that ferrous sulphate is a good reducing agent of Cr^{+6} at very basic conditions. Optimal conditions were at pH=12, 22°C, with the presence of suspended solids and at molar ratios 1:15 (Cr^{+6}/Fe^{+2}); 97.8% of Cr^{+6} was removed under these conditions. On the other hand, electrocoagulation was better reducing Cr^{+6} at lower pH; 99.3% of Cr^{+6} was removed at pH=8, 0.5mA/cm^2, and 8min of reaction time. At very basic conditions the removal of Cr^{+6} could be achieved by means of higher current density values.

Keywords: Hexavalent chromium, Tunnelling wastewater, Ferrous sulphate, Electrocoagulation

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Study of adsorption mechanisms of free amino acid l-tryptophan on chemically activated porous carbons derived from biomass wastes date pits

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Free and combined Amino acids constitute an important class of dissolved organic nitrogen which can form unwanted disinfection by-products during chlorination in drinking water treatment plants. Therefore, the objective of this work is to examine the effectiveness of three environmental-friendly low cost materials as adsorbents for the removal of free amino acid (l-tryptophan) from aqueous solutions. The adsorbents were prepared from date pits and activated with H_3PO_4(DPH), $ZnCl_2$(DPZ) and KOH (DPK). The textural properties of the activated carbons were characterized by FT-IR, SEM and N_2 adsorption-desorption isotherms. Batch adsorption experiments were investigated to examine the effects of adsorbent dose, contact time, initial l-tryptophan concentration, temperature and pH on the uptake of l-tryptophan. The adsorption process showed that the temperature has little influence on l-tryptophan uptake. On the contrary, the adsorption capacity of activated carbons is significantly affected by the solution pH, with a maximum at pH 5.7. Experimental data were successfully fitted to the pseudo-second order kinetic model. Among four isotherm models, the Langmuir model gives a perfect fit for l-tryptophan adsorption on the three activated carbons. The maximum monolayer adsorption capacity of l-tryptophan (232.185 mg g^{-1}) was obtained on DPK. The thermodynamic parameters suggested that l-tryptophan adsorption is spontaneous, exothermic with a physisorption process.

Keywords: Free amino acid l-tryptophan; Mesoporous activated carbon; Microporous surface; Adsorption mechanism

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Inhibition of $CaCO_3$ scaling by humic substances in a reverse osmosis system treating anaerobic groundwater

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In brackish water reverse osmosis (BWRO) applications, $CaCO_3$ scale as the most common constitute of membrane scaling, is one of the main factors that limits system recovery. To allow the operation of BWRO at high recovery rates, antiscalant addition to the feed water is a common approach. However, the use of chemicals in water industry is less favoured as it has its negative impacts on the environment. In this study, the objective was to investigate the role of humic substances in inhibiting $CaCO_3$ scaling in BWRO. Induction time experiments were conducted without and with humic substances. Additionally, pilot experiments, with an RO unit treating anaerobic groundwater in a location in The Netherlands, were conducted in the presence of humic substances. It was found that the formation of $CaCO_3$ scale delayed considerably in the presence of humic substances. For instance, in the presence of humic substances, $CaCO_3$ precipitation did not occur in a period longer than 10 days for a real RO concentrate at 80% recovery (SI 1.5), while in the absence of humic substances, $CaCO_3$ precipitation occurred in 6 h for a synthetic concentrate with the same ion Ca^{2+} and HCO_3^- concentrations that were present in the real RO concentrate. When 30 mg/L of humic substances were added to the synthetic concentrate, $CaCO_3$ precipitation did not occur in 18 days. This study revealed that the humic substances, naturally present in the RO feed water, may function as natural antiscalant to control $CaCO_3$ scaling which as a result, may reduce or completely eliminate the use of commercial (synthetic) antiscalants.

Keywords: $CaCO_3$ scaling, Induction time, Humic substances, Antiscalants, BWRO

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Investigating seawater scaling potential in single pass SWRO desalination plants with relation to boron removal at moderate pH conditions

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With the development of new membranes for seawater reverse osmosis (SWRO) with significantly improved boron rejection, it is now possible to meet the WHO guideline for acceptable boron levels in drinking water (WHO, 2017) with a single pass RO desalination plant (Bartels, et al., 2009). This plant design will allow substantial CAPEX and OPEX savings (Arias, et al., 2011; Hilal, et al., 2011) . However, for proper operation the feed pH has to be increased to 8.8, where at high recovery rates the scaling potential of sparingly soluble inorganic salts such as calcium carbonate, magnesium hydroxide and to some extent calcium sulphate will reduce process efficiency (Antony, et al., 2011). Therefore, it is crucial to identify antiscalants that mitigate mineral incrustation under the mentioned operating conditions. To achieve this, a thorough understanding of the chemistry and formation mechanism of the different types of scales occurring in these systems is required.

The goal of this work is to study the nucleation and early growth of inorganic minerals at conditions similar to those prevailing in a single stage SWRO desalination plant in relation to boron removal. Considering the impact of concentration polarization and to mimic the conditions at the membrane surface during the RO process, samples with 8.5% salinity (i.e. a concentration polarization factor of 1.3) were also investigated. Experiments were performed with synthetic seawater at the two chosen salinities over a pH range of 8.7-9.3. Mineral precipitation from these model solutions was examined in detail by three different testing methods. To analyze bulk crystallization under static conditions, beaker tests were carried out with online monitoring of solution turbidity, pH as well as calcium and in some cases magnesium ion concentrations. This gave quantitative information on homogeneous nucleation and growth rates as a function of solution composition. In turn, the crystallization behaviour on surfaces (i.e. the heterogeneous case) was probed selectively by means of a quartz crystal microbalance (QCM). Finally, scaling under dynamic conditions – mimicking those in the real process and (potentially) involving both homogeneous and heterogeneous crystallization phenomena – was studied in a differential dynamic scale loop (DSL) apparatus comprising an integrated polyamide capillary.

Scale formed in beaker and QCM tests was characterized with scanning electron microscopy (SEM), energy-dispersive X-ray (EDX) analysis, X-ray diffraction (XRD), infrared (IR) spectroscopy, cryogenic transmission electron microscopy (cryo-TEM) and dynamic light scattering (DLS), in order to obtain structural and morphological information. Taken together, the collected data provide fundamental insight into processes underlying homogeneous and heterogeneous scale formation under typical SWRO conditions, and how variables such as pH or salinity affect the crystallization kinetics as well as the output in terms of scale chemistry and structure. After investigating the basic mechanisms of scale formation in our systems, further experiments were carried out using commercial available antiscalants, which are chemically different under otherwise identical conditions, in order to assess and quantify the effects of these additives on different stages of the crystallization process. By varying the chemistry of the used antiscalants and probing their inhibiting power with

respect to nucleation and growth, the best working product for the given type of SWRO operation was determined. Finally, a comprehensive comparison of the results obtained from the three laboratory methods (Beaker, QCM and DSL tests) was given.

The experimental data obtained in this work showed that a single pass RO process has definitely a potential to be further investigated and optimized. The harshest condition at which the best performing antiscalant could fully inhibit the precipitation process during 4 h of experimental time with 1 ppm dosing rate on the DSL apparatus was at 8.5% salinity and pH 9.1.

Keywords: Antiscalant, Boron removal, Crystallization control, Fouling, Polycarboxlate, Reverse osmosis, SWRO desalination

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Influence of an innovative biodegradable foam control agent on the operation of thermal desalination plants

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The foaming tendency of seawater in distillation plants is unforeseeable. In general, foam is formed when dissolved organic matters, such as when algal blooms decompose [1], are concentrated in the brine, giving rise to surface-active effects that increase the liquid film strength at phase interfaces. At typical dose rates, foam control agent penetrates the surface liquid film of bubbles where it acts as a surfactant and reduces the film strength. The result is that the film readily breaks down and stable foam does not form. In this way, a uniform boiling or flashing action is achieved and carry-over is minimized.

In seawater distillation plants, foam control agents are normally dosed as a neat product or as a solution between 1 to 5 weight percent of product prepared in distillate.

Current state of the art foam control agents like polyethylene and polypropylene glycols, ethoxylated oleic acid or ethoxylated fatty acids, are not soluble in water and forms a white milky mixture, which separates in few hours. Such foam control agents are only soluble in polar and/or aromatic solvents.

Furthermore, by considering the impact of the discharge, it is suspected that typical antifoaming agents like polyethylene and polypropylene glycols, which are not toxic, but may be rather persistent in the environment due to a poor biodegradability, are cumulating in the sea. [2]

In this work, the suppression of stable foam in seawater in presence of an innovative sustainable, readily biodegradable foam control agent was investigated. To study the foam formation, a versatile foam column was designed to mimic conditions of thermal desalination plants. In addition, a recipe to prepare synthetic foaming seawater to gain reproducible comparable results was established.

The aim was to develop a high performing, sustainable, readily biodegradable and fully water-soluble foam control agent that requires very low dose rates in order to maintain high operational efficiency. These properties allow the new foam control agent to increase cost saving due to minimized cleaning requirements, therefore longer operation time of multi effect distillation (MED), and multistage flash distillation (MSF) plants.

Keywords: Foam control; Foaming; Antifoam; Defoamer; Distillate conductivity; Thermal desalination; Multi effect distillation; Multistage flash distillation; Sustainability; Environmental impact

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Development of novel materials and process control system in MIDES project

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Development of novel electrode materials for MDC application

Both anode and cathode electrode materials are key components of Bioelectrochemical Systems and play an important role on their performance. In the present work, different materials were assessed for anode application. The types of materials include woven and unidirectional carbon fibre fabrics as well as carbon felts. Besides, different activation procedures were undertaken, including thermal and chemical treatments.

Tailor made cathode materials have been developed by Leitat, based on carbon nanofibers (CNFs) doped with metal nanoparticles to serve as air-cathode in MDC. The main goal was to overcome low oxygen reaction reduction (ORR) kinetics, the main bottleneck of air-cathode electrodes. Different CNFs were synthesized from polymeric nanofibers with metal precursors obtained by electrospinning, followed by thermal treatment. Metal nanoparticles (Fe and Co) were synthesized inside the CNFs matrix during the fabrication process and play catalytic role. In terms of cathode materials, more than 15 materials were characterized to evaluate their performance.

ORR kinetics of different materials were characterized in an abiotic cell by electrochemical techniques. Results indicate that the developed CNFs have proper ORR performance to be used as air-cathode-MDC electrodes and the concentration of metal ion precursor in polymeric nanofibers as well as the thermal treatment are important parameters to improve final ORR performance. However, CNFs containing Fe nanoparticles showed higher performance than CNFs containing Co nanoparticles. Achieved results can lead to an overall better design of BES reactors, an improvement of power generation (in case of Microbial Fuel Cells) and a general reduction of internal resistance (in case of Microbial Electrosynthesis Cells). Air-cathode CNFs doped with Fe have been successfully tested in MDC application.

More than 20 different carbon materials, developed and provided by SGL company, were tested as anode electrode in microbial fuel cells. Anodes underwent an inoculation protocol to establish an electroactive biofilm onto electrode surface. Inoculation performance was assessed by measuring

electrochemical parameters (such as current density, open circuit voltage and cyclic voltammetry) evolution over time. Also, SEM images of electroactive biofilm grown onto electrodes surface were obtained. Results demonstrated that both carbon fibre and carbon felt materials are suitable as anode materials as these materials could be efficiently inoculated with an electroactive biofilm in less than 20 days, achieving proper current outputs (> 0.15 mA/cm2). Besides, anode open circuit potential (OCP) ranged around -350 mV Vs. SHE. Finally, cyclic voltammetry showed oxidation peaks, indicating the formation of an electroactive-biofilm on the anode surface, which was further confirmed by SEM images. These results support their use in MDC application.

Development of novel Ionic Exchange Membranes (IEMs) for MDC application

Ionic exchange membranes (IEMs) are used in a wide number of processes, which are rather different in their basic concept, practical application and technical relevance. However, IEMs carrying electrical charges are used to control the transport of ionic species and to separate them selectively from a mixture with neutral components. One of the aforementioned technologies is the microbial desalination cell (MDC).

In the context of MIDES project, FUJIFILM and Leitat have developed innovative IEMs for MDC application from FUJIFILMâ€™s current portfolio (mainly Anionic Exchange Membranes, AEMs). IEMs were specifically designed to suit the MDC process requirements: low-fouling tendency, high permeability, reduced thickness, low ohmic resistance.

Different surface modification processes were implemented to develop innovative anti-fouling and anti-scaling membranes. Also, different monomers were used to modify AEMs surface and to confer different properties such as: anti-adhesive, anti-bacterial, zwitterionic and repulsion. In a first approach, IEMs were tested in lab-scale trials in views of its future implementation at industrial production scale.

Modified AEMs properties were assessed by determining the (bio)fouling trend, humic acid (HA) adsorption test, ATP test, scaling as well as surface characterization (SEM microscope, XPS and ATR-FTIR). The surface smoothness of the membrane had no influence on the fouling performance (particulate fouling). Mainly, the fibers present on the AEM surface and the reactor spacer collected the foulant. In terms of AEMs modifications, the negatively charged monomer in the anti-fouling layer showed a positive impact on the fouling performance of the coated AEM. Mixtures of non-charged/charged monomers proved their feasibility to prevent fouling of the AEM membrane. Besides, some anti-adhesive monomers showed good activity in ATP test but not in HA adsorption test. Finally, neither zwitterionic and antibacterial monomers nor coatings with/without NP did show good results for AEM modification. Lead candidates were identified for the next step of AEMs developments: 1) coating based on a charged monomer at medium level of photo-initiator/monomer ratio and solid content, 2) 1:1 mixture of non/charged monomer at high photo-initiator/monomer ratio and high solid content. Finally, IEMs were tested in MDC experiments to benchmark their performance respect state-of-the-art membranes.

Simulation and analysis, automation and control

The mathematical models required to simulate the MIDES process are created using SimTech's IPSEpro Simulation Environment [1], within a customized model library especially created for the MIDES concept — MIDES_Lib. This component library is based on IPSEpro standard desalination library DeSal_Lib [2] and is extended in several ways to be able to simulate the MIDES overall process [3] for combined waste water treatment and water desalination.

Within the simulation environment different variants of the MIDES process can be compared and

the impact of process modifications evaluated. One main goal of the steady-state process model is to generate relevant performance figures and to assess and optimize energy consumption of the overall MIDES process.

Keywords: Anode, Air-cathode, ORR, IEMs, Fouling, Model process simulation, IPSEpro, MDC model simulation

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An innovative approach to enhance tube wetting and scale inhibition in falling film evaporators for seawater desalination

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Horizontal tube falling film evaporators are commonly used in multiple-effect distillation (MED) plants for seawater desalination. Seawater is distributed by spray nozzles onto the upper tube rows of a tube bundle, flows down onto the subsequent tube rows forming a thin liquid film and partly evaporates. In order to achieve high heat transfer performance and to limit crystallization fouling caused by calcium- and magnesium-containing salts, a closed and uniform seawater film on the evaporator tubes is required in all areas of the tube bundle.

The wetting rate, which is defined as the seawater mass flow rate on one tube divided by the tube length, is an important design and operation parameter to characterize the film flow in falling film evaporators. A low wetting rate is favorable for heat transfer, thermal and electrical energy consumption and consequently investment and operating costs. However, the falling film tends to become unstable when lowering the wetting rate. Wave formation strengthened by thermocapillary effects gives rise to film breakdown. Dry patches decrease the effective heat transfer area and therefore deteriorate the heat transfer performance. Moreover, crystallization fouling is worsened since severe scale formation preferably starts at the edges of the dry patches. Furthermore, tube wetting plays an important role in the design of MED plants and future development. Achieving uniform tube wetting represents a major task in dimensioning the tube bundles. In order to raise the MED unit capacity and to design MED plants with high thermal efficiencies, tube wetting and crystallization fouling have to be controlled. Common scale control strategies are based on the limitation of process conditions (e.g. top brine temperature, salinity and wetting rate) and the use of polymeric antiscalants.

An innovative approach to improve tube wetting and scale inhibition based on the combined use of a wetting agent and a polymeric antiscalant has been developed. The addition of a novel wetting agent developed by BASF to a falling liquid film at a very low concentration affects the film flow characteristics and improves tube wetting.

The enhancement of tube wetting by applying the novel wetting agent was studied in a horizontal tube falling film evaporator at pilot plant scale with different common tube materials such as aluminum brass, copper-nickel 90/10 and aluminum alloy AlMg2.5. Furthermore, scale formation and mitigation were systematically investigated at very low wetting rates in order to mimic bad wetting conditions, for example at the bottom of a tube bundle. The effects of the combined use

of the antiscalant and the wetting agent were studied.

Wetting experiments reveal a significant improvement of tube wetting on all investigated tube materials by applying the wetting agent at a very low concentration. Scale formation is already reduced within the tube bank by using the wetting agent alone, especially at very low wetting rates. The combined use of the antiscalant and the wetting agent shows synergistic effects and results in enhanced scale inhibition even at very low wetting rates and in critical tube areas in terms of wetting such as the tube ends.

Keywords: Recent developments in desalination, Multiple-effect distillation, Novel wetting agent, Tube wetting, Scale formation

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Crystallization fouling propensity of novel polymer composite heat exchanger tubes compared to metal tubes

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Metals such as stainless steel, copper, nickel and aluminum alloys, and titanium are common construction materials for heat exchangers. However, metals may suffer from failure due to corrosion and erosion, especially in harsh environments prevailing, for instance, in industrial water treatment and desalination applications. In addition, metals have disadvantages in terms of weight and cost and they are prone to fouling. Thus, it is a major concern of various industries to find alternative materials for heat exchangers that can overcome these disadvantages. Driven by the high chemical resistance, low weight, great freedom in shaping and low cost of many polymers, considerable attention has been dedicated to the development and implementation of polymer heat exchangers. However, the major drawback of polymer materials for using them in heat exchange applications is their low thermal conductivity.

Innovative thermally conductive polymer composite tubes based on polypropylene (PP) or polyphenylene sulphide (PPS) filled with graphite have been developed by Technoform Kunststoffprofile GmbH (Lohfelden, Germany). A special extrusion process allows high filler loadings of up to 75% and the orientation of filler particles in the polymer matrix to reach enhanced thermal conductivities in the radial direction of about 13–20 W/(m K). The tubes open up cost-efficient opportunities for heat exchangers in various applications such as industrial water treatment and seawater desalination.

Crystallization fouling of inversely soluble salts is one of the biggest problems in thermal plants for industrial water treatment and desalination. Scale formation on the heat transfer surface creates an additional resistance to heat transfer decreasing the performance of the heat exchanger. Over-sizing the heat transfer surface area, cleaning procedures as well as production losses during plant shutdown create considerable capital, operating and maintenance costs. Operating parameters, solution composition and properties of the heat exchanger material are influencing factors for crystallization fouling. Scale formation on metal surfaces has been extensively studied. However,

fouling data for polymer surfaces are very limited.

Various test rigs have been designed and installed at the University of Bremen to study crystallization fouling on different tube materials and to get an indication of the fouling propensity under practical conditions. In the current study, a stirred vessel test rig and a horizontal tube falling film test rig were used to compare the fouling propensity of the novel polymer composite tubes and common stainless steel tubes. The induction period, the initial fouling rate and the asymptotic fouling resistance were measured. Results obtained with calcium sulphate solutions and mixed salt solutions containing calcium carbonate and calcium sulphate will be presented and discussed.

The novel polymer composite tubes showed a lower crystallization fouling propensity compared to the stainless steel tubes. The induction period was longer and the reduction of the overall heat transfer coefficient over time was notably lower compared to the metal tubes.

Keywords: Recent developments in thermal seawater desalination and industrial water treatment, Novel polymer composite heat exchanger tubes, Scale formation

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A supercapacitor charge for a photovoltaic-powered desalination system

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The development of renewable energy powered membrane (RE-membrane) desalination systems is of increasing interest as a solution for providing clean drinking water in smaller communities, especially in remote areas and developing countries. In a photovoltaic membrane (PV-membrane) system, the amount of power generated fluctuates due to clouds passing in front of the sun, while there are periods of intermittency without power, both at night and under heavy cloud. The lack of power can result in lower permeate quality as well as reduced daily permeate production.

Usually energy storage devices are employed to balance demands from the electrical load with the power generated from the PV system. Energy storage technologies such as supercapacitors (SCs), batteries, pressure accumulators have been previously used for energy buffering in small-scale RE-membrane desalination system [1-3]. Amongst them, SCs are favourable for buffering fluctuations and periods of short-term intermittency in the systems due to high efficiency, long lifetime and a high number of charge/discharge cycles, hence improving both permeate quality and daily permeate production as well as reducing the specific energy consumption (SEC) [4]. Typically, SC's are introduced as passive components or a controlled via a simple on-off approach [4]. Consequently, once the lower threshold of state-of-charge (SOC) of the SCs is reached (and there is no power source available), the RE-membrane system either shuts down or becomes directly subjected to the power fluctuations. This is potentially harmful to the permeate quality, as well as increasing the potential wear of the pump and motor.

In this work, a charge controller is developed to ensure the best use of power generated from the PV panels when the SCs are either being charged or discharged. The controller can monitor and control the power and charge states via the microcontroller, which measures both voltage and current and has RS232 communication implemented. The SCs are connected to the PV panels

via a charge controller, which is demonstrated to buffer short-term fluctuations in solar irradiance for up to six minutes. The various operating states of the controller are reached via determining the voltage thresholds (Vth_low, Vth_high, Vmax). Voltage sensing can be used as a measure of the amount of energy stored in the SCs since it is directly proportional to the voltage and capacitance.

Experiments to verify the performance of the interface were carried out under very cloudy conditions. On this day, the solar irradiance varied from 150 to 980 W/m^2 (data interval 60 s) over a 7.5 h period, with no charge controller and SCs present, using synthetic brackish feed water (7812 µS/cm NaCl). Results show that the PV-membrane system shut down for 30 min due to the lack of power during this period, while it is capable of producing 0.4 m^3 of clean water (280 µS/cm NaCl) with a recovery less than 30% and retention higher than 96%. The robust charge controller is expected to deal with three greatly different solar days (sunny, very cloudy, partly cloudy) exhibiting different levels of fluctuation and intermittency. Further, the control system was successful in matching the membrane to a particular feed water salinity, which enable the PV-membrane system to achieve the highest permeate production complying with drinking water guidelines at the lowest SEC.

Keywords: Photovoltaic, Reverse osmosis, Nanofiltration; Supercapacitors, Energy buffering

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A kinetic approach to corrosion control by $CaCO_3$ films

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Since desalinated water is devoid of minerals, it is of corrosive nature and cannot be conveyed through iron pipe systems without appropriate treatment. The approach to this problem is based on the traditional method of forming a corrosion protective coating of calcium carbonate. Acidified desalinated water is contacted with $CaCO_3$ particles in order to introduce dissolved calcium and carbonate ions into the water so as to make it supersaturated with respect to $CaCO_3$. The aim is to control the supersaturation such that it is at a level which is not sufficiently high to create scale deposition difficulties and is still able to deposit an adequate $CaCO_3$ corrosion protection film. It is however recognized that the considerable research efforts aiming to provide water composition criteria for controlling the formation of a $CaCO_3$ coating yielded only rough qualitative guidelines with the goal of reliable quantitative criteria remaining elusive.

Several issues generate uncertainties in predictive abilities. All developed criteria that specify water compositions aiming to ensure deposition of an adequate calcium carbonate layer are of a thermodynamic nature, ignoring the fact that the deposition is governed by process kinetics. The most common criteria, LSI and CCPP, denote the extent of a supersaturation level with no information on the rate of deposit formation other than the qualitative understanding that the higher the supersaturation level, the higher the deposition rate.

The above approach, which attempts to control a kinetic process by thermodynamic tools, leads to inconsistencies in regulatory specifications. The objective of this paper is to stress the need to modify the current approach by application of quantitative kinetic criteria. It will be shown that induction time assessment and $CaCO_3$ deposition rate evaluation are essential kinetic tools for guiding the formation of adequate $CaCO_3$ protective layers and should therefore be fully integrated in regulatory specifications of remineralized desalinated water composition.

Keywords: Corrosion protection, Remineralzed desalinated water, Supersaturation control, Kinetic approach

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Utilization of calcined gypsum in water and wastewater treatment: removal of ibuprofen

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Adsorption is a widely used technique for the removal of pharmaceutical organic micro-pollutants. In this article, calcined gypsum ($CaSO_4.1/2H_2O$) was utilized for the removal of ibuprofen medicine from polluted water. Several factors including the adsorbent dose and contact time were studied. From thermodynamic parameters, the negative values of ΔG° indicated a spontaneous and physisorption process of ibuprofen onto the calcined gypsum surface. Kinetic study results showed that the adsorption of ibuprofen follows the pseudo-first order kinetics.

Keywords: Calcined gypsum; Wastewater treatment; Removal; Ibuprofen

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The effect of some green inhibitors on the corrosion rate of Cu, Fe and Al metals

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Density functional theory (DFT)with B3LYP/6-31G* level (d, p)have been performed on APDTC, CMI, HPMA, PASP and PESA polymersas a green source of environmentally friendly corrosion inhibitors for Cu, Fe and Al metals. Global quantum parameters of inhibitors and thermodynamic Gibbs function (ΔG_{ads}) of adsorption of metals have been calculated and used to investigate the efficiency of the corrosion inhibition of each inhibitor. Our results showed that APDTC exhibits the highest anti-corrosion efficiency among all compounds with Cu, Fe and Al metals showing remarkable

inhibition efficiency with Cu comparing with Fe and Al. The distinguished corrosion inhibition of APDTC is explained by its unique high electrophilicity power ω and ΔG_{ads}.

Keywords: DFT, Metals, Polymers, Green inhibitors, APDTC

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Development of a dashboard for energy consumption management in activated sludge treatment plants using analytic hierarchy process

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Wastewater treatment plant is a structure that needs a precise and rigorous control to obtain satisfactory results of purification efficiency, low cost energy and discharges compatible with environmental standards.

In the present paper, a dashboard was performed to manage, control and monitor the operation of an activated sludge process of a wastewater treatment plants to make the right decisions for the situations encountered. Based on daily variation of different criteria necessary for the estimation of the biological treatment process, that is: energy consumption, purification efficiency, respect of rejection standards considering pollution degree of the income wastewater.

A data analysis was performed, combining two methods: Analytic Hierarchy Process (AHP), as a multicriteria analysis tool of all observations, and Principal Component Analysis (PCA) for the weighting of the criteria and sub-criteria considered. The dashboard elaborated allows the classification and estimation of the performance of different management strategies in wastewater treatment plant based on the importance allowed to each decision criteria. The result is a tool for an efficient management of wastewater treatment plant.

Keywords: Dashboard, AHP, PCA, Wastewater plants, Activated sludge.

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Emerging technologies for next generation low carbon power-desal plant configurations

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Water scarcity is a significant challenge and is intrinsically linked with the demand growth for energy. Globally, renewable energies are rapidly increasing their share in the global mix, with solar energy having the greatest potential. Many countries with water scarcity are blessed with high solar radiation levels and high population areas typically along the coast, the conclusion seems clear that emerging power generation and desalination technologies must be further developed to utility-scale applications and system integration and optimization is the roadmap to achieve the next level of cost reduction and for a sustainable long -term solution. Provision of clean water inevitably requires energy, which is currently being provided primarily by non-renewable fossil fuels in GCC countries. This paper presents innovative concepts for economical, reliable, sustainable, low carbon power-desal configurations using emerging power generation cycles, solar-thermal heat and PV.

Keywords: Renewables, Carbon footprint, Sustainable

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Novel feed spacers design for fouling mitigating in membrane filtration

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Hydrodynamic characteristics and fouling pattern are significantly influenced by the geometrical design of the feed spacer in a spiral-wound membrane module. In the present work, novel spacer designs are proposed by modifying the filament geometry at elemental level using perforations and then in-house prototyped using 3-D printing technology. Three different designs consisting of symmetric spacers having different numbers of perforations are investigated: 1-Hole design (single perforation at spacer filament intersection), 2–Hole design (single perforation at filament intersection and one at filament center) and 3-Hole design (single perforation at filament intersection and two perforations at filament). Direct Numerical Simulation studies were initially performed to optimize spacer designs and to elucidate the fundamental hydrodynamic occurring at an elemental level. Unsteady micro-jets were formed inside the filament cells which had potential to sweep away the foulants and particles from the membrane surface. The optimized designs were also experimentally studied to check the performance of these spacers in an in-house designed membrane filtration cell. Impact of perforations on permeate flux, pressure drop and fouling development were investigated. 1-Hole spacer produced the highest permeate flux among the perforated spacers with 75% (at constant pressure) and 23% (at constant feed flow) flux recovery relative to standard spacer (without holes). Fouling development was monitored using Optical Coherence Tomography

(OCT) and the cleanest membrane surface was observed for the 1-Hole spacer which potentially leads to highest permeate flux production. However, in terms of energy consumption, the 3-Hole spacer reduced the net pressure drop across the spacer filled channel reaching 50%-61% when compared to standard spacer.

Keywords: Perforated spacers, Optical coherence tomography (OCT), Novel design spacers, CFD, Filtration, Fouling

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Novel VMD configuration for water vapor flux enhancement

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Membrane Distillation (MD) has four major process configurations, namely direct contact MD (DCMD), air gap MD (AGMD), sweeping gas MD (SGMD) and vacuum MD (VMD). Other configurations based on the conventional ones, such as liquid/water gap MD or material gap MD, are also possible. All these configurations are options at the coolant side of the MD module. However, the major challenges of the MD process, such as temperature polarization (TP), are dominated at the feed side. In this work, a novel custom-made vacuum MD (VMD) module design, namely flashed-feed VMD, is proposed. It consists of decoupling the effect of TP from the membrane mass transfer coefficient (MTC) by preventing the liquid feed stream from contacting the membrane surface (at the feed side). Results showed that a transmembrane temperature difference of 10°C at the membrane surface/interface (representing TP) is estimated to take place in the typical VMD configuration, while our novel configuration eliminates TP effect and gives a flux 3.5-fold higher under similar operating conditions. Therefore, it can be concluded that heat transfer coefficient is considered to be the main factor controlling resistance of water vapor flux in the typical VMD configuration. The MTC was found to be more accurate and the highest among all reported values in the literature. This configuration was then evaluated under large scale module operating conditions and it was found that a ΔT of 5°C and 10°C in the novel configuration can produce water vapor fluxes of about 9 kg/m^2.h and 40 kg/m^2.h, respectively, at an inlet feed temperature of 70°C, which is very attractive for industry implementation.

Keywords: Vacuum membrane distillation (VMD); Flashed-feed VMD configuration; Desalination; Mass transfer coefficient (MTC); Temperature polarization (TP)

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Performance of acacia gum as a novel additive in thin film composite polyamide RO membranes

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Novel thin film composite (TFC) polyamide (PA) membranes blended with 0.01 – 0.2 wt. % of Acacia gum (AG) have been prepared using interfacial polymerization technique. The properties of the prepared membranes were evaluated using contact angle, zeta potential measurements, Raman spectroscopy, scanning electron microscopy, and surface profilometer. It was found that, the use of AG as an additive to TFC PA membranes increased the membrane's hydrophilicity (by 45%), surface charge (by 16%) as well as water flux (by 1.2 fold) compared with plain PA membrane. In addition, the prepared PA/AG membranes possessed reduced surface roughness (by 63%) and improved antifouling behavior while maintaining NaCl rejection above 96%. These findings indicate that AG can be used as efficient additive to enhance the properties of TFC PA membranes

Keywords: Reverse osmosis, Polyamide membrane, Salt rejection, Acacia gum, Interfacial Polymerization, Hydrophilicity, Surface charge, Antifouling properties

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Surface coating of polymer membranes for water treatment: a new approach to mitigate fouling

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The main problem arising upon water treatment and desalination with pressure driven membrane processes such as microfiltration, ultrafiltration, nanofiltration and reverse osmosis is membrane fouling that seriously hampers the application of the membrane technologies [1]. In general, membrane fouling is mainly determined by the foulants' ability to adsorb on the membrane surface [2]. Therefore, one of the main strategies towards reducing membrane fouling is the prevention of the undesired adsorption or adhesion between a foulant and a membrane to inhibit or, at least, to minimize the fouling process The surface coating of the membranes via layer-by-layer (LbL) deposition of polyelectrolytes seems to be a simple and flexible technique to improve the membrane fouling resistance [3,4].

In this study composite polyamide membranes NF-90, NF-270 and BW-30 were modified via LbL approach using electrostatic deposition of polyelectrolyte multilayers made from various polycationic and polyanionic polymers of different molecular weights. Four anionic polyelectrolytes such as: poly(sodium 4-styrene sulfonate), poly(vinylsulfonic acid, sodium salt), poly(4-styrene sulfonic acid-co-maleic acid) sodium salt, poly(acrylic acid) sodium salt and three cationic polyelectrolytes such as poly(diallyldimethylammonium chloride), poly(ethylenimine) and poly(hexamethylene biguanide were used for modification. The surface morphology of the prepared composite membranes were studied using atomic force microscopy. An effect of deposition time, a number of polyelectrolyte layers, chemical nature and molecular weight of used polyelectrolytes on degree of membrane modification has been evaluated.

It was shown that the surface charge of LBL modified membrane can be switched between positive and negative after coating with a cationic or an anionic polyelectrolyte. The contact angles of unmodified NF90 and BW30 membranes and LbL modified samples decrease with increasing a number of polyelectrolyte layers. The hydrophilization of the modified membranes might reduce their fouling with organic compounds and microorganisms.

The antimicrobial properties of the modified membranes towards *Pseudomonas aeruginosa* bacteria have been studied using confocal imaging of the bacteria's growth on the membrane surface. A clear difference in the number of live and dead cells on the membrane surface were found when comparing the unmodified BW30 membrane and the modified membrane sample. A possible mechanism of the bactericidal action of the modified membranes has been discussed. An enhanced performance of the modified membrane samples was shown during treatment of sea water in the non-continuous regime.

Keywords: Polymer membranes, Surface coating, Polyelectrolytes, Membrane fouling

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Optimization of the sequence of cleaning and replacement of reverse osmosis membranes

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Advance in membrane technology make it possible to use reverse osmosis as a water treatment process. However, due to the characteristics of membrane-based process, foulants in the feed water is accumulated in the membrane. Membrane fouling is a major cause of degradation of the process performance. When fouling is deposited in the membrane, operating pressure should be

increased to meet the designed freshwater production. In this case, energy consumption increases, and operating cost increases due to increase of operating pressure. Periodical cleaning and replacement of membrane can recover the process performance and reduce energy consumption. The criteria of cleaning state are proposed by membrane manufacturer. Increase of normalized pressure drop in the range of 10–15% is usually used. Also, it is suggested that cleaning the membrane after 3–12 months of plant operation depending on feed water quality. However, these kinds of decision making are based on the operator's experience. Determination of membrane state based on the operator has limitation that unnecessary cost is consumed due to the determination of inaccurate cleaning timing.

The objective of this study is to investigate the optimal sequence of cleaning and replacement of reverse osmosis membrane. Constant flow operation model was proposed using the previously-developed model to investigate performance change in reverse osmosis process after membrane cleaning and replacement. The model can simulate deposition of fouling on the membrane with time. Then, the membrane cleaning and replacement were performed to analyse the change in the process performance. The membrane in the model was cleaned or replaced when the model simulation reached the cleaning and replacement criteria. Using the simulation results, it was suggested that an optimal sequence of cleaning and replacement to minimize operating cost. The results from this study can be used to predict performance of reverse osmosis process.

Keywords: Reverse osmosis, Membrane cleaning and replacement, Operating cost

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The design of a unit sweeping gas membrane distillation: experimental study on a membrane and operating parameters

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This article focuses on the application in membrane processes for the desalination of salt brines using the sweeping gas membrane distillation (SGMD) process is studied. SGMD is the least used configuration of membrane distillation (MD). As a result, the design of the system is complicated and rather expensive. Similarly, SGMD can be used to treat solutions containing non-volatile compounds, such as salts. Salt rejection is almost 100% and high purity water can be obtained. Vapor transfer is an important thermally induced phenomenon in the membrane membrane (MD) by membrane evaporation and membrane condensation. In our study, mass transfer phenomena in

sweeping gas membrane distillation (SGMD) were examined and the effects of the parameters on the process were studied. We found that the mass transfer in the SGMD is determined by the evaporation temperature of the gas and the sweep rate, so it influences the operational parameters (fluid velocity) across the layer on both sides of the the membrane, which causes great importance for the transfer of heat and mass in many membrane processes.

Keywords: Vapor transfer; Membrane distillation; Mass and heat transfer; Sweeping gas membrane distillation

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Experimental performance investigation of a silica gel-based adsorption desalination system: Effect of brine salinity and vapor pressure

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In this paper, we developed a prototype of adsorption desalination (AD) system using commercially available alumina-silica gel and attempted to evaluate, demonstrate and improve the performance of AD system. Thermophysical properties and surface characteristics of the adsorbent were investigated using a nitrogen adsorption isotherm at 77 K based on the static volumetric method, followed by the adsorption equilibrium isotherms of water vapor on the adsorbent, to identify its applicability as a candidate adsorbent in the AD system. The performance of the AD system was then evaluated for the different types of brine feeders in the evaporator (i.e., perforated plate and spray nozzles) using tap water as a feed over a wide range of operating conditions such as hot-, cooling- and chilled-water temperatures, which was assessed in terms of specific daily water production (SDWP) and specific cooling capacity (SCC). Furthermore, the AD process of seawater at a high water recovery operation was conducted to demonstrate the desalting mechanism and

consistent desalination performance of the AD process in contrast to the existing thermal driven desalination technologies such as MSF and MED. It was observed that the performance of the AD system was not affected by the brine concentration in the evaporator, at least up to about 80% water recovery, and the chemical quality of produced fresh water was demonstrated to be comparable to deionized water quality. This was because the desalting by evaporation was initiated by the affinity of the silica gel to the water vapors, and more specifically the water production in the AD system was basically governed by the adsorption isotherms of the adsorbent-adsorbate pair, depending only on the temperature and pressure of adsorption and desorption conditions. It was also noted that the enhancement of water evaporation by using spray nozzles in the evaporator led to a higher vapor pressure in the evaporator and thereby resulted in an increased water uptake on the adsorbent and a shortened evaporation-adsorption process and thus, a higher SDWP and SCC.

Keywords: Adsorption desalination; Brine salinity; Vapor pressure; Performance evaluation

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The values of water

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The value of water is generally thought of as the cost of water. If this were always true, governments and municipal agencies would only purchase the least costly next increment of water. But, many agencies find value in adding non-conventional water sources to augment traditional surface and groundwaters. The presentation explores a number of values beyond cost based on our ability to manufacture "new" water through advanced water treatment technologies. The presentation also looks at the impacts of innovation on the values of water and asks what that might make possible.

Keywords: Advanced water treatment, Desalination, Value of water, Cost, Non-conventional water sources

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Dynamic modelling and analysis of an industrial reverse osmosis plant for scheduling and control with renewable energy power input

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Throughout the last decade, desalination industry using reverse osmosis (RO) has grown constantly in response to water scarcity challenges faced by a number of countries. Although the energy required for RO desalination is approaching the thermodynamic limit, it is still considered an energy-intensive process. Accordingly, several studies used renewable energy sources (RESs) to drive RO plants at small scale. However, the technology has not yet been transferred to large-scale applications, especially without using backup systems. This studyispartofaninternationalprojectthataimstoaccommodatethevariableandintermittent nature of RESs thus making possible the large-scale implementation of renewable energy- driven RO. As an initial step, the work presented aims to develop an understanding of an RO plant's dynamic behaviour, to help develop a method for plant scheduling and to select and tunethecontrolsystem.Consequently,adynamicmodelofasimpleROplantwillbepresented based on the solution-diffusion model. In addition, the dynamic response of permeate fluxand conductivity to step changes in feed flow rate and feed pressure will beanalysed.

Keywords: Reverse osmosis; Dynamic Model; Solution-diffusion model; Transient response; Renewable energy

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Application of a model-based method for hydrodynamic processes in constructed wetland to management of livestock wastewater based on finite element method

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Nowadays, the increase in production and concentration of intensive livestock operation throughout the years all around the world, together with mismanagements of livestock manure, have raised the risk of contamination to the environment. The increasingly strict environmental regulation has created the need to find several solutions which combine low-cost facilities and

resource efficiency in wastewater treatment. Constructed wetlands (CWs) are now more widely applied than other technologies as an alternative of conventional methods. Several models of biochemical reaction in CWs have been developed over the last 60 years, however the great majority of authors agree that it is necessary to approach with more in-depth understanding processes in these treatment systems.

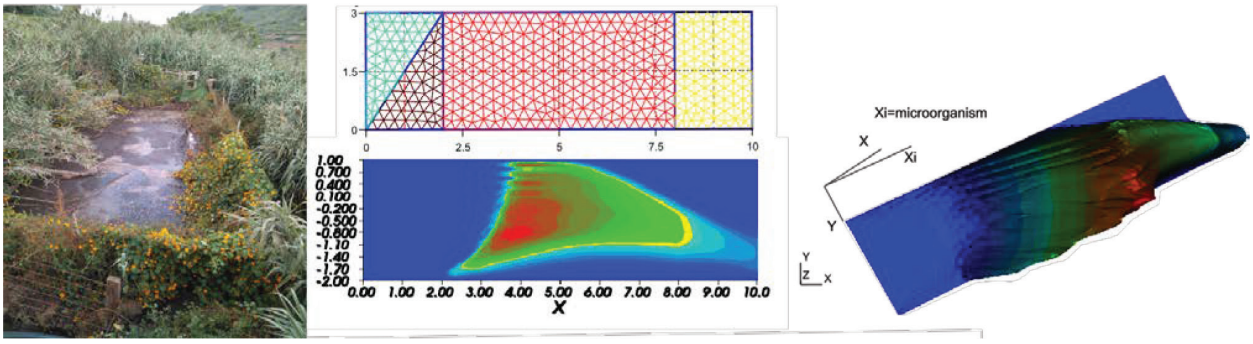
The main objective of this work has been to develop a computational fluid dynamic (CFD) Model to describe anaerobic digestion, that regularly occurs into the CWs in order to simulate the complex physicochemical and biochemical processes, offering higher spatial resolutions and different reaction rates, and considering simultaneous processes.

The method involves, simultaneously, dynamics characteristics of fluids with kinetic growth based on the IWA Anaerobic Digestion Model N°1 (ADM1). A mathematical model was developed based on mass balance for each system component, resulting 18 non-lineal system for second-order elliptic equations. On the other hand, a generalized Stokes variational formulation was implemented to describe the hydraulic performance. Finite element method (FEM) was applied to solve the equations subjetcted to Dirichlet and Neumann boundary conditions. To validate the method, simulations implemented with FreeFem++ are presented.

The obtained result offers dynamic behaviour of the model solutions for the microbial and the substrate in CWs, for each one of the phase of the biological processes. The performance will depend on the boundary condition. The result indicates that the model was be able to simulate, with good accuracy, substrate, microorganism, pH and total volatile fatty acids (TVFA) concentrations inside the system.

The conclusion was that the model was successfully implemented to simulate biochemical and physicochemical processes in CWs. This original method of simulation which has been applied to CWs allows develop different design including boundary conditions. Plans for the future will be to develop 3D model and to validate the results with experimental models.

Keywords: Constructed wetland; Water quality; Anaerobic digestion ; ADM1; Numerical simulation; Finite element method



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Application of the ADM1 model in a batch multi-chamber anaerobic digester

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A model of anaerobic digestion process is a very useful tool that allows to determine the effect of the characteristics of the substrate and the load in the evolution of the process, to implement control systems in the operation, to predict the development of processes and to improve the knowledge of them in comparison with experimental data and test assumptions.

In this article, a model proposal based on the ADM1 is described, which corresponds to a digester installed in a livestock farm since 2008 together with natural treatment wastewater systems (NTWS), formed by three serial chambers. This biodigester follows a batch workflow and it is a key element in the design of NTWS, in which a typical anaerobic process is developed that allows modeling with several variables and clear and defined equations.

Starting from a system with a reactor with continuous load, the mathematical model has been adapted to be able to simulate a complete mixing reactor operating in batches. In the references consulted, digestion takes place in a single anaerobic digester. Once the proposed model has been implemented, it can be assumed that this process can be extrapolated to multiple serial digesters.

Simulations have been carried out taking different initial states, volumes of digesters, different seasons of the year, etc. Throughout all the simulations it has been proved that, with the proposed model adapted to three serial digesters operating on a discontinuous basis, you get a stable response from the system.

The proposed model of the anaerobic digestion process allows to analyse the behavior, thus it can be predicted the concentration values of the substances and chemical elements, for a certain substrate.

Keywords: Anaerobic digestion, Batch digester, ADM1, Mathematical model

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Effect of pressure on feed solution at hollow fiber FO process

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In these days, wastewater reclamation and seawater desalination play essential role in addressing the challenge of worldwide water scarcity. Particularly, reverse osmosis (RO) for seawater desalina-

tion process is commonly used due to less energy consumption than conventional thermodynamic systems. However, membrane fouling and electrical energy consumption during operation of RO system for seawater desalination haver continued to be a obstruction to its application. Forward osmosis (FO) process has been attracting attention for its potential applications such as industrial wastewater treatment, wastewater reclamation and seawater desalination. Particularly, in terms of fouling reversibility and operating energy consumption, FO process is assumed to be more preferable to RO process. The objective of this study was to optimize operating condition of pilot scale hollow fiber FO process. The experimental water flux with different module lengths was first compared with the modelling result to validate the suitability of modelling process. After then, fouling along the membrane module length and subsequent fouling reversibility were evaluated by systematic fouling experiments simulated by modelling. Finally, the effect of flow configurations on fouling distribution was assessed by employing different cross flow directions. The simulated fouling experiments revealed that higher fouling and thus more flux decline were observed at the last section of a membrane module, as foulants in feed solution became more concentrated. Furthermore, the water flux in FO process declined more severely as the recovery increased due to more foulants transported to membrane surface with elevated solute concentrations at high recovery. Lastly, it was revealed that such fouling distribution was slightly less in counter-current operation as expected from less feed concentration and draw dilution, particularly at smaller module lengths.

Keywords: Forward osmosis, Reverse osmosis, Desalination, Hollow fiber

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Study on liquid film thickness and flow characteristics of falling film outside an elliptical tube

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In this paper, the volume-of-fluid (VOF) method is used to simulate the falling process of liquid film outside the elliptical tube. The corresponding Re number is 187 and the flow mode is stable column flow. Long half-axis of the ellipsoidal tube is 26mm and the short half-axis of the ellipsoidal tube is 13mm. The countercurrent airflow speeds of 0.1 m/s and no airflow effects are simulated. The 3-D numerical simulation results show that the liquid film thickness increases first and then decreases along the circumferential direction of the elliptical tube. And the position of the minimum liquid falling film thickness is about 120° in a static environment. The countercurrent velocity of

0.1m/s causes slight disturbance to the falling film, and the minimum liquid film thickness angle is advanced.

Keywords: VOF method, Falling film, Counter-current air flow, Liquid film thickness, Flow behavior

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Mechanisms and control of scale formation in FO membrane under low temperature conditions

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Many researches have been actively carried out using a forward osmosis (FO) membrane process capable of producing fresh water using osmotic pressure generated by high concentration salts present in seawater or artificial draw solutions. Municipal and industrial wastewater are used as a feed water for FO process which have various conditions and properties. In cold regions, the water temperature is low (~ 0 °C), leading to difficulties in treating wastewater of low temperature. If FO process is applied, it should deal with such wastewater. Unfortunately, little information is available on the capability of FO for the treatment of low-temperature wastewater. Accordingly, this study intends to examine the technical feasibility of FO process applied to treat low-temperature feed water. The effect of feed temperature on fouling and $CaSO_4$ scaling of FO membranes was investigated in a bench-scale experimental set-up using flat sheet commercial FO membranes. The effect of draw solution temperature was also examined. Mechanisms of scale formation under low temperature conditions were explored. The effectiveness of antiscalant to control scale formation in FO process was studied as a function of feed temperature. Results showed that the mechanism of scale formation under low temperature are different from those under room temperature and high temperature conditions. The kinetics of scale formation was also affected by the feed water temperatures. The comparison of morphologies of the crystals on the FO membrane surfaces revealed the different mechanisms of scale control by antiscalants under different temperatures.

Keywords: Forward osmosis (FO), Low temperature, Gypsum scaling, Antiscalant, Mechanisms

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Performance of ceramic membrane for closed hydroponic system

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Rooftop greenhouses have gained interest due to the recent significant population growth in urban areas. Most of the greenhouses adopt hydroponic cultivation, which is a method of growing plants without soil using nutrient solutions. In closed hydroponic system, the nutrient solution is treated and reused instead of replacing the entire solution. Although closed hydroponics system provides savings in water and fertilizer, potential spread of root-infecting pathogens need to be controlled. This study investigates the application of ceramic membrane for reuse of hydroponic nutrient solutions. Ceramic membrane was chosen due to high mechanical, thermal, and chemical stability, bacteria resistance and ease of cleaning and sterilization over polymeric membranes. The major limitation of membrane for closed hydroponic system is membrane fouling by organics and inorganics. To mitigate the membrane fouling, a cylindrical membrane module with retentate port was designed for vortex-flow on the membrane surface. The effectiveness of vortex-flow on membrane fouling was investigated using the kaolin solution at various vortex-flow velocities. Even in high turbidity of 200 NTU, the ceramic microfiltration membrane high reversibility of membrane fouling and constant removal efficiency. In addition, the nutrient quality did not change after the ceramic membrane filtration.

Keywords: Ceramic membrane, Closed hydroponic system, Vortex-flow, Fouling, Turbidity

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Power generation and performance enhancement of energy recovery turbine

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Hydraulic turbines are widely used for power generation from potential energy of the water. There are several types of them and the selection depends on the normal operating conditions such as flow rate and water head (or pressure indicated as potential energy). In hydrodynamic perspectives, PRO process normally operates under high pressure and low flow rate relatively. Under these working environments, Pelton type turbine can be selected as one of good devices for energy recovery of PRO process and electric power can be efficiently generated through high pressure energy of the concentrated saline water.

This research is focused on some evaluations of power generation and performance enhancement of Pelton turbine for energy recovery in PRO system, which include the hydrodynamic design of Pelton turbine, some loss models for performance prediction and the experimental results on some methods to increase the hydraulic efficiency. At the design operating point (400 ton/d flow rate and 30 bar pressure), the hydraulic efficiency of the Pelton-type ERT with a circular casing was approximately 85.3% by the performance test and the electric power was generated up to 10 kW which corresponded to approximately 77.2% energy recovery efficiency.

Keywords: Energy recovery turbine, PRO (pressure-retarded osmosis), Desalination, Pelton turbine, Power generation, Hydraulic efficiency

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Recovery of magnesium with high purity from seawater desalination brine using an organic solvent

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As the global seawater desalination industry widely grows, there are many increasing interests in the environmental issue that concentrated brine is released into the sea. Quite a few researches, therefore, have been conducted to recover the valuable resources including magnesium from the brine. Calcium is the main impurity in the recovered magnesium resource. In this study, magnesium was recovered from the seawater desalination brine in a form of magnesium sulfate with higher than 99% purity through a three-step process (pre-precipitation, concentration, and precipitation). Note that the concentrations of magnesium and calcium in the brine were 2400 mg/L and 600 mg/L, respectively.

From the brine, firstly, the magnesium was precipitated in a form of $Mg(OH)_2$ using paper sludge ash, which is an alkali by-product. Next, magnesium was eluted with sulfuric acid, and the magnesium concentration of the eluent was 8000 mg/L corresponding to 3.5 times that of the brine. Finally, organic solvents such as acetone and ethyl alcohol were added into the eluent to precipitate magnesium in a form of magnesium sulfate. The organic solvent was appropriately added through two sub-steps to remove calcium, thereby improving the purity of magnesium sulfate. When the ratio of the eluent to the organic solvent was 1:0.4, most of the calcium and a small amount of magnesium were precipitated from the eluent. After removing the precipitated solids, the organic solvent was further added to the calcium-free eluent to finally precipitate high purity of magnesium. It was

found that the optimum ratio of the eluent to the organic solvent is 1:0.6 to recover magnesium in a form of $MgSO_4 \cdot 7H_2O$ with a high purity (99.8%). A total of 10 kg of magnesium sulfate was recovered from 1 ton of seawater desalination brine through the three step processes.

Keywords: Seawater desalination brine, High purity of magnesium, Magnesium sulfate, Organic solvent, Paper sludge ash, Sulfuric acid

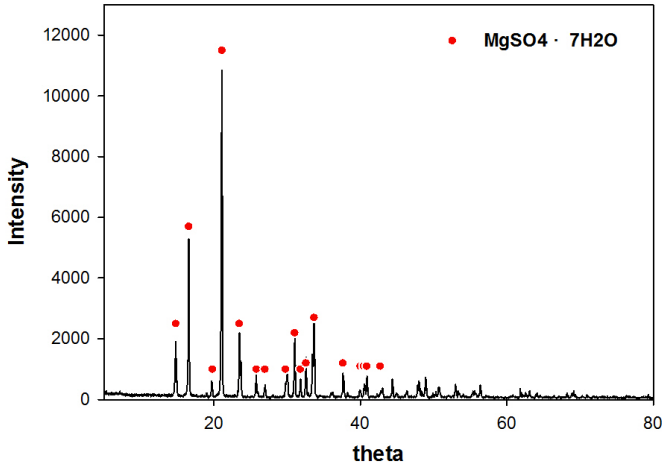

Fig. XRD pattern of recovered magnesium sulfate from the seawater desalination brine

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Cloud-based design optimization based on simulation of desalination systems powered by renewables

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Many people around the world (>1 bn) do not have access to clean water. Many times, there is available water either brackish or sea water, which could after desalination meet the needs of this population. At the same time most of this population lives in rural remote areas, which often does not have access to electricity. Renewable energy especially in the form of solar photovoltaics can be used to power autonomous power systems which in turn can power the desalination units. Currently, the design process of such systems usually takes place in two distinct steps. The first step includes the design of the desalination system based on the required potable water profile and an assumption relating to the capacity factor of the unit (average hours of operation per day) and the second step includes the design of the renewables system based on the desalination unit designed in the first step. Essentially this means that a power profile is generated initially, which is then used as input for the design of the renewables system. Experience has shown that this approach can lead to non-optimized systems. In smaller systems (<5 m^3/d) the differences in cost are

marginal and as a result the impact on the total cost of the system is minimal. On the other hand, for higher production systems (>50 m^3/d) this reality can lead to a considerable cost impact. The presented solution is built on the Fortissimo marketplace. The Fortissimo Marketplace provides one-stop, pay-per-use, on-demand access to advanced simulation, modelling and data analytics resources including software, hardware and expertise*. The novelty of the proposed approach lies in the simultaneous optimization of both the desalination system and renewable energy system, along with the control system. Since renewable energy depends on the weather conditions, yearly simulations must take place for the optimization procedure using a time-step equal to 15 min or less. The number of variables to be optimized is large (>10) and even with the use of advanced heuristic methods (e.g. particle swarm optimization) the computational time needed is big. Using a cloud architecture with considerably higher computational power can minimize the needed time. As a result, an optimized design leads to systems presenting lower cost of water.

Keywords: Cloud computing, Optimization, Design, Renewables, Reverse osmosis, Artificial intelligence

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High performance RO membranes comprising cucurbit[6]uril as a selective water transport channel

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Despite many efforts to understand the nature of nanoporous materials, it is still rare to find research that demonstrates experimental evidence of selective water transport through their pores or channels. In this work, we present the first practical evidence for selective water transport through cucurbit[6]uril (CB[6]) and the underlying mechanisms elucidated by molecular dynamics simulation. We confirm that CB[6] is energetically favorable for water permeation while preventing salt passage due to a high energy barrier. These characteristics stem from its carbonyl-fringed portals, which are well-defined with a right dimension (3.9 Å) and have a partial negative charge. Such unique characteristics allow a thin-film nanocomposite membrane comprising CB[6] to perform better than both commercial membranes and recently developed thin-film nanocomposite membranes. Furthermore, our molecular dynamics simulations reveal that CB[6] assembled into two-dimensional porous nanosheets possesses great potential as a next-generation desalination membrane.

Meanwhile, increasing the surface porosity of a support membrane has been proposed as an effective way to improve the water permeability of thin-film composite (TFC) reverse osmosis

(RO) membranes by reducing the diffusion pathway in the active layer. Thus, we prepared a highly porous microstructured (HPμS) support membrane with a suitable mechanical strength to enhance the water permeability of an RO membrane. The HPμS support membrane was prepared by increasing the thermodynamic instability of a 10 wt.% polymer solution and thereby facilitating rapid desolvation. CB[6]-containing thin film nanocomposite membrane formed on this support showed an oustanding performance surpassing commercial RO membranes and thin-film nanocomposite membranes recently reported in the literature.

Keywords: Cucurbit[6]uril, Molecular dynamics simulation, Reverse osmosis, Thin-film composite, Porous support

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Sensitivity analysis of a forward osmosis-reverse osmosis hybrid process for seawater desalination

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The reduction of energy consumption in the reverse osmosis (RO) process is critical. The forward osmosis (FO)-RO hybrid process can be suggested to reduce RO energy consumption. In this study, a numerical FO-RO process model was developed to analyze the FO-RO hybrid process. The performance of the FO-RO hybrid process was compared with the stand-alone RO process. In addition, the impacts of the control parameters for operation, and the intrinsic membrane parameters, were analyzed using sensitivity analysis. In conclusion, the FO-RO hybrid process involves less RO energy consumption than the stand-alone RO process. The FO draw flow velocity and the RO applied pressure were derived as the major factors for controlling the FO-RO process. In addition, the control parameters for operation were found to be more important than the intrinsic membrane parameters in the minimization of RO energy consumption. Subsequently, the FO elements installed in front of the RO process should be configured with a parallel connection, in order to minimize RO energy consumption. The results in this study could be used to develop guidelines for the optimal design of the FO-RO hybrid process.

Keywords: Forward osmosis; Reverse osmosis; Hybrid process; Sensitivity analysis; Desalination; Wastewater reuse

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Microbial desalination (MIDES) cells: an innovative solution for low energy drinking water production

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Water desalination has become a technologically and economically viable solution to tackle increasing water shortages in many regions of the world. Presently, the total global desalination capacity is around 90 million m^3 d^{-1} [DesalData, 2018]. The desalination market is mostly dominated by reverse osmosis (RO), compared to competition between multi-stage flash (MSF) and multi-effect distillation (MED). However, the high energy cost continues to be a major concern, with energy consumption accounting for around 75% of the desalination operating cost when excluding capital costs or around 40% including capital costs [El- Mekawy, 2014].

This energy cost for desalination is about 10 times higher than for conventional water sources, leading to high water prices, that can easily exceed 0.5 € m^{-3}. In this context, the MIDES project aims to revolutionize desalination by developing a low-energy sustainable process called Microbial Desalination Cell (MDC) as a pretreatment for RO. The integration of MDC technology with commercial RO allows seawater desalination with an energy consumption below 0.5 kWh m^{-3}. MDC treats simultaneously wastewater and performs desalination using the energy contained in the wastewater [Cao et al, 2009]. In fact, MDC can produce around 1.8 kWh of bioelectricity from energy contained in one cubic meter of wastewater. This energy is directly used to lower salt content in seawater from 35 to 5 g L^{-1} (brackish water) without external energy input, while further salinity reduction to achieve drinking water quality is performed in the subsequent RO step.

The advantages of an MDC include less external energy for the desalination process and simultaneous WWT. Moreover, MDC operates under neutral pH, pressure and temperature conditions [Zhang, 2016].

MIDES project is developing the World's largest demonstrator of an innovative and low-energy technology for drinking water production. The overall MIDES process includes a pre-treatment of the saline stream by ceramic membranes prior to enter the MDC unit, where it is partially desalinated (70-90 %) before the RO post-treatment.

The project will focus on overcoming the current limitations of MDC technology such as low desalination rate, high manufacturing cost, biofouling and scaling problems on membranes, optimization of the microbial-electrochemical process, integration with RO, ceramic membranes as pre-treatment, system scale up, and economic feasibility of the technology.

This will be achieved via innovation in nanostructured electrodes, antifouling membranes (using nanoparticles with biocide activity), electrochemical reactor design and optimization, microbial electrochemistry and physiology expertise, and process engineering and control, such as optimized pre- and post-treatment.

The overall process schematic of the MIDES technology is presented in Figure 1 where the core technologies, named MDC and RO, are integrated with other complementary technologies. The overall process includes the initial treatment of municipal wastewater in a conventional anaerobic reactor to increase the concentration of volatile fatty acids (VFAs), used as a fuel for the MDC, obtaining after all a stream of treated wastewater. In conventional RO desalination, seawater undergoes several pretreatment steps (chemical coagulation, settling and filtration) to protect the membranes from particles and organic matter.

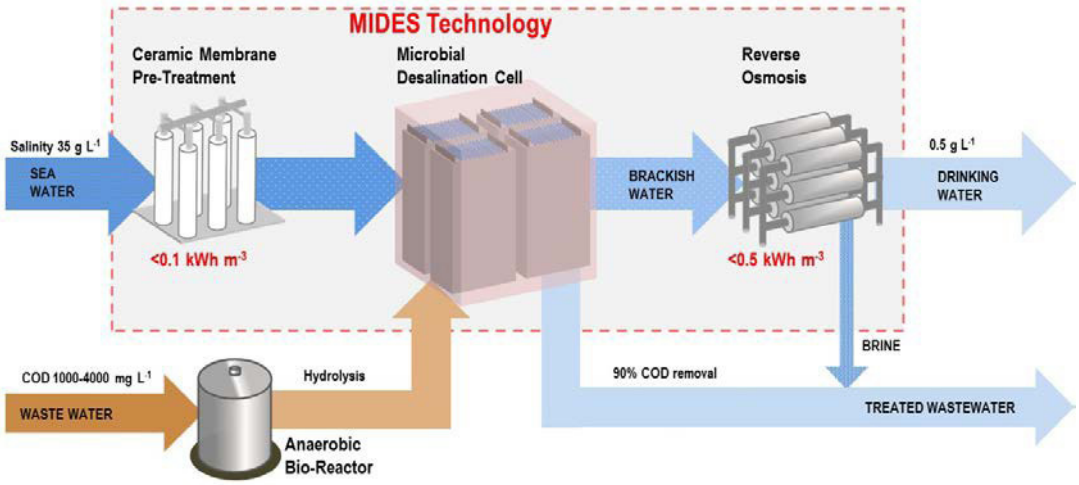

Fig. 1: MIDES concept schematic

In MIDES, this whole pre-treatment will be substituted by nano-coated ceramic membranes. This will result in a relevant reduction in chemicals usage and footprint as well as lowering by 80% the energy demand (going from about ~ 0.48 to <0.1 kWh m^{-3}).Ceramic membranes have never been industrially employed as desalination pre-treatment, this novel use will bring innovation to the MIDES Technology by improving system stability and self-cleaning capacity.After pre-treatment, seawater will enter MDC unit where it will be partially desalinated (70-90%) before it fully processed in the RO unit.

The MIDES Horizon 2020 project will develop the world's largest demonstrator of the innovative MDC technology in three sites: Denia (Spain), Canary Island (Spain), and Chile. Three pilot plants of 150 L day^{-1} will be constructed and operated under real environments in brackish water and seawater desalination plants.

Keywords: Desalination; Energy; Drinking water; Pre-treatment; Innovative technology

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High-pressure reverse osmosis for industrial water reuse – evaluation of factors reducing the effective driving pressure

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As the industry is increasingly forced to enhance concepts concerning water reuse and the recovery of valuable substances to strive for a waste water-free production, viable methods for the treatment of high osmotic solutions are required. In terms of the sustainable approach of a minimal liquid discharge, membrane based processing turns out to be a suitable option. Extending the application of the pressure-driven reverse osmosis process towards higher operating pressures is a reasonable approach as the achievable concentration factor defines the size and the costs of the subsequent thermal concentration step.

Reverse osmosis spiral wound elements are usually able to withstand a maximum feed pressure up to 83 bar. To replace the energetically unfavourable thermal desalination processes sufficiently a high-pressure reverse osmosis (HPRO) element should be operational up to at least 120 bar. However, exceptional feed pressures lead to increased mechanical stresses on the components of the spiral wound element. To optimize the design parameter and establish constructive requirements, performance- limiting factors have to be redefined and evaluated.

In order to establish a better understanding of the behaviour of spiral wound elements under high-pressure operation, this study focusses on the investigation of the performance of available elements by scrutinizing the crucial effects reducing the effective driving pressure and limiting the achievable recovery rates. Taking this approach, the flux reduction as a result of membrane compaction and the influence of permeate-sided pressure drop induced by membrane-spacer interactions are examined experimentally.

Performance tests were conducted on a pilot plant with different available 4-inch HPRO elements and sodium chloride solutions as the feed. For the evaluation of the material resistance and durability of the elements, long-term trials were done at the maximum pressure of 120 bar. The investigation of the flow conditions on the permeate side were done in a laboratory scale plant with water as the flowing fluid. Through the development of a special test cell, the consequences of membrane intrusion on the permeate-sided pressure drop and its dependence on an operating pressure of up to 120 bar were experimentally validated and quantified for the first time.

The results of the long-term HPRO tests show an initial decline in permeability and an increase in rejection over time that are caused by undesired deformation and compaction effects of the polymeric membrane during high-pressure exposure. The permeate-sided pressure drop measurements show a considerable influence of membrane intrusion on the element performance with a strong dependence on the feed pressure. Despite the considerable influence of the membrane deformation on the achievable permeate flux, HPRO can explicitly be considered as an energy- efficient method for the further concentration of high-salinity brines.

This study was supported by the project Re-Salt funded by the Federal Ministry of Education and Research of Germany.

Keywords: High-pressure reverse osmosis, Spiral wound element, Membrane compaction, Membrane intrusion, Permeate-sided pressure drop

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Inhibitors for $CaCO_3$-scaling in reverse osmosis-plants – influence of suspended matter on membrane clogging

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The inhibition of scale formation on membrane surfaces has been widely investigated but there is not much literature about laboratory investigation on $CaCO_3$-scaling in the presence of suspended solids.

Even though the brines of reverse osmosis (RO) plants are usually supersaturated, the scale formation on the membrane is mainly governed by the availability of sufficient crystallisation nuclei. This is so important because standard tests to evaluate the effectiveness of anti-scalants (AS) are carried out with particle–free test waters, i.e. there are no crystallisation nuclei where the precipitation can start. In this context suspended matter plays an important role for the crystallisation process. It can influence the kinetics of scaling as well as directly contribute to scale formation by sedimentation processes and by incorporation into deposits formed by crystallisation.

The suspended solids are influencing the kinetics of scale formation in two ways. First the particles work as nuclei for the crystallization resulting in a low induction time and crystallisation occurs even at moderate supersaturation rates. The second influence of the suspended matter is its ability to adsorb the AS so that the concentration of the inhibitor is reduced. Both effects increase the risk of scaling and membrane blocking.

Furthermore the permeability of the scaling layer is influenced by its morphology. In the case of surface crystallisation the scale deposit on the membrane surface grows laterally, leading to an increasing surface blockage and flux decline. In bulk crystallisation small crystal particles are formed through homogeneous crystallisation. They may deposit on membrane surfaces and form a cake layer that also leads to flux decline. In supersaturated scale forming conditions these two effects occur simultaneously, resulting in scale growth and agglomeration.

The effectiveness of an AS is often determined in laboratory tests like the NACE Standard Test Method 03-74 for calcium carbonate and calcium sulphate. In these tests, the AS is added to the sample, and after a defined reaction time a period to settle the scales follows. The concentration of Ca-ions in the solution is used to calculate the efficiency of the inhibitor.

These test methods have the advantage that they are easily to apply, but the interaction with the membranes under real operating conditions is neglected, because the test results are strongly affected by the relatively long reaction and settling time. During this time, crystal morphologies are formed which might not be comparable to those in a RO-plant. Therefore, only limited statements about the blocking of the membrane can be made with these test methods.

For this reason a membrane-based method was applied to investigate the performance of a standard phosphonocarbonic (PCA) based additive preventing calcium carbonate scale.

To make the test more comparable to real RO-processes, suspended solids are added to the feed water to investigate the influence of additional crystallisation nuclei. The challenge is to prevent

scaling and also to disperse the suspended solids. PCA-based anti-scalants serve as good CaCO3-inhibitors but on the other hand they show weaknesses as dispersers. Therefore the investigation about the influence of suspended matter on this kind of additives is very relevant and the results are presented in this work.

The calculated scaling potential of the test water concentrate, expressed as Langelier Saturation Index (LSI), is in the range of LSI 1.8 up to 2.5. The concentration of suspended solids was between 30 and 120 ppm.

The applied membrane test procedure uses a test plant which is highly adapted to a full scale RO-plant, namely in terms of reaching the supersaturation by starting with a feed water with only moderate scaling tendency. The test plant is operated at a constant permeate flux and a constant recovery rate. If the membrane is blocked by scaling the pressure is automatically adjusted to keep the permeate flux constant. The time-dependent increase of the pressure is the main indicator for the effectiveness of the AS. After the tests the scaling layer morphologies are examined by a scanning electron microscope.

As a result the time-dependent pressure development of test runs with different feed waters and increasing PCA-dosages and the corresponding SEM-images are shown. The test runs prove that PCA is able to completely inhibit membrane clogging by calcium carbonate up to a certain scaling potential even at a low AS concentration of 1.3 mg/L in the feed water.

On the other hand, depending on the feed water, there is a specific dosage of PCA where the membrane is blocked more rapidly, indicating a Ca-sensitivity of PCA. These critical concentrations of PCA hold a considerable risk of overdosing and induced membrane blocking, if these levels are exceeded.

Tests with $SrCO_3$ as model substance for suspended matter show the ability of PCA to completely stabilize calcite up to 60 mg/L $SrCO_3$ in the concentrate. The EDX-analysis of the scaling layer with $SrCO_3$-crystals as suspended matter show that the $CaCO_3$ is formed attached to the $SrCO_3$-crystals and not as separate $CaCO_3$-crystals. This finding in combination with increasing relative Ca-concentration suggests that clogging of the membrane by $SrCO_3$ is fostered by the calcium carbonate precipitating on the $SrCO_3$ crystals.

Keywords: Phosphonocarbonic acid, Calcium carbonate, Scale inhibition, Suspended matter, Reverse osmosis

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Studies on the recovery of calcium and magnesium from Red Sea water by NF membrane

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This paper reports the results of nanofiltration (NF) polymeric membrane for the recovery of divalent ions (calcium and magnesium) from Red seawater. Pilot plant experiments have been

carried out using Alfa-Laval (NF 2517/48) membrane module. System was operated in both total circulation mode (permeate and brine) and brine circulation mode under hydraulic pressure of 15 bar. Impacts of some chelating agents on both flux and rejection have been also investigated. Results indicated stable performance and pure water permeability ranging from 17 to 85.5 LMH at 2-15 bar. Comparison with seawater permeability under the same operating pressures reveals 48-64% reduction manifesting the effect of the osmotic pressure of seawater. Overall TDS reduction was almost constant without incorporation of chelating agents. On the contrary of expectations, the use of chelating agents (HEDTA & EGTA) showed flux decline of about 3-15%. Analysis of rejection data of both operation modes showed reasonable rejection values for Ca, Mg and SO4. For the full circulation mode, those values were 35%, 59% and 90% for Ca, Mg and SO_4, respectively. Operating under brine recirculation mode only showed decrease of rejection to 33%, 56% and 86% for Ca, Mg and SO_4, respectively. The use of chelating agents has no substantial effect on NF membrane performance while increasing the total Ca rejection to 48-65% for EGTA and HEDTA. Results in general confirmed the powerful separation of NF technology for softening and recovery of divalent ions from seawater. It is anticipated that increasing operating pressure beyond the limits of our investigations would improve the rejection and flux. A trade-off should be considered between operating cost (due to higher pressure and marginal benefits as manifested by expected improved performance). The experimental results fitted well with the formulated rejection empirical correlations and the published ones.

Keywords: NF, Seawater, Recovery, Calcium, Magnesium

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Development of measurement techniques for wetting potential of hydrophobic membranes in membrane distillation

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One of the challenges of membrane distillation (MD) technology is the wetting of the membranes. It is known to be caused by amphiphilic contaminants, such as natural or synthetic surfactants. Fouling due to scale formation is also regarded as one of the main reasons for membrane wetting. However, relatively little information is available on membrane wetting in MD process. It is difficult to predict how and when membrane wetting occurs. The pretreatment conditions to mitigate membrane wetting have not been revealed. In this context, this study focused on the measurement of membrane wetting potential. Various feed solutions containing NaCl, $CaSO_4$, humic acid, alginate, and SDS, respectively, were used for the experiments. Polyvinylidene fluoride (PVDF) and polytetrafluoroethylene (PTFE) membranes with different nominal pore sizes were compared. Protocols for accelerated wetting tests were developed together with the test devices. Liquid entry pressure (LEP) and dynamic contact angle were measured to find correlations with the wetting potential. Results showed that LEP and contact angles were not enough to predict membrane wetting under various conditions. To develop prediction models, response surface methodology (RSM) was used as well as semi-empirical models. A standard protocol for accelerated wetting tests was also suggested.

Keywords: Membrane distillation(MD), Membrane wetting, Measurement, Prediction, Liquid entry pressure, Contact angle

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A liquid desiccant cycle for sustainable water use in controlled environment agriculture

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Humidity control and fresh water supply are two important factors that affect the overall productivity, energy efficiency, and sustainability of controlled environment agriculture. Liquid desiccants offer the potential for pinpoint control of humidity levels in controlled environments. In addition, desalination for regeneration of the liquid desiccants offers the potential for fresh water recovery and reuse. In the present work, we incorporated the dehumidification processes into a bench scale controlled environment agriculture system (CEAS). Hollow fiber membranes were combined into an array and placed near the crops for humidity control. Concentrated magnesium chloride liquid desiccant solution with a vapor pressure lower than that of the CEAS was pumped through the hollow fiber lumens. The dehumidification permeance rate responded dynamically to the changing transpiration rate of the plants, as influenced by changes in environmental factors such as light, temperature, and vapor pressure. In addition, the permeance rate increased from an average of 0.26 to 0.31 g m^{-2} h-1 Pa^{-1} as the velocity of the liquid desiccant through the hollow fibers increased from 0.023 to 0.081 m s^{-1}. For the first time, a membrane-based liquid desiccant system was demonstrated to successfully control humidity at target levels within a bench-scale CEAS. When combined with a desalination system such as membrane distillation for recovery of fresh water from the dehumidification system, the potential exists to irrigate plants with recovered fresh water and to reduce the water footprint of the crops by up to ~99%.

Keywords: Desalination, Membrane dehumidification, Liquid desiccant, Membrane distillation, Urban agriculture, Vertical farming, Controlled environment agriculture

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Development and investigation of a new submerged low-pressure spiral-wound-element for micro- and ultrafiltration

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The main requirements for submerged membrane elements are a high packing density resp. a small footprint, and a low energy demand for the operation.

To reach these goals a new type of a spiral-wound-membrane-element with an open-channel feed spacer for micro- and ultrafiltration in submerged operation was developed and investigated in this work.

Laboratory tests and CFD simulations based on a flow model developed allowed the determination of an optimal bubble size and thus the optimal channel height of the corrugated feed spacer of 5 mm. To generate suitable air bubbles with a geometric distribution adapted to the spiral wound membrane element, several systems were tested and a suitable design was manufactured by means of a 3D printer.

Field tests with a fully automatic pilot plant for particle and activated sludge filtration were carried out. The main subject of the experiments was the development and investigation of adapted filtration techniques to minimize the energy demand and the needed purge air volume. Furthermore the cleaning procedures were investigated and optimized.

With regard to the air purge and the manufacturing of the membrane elements, a spacer height of 5 mm has proven to be suitable. With smaller spacers, the distribution of the gas volume flow to the individual channels of the feed spacer becomes inhomogeneous. With a spacer height of 5 mm, it was also possible to produce spiral-wound-elements which are stable in form and have a high packing density. Moreover, the fabricated elements can be backwashed to a sufficient degree without damaging the element, due to the necessary backwash pressure. So it is possible to clean the modules chemically from both, the feed side and the permeate side, and to perform this cleaning without removing the elements.

For the filtration of particles, a deposition of the particles can be estimated on the basis of a force equilibrium as a function of the filtration volume flow, particle diameter and crossflow velocity. With the chosen specific air flow rates up to about 0.2 $m^3/m^2/h$ relatively low crossflow velocities of up to 0.4 m/s are achieved. The low crossflow velocities are associated with a low energy requirement, but they also result in a deposition of particles on the membrane surface at lower filtrate volume flow rates. Under the described operating conditions this results in a critical particle diameter of about 1 µm and a limiting permeate flux of 10 $L/m^2/h$. In case of back-washing or in case of filtration of larger particles, the actual permeate flux can be increased.

The required energy depends on the mode of operation, as well as the suspension and its concentration, since these affect the permeance of the membrane. For the filtration of activated sludge from a municipal wastewater treatment plant only about 150 Wh/m^3 are needed. For particle filtration the energy requirement could be reduced to 40 to 60 Wh/m^3. Thus, the required specific energy requirement is significantly below that of comparable systems.

In particular, the particle filtration experiments have yielded very promising results. Besides specific applications, for example the filtration of aqueous process streams from the ceramics industry, the new submerged spiral-wound-element can be used as a pretreatment step for reverse

osmosis applications. Compared with standard ultra- and microfiltration systems the required specific energy demand is considerably lower.

Keywords: Submerged ultrafiltration, Microfiltration, Energy demand, Pretreatment, Corrugated feed spacer

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Functionalized graphene oxide-gadolinium based composites for adsorption removal of radionuclides

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It is well known that RE_2O_3 (where RE is the rare-earth element) compounds have been widely used as heat-resistant materials, high-performance luminescent devices, and catalysts based on the electrical and optical properties of their 4f electrons of lanthanide. Among different RE_2O_3 materials, gadolinium oxide (Gd_2O_3) is promising as host matrix for down- and up conversion luminescence due to its good chemical durability and low phonon energy. Moreover, Gd_2O_3 have similar properties of Fe(III) and Al(III) which are widely used for removal of arsenic. In addition, Gd and its oxonium ions possessing a large magnetic moment. Gadolinium(III), like most lanthanide ions, forms complexes with high coordination numbers. Gadolinium can combine with nitrogen, carbon, sulfur, phosphorus, boron, selenium, silicon, and arsenic at elevated temperatures, forming binary compounds [1]. However, gadolinium based nanocomposites have not been applied for wastewater treatment so far. In addition, GO is a good candidate for constructing GO-based metal oxide composites. Recently, graphene oxide(GO)-based metal oxide nanocomposites have been used for the adsorption of various organic and inorganic pollutants from water[2-7]. However, those reports limitation in view real application. This study prompted us to synthesized polymer functionalized graphene oxide-gadolinium- (Poly.-GO-Gd) composite for adsorption removal of radionuclides from aqueous solutions. As synthesized material, Poly.-GO-Gd characterized by microscopic and spectroscopic techniques. The characterized material well applied for batch adsorption removal of radionuclides in view of study their adsorption process and efficiency studied in this present study.

Keywords: Graphene oxide, Gadolinium oxide, Functionalized Graphene oxide-Gadolinium, Radionuclides removal, Adsorption, Composite hybrid materials

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Lanthanum-graphene oxide hybride composite for adsorption removal of heavy metals

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Water pollution is a worldwide problem. Heavy metals, one of the big source for the pollution of water and causes adverse health impacts in the human organs and immune system etc.[1]. As we know graphene oxide (GO) based hybrid nanocomposites have potential applications for water treatment. In addition, some of the lanthanum-based materials has been reported for adsorption removal of pollutants which can improve base material adsorption capacity and adsorption kinetics [2, 3]. Hence, here we synthesized lanthanum-graphene oxide (LAGO) based hybrid composite for adsorption removal of heavy metals from aqueous solutions. As synthesized LAGO properties and purity was evaluated by using microscopic and spectroscopic techniques. The adsorption efficiency of as-synthesized, LAGO for heavy metals was tested through batch adsorption studies.

Keywords: Graphene oxide, Lanthanum oxide-graphene oxide, Composite materials, Adsorption, Heavy metals

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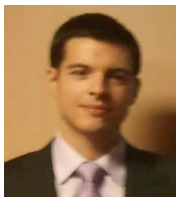
Performance assessment of a full-scale BWRO desalination plant. Influence of the RO system design and operating conditions



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The design and operating conditions of a RO system is key on its performance in long-term. The BWRO desalination plant is located in Gran Canaria (Canary Islands, Spain). Two long-term operation periods were studied in this work, from 1986 to 1993 and from 2004 to 2015. At the beginning of the first period, the plant had an arrangement 2(4):2(4), so two stages, two pressure vessels (PV) per stage, four elements per PV and the membrane was the BW30-8040. This strange arrangement was done by a previous RO designer company in 1982. After 2,300 operating hours working with the above mentioned arrangement, the plant was reformed adding a PV in the first stage, so the arrangement was 3(4):2(4) increasing a 15% the production capacity. The total operating time was around 40,000 h. In 2004, a second reformed was carried out, the same arrangement, but six elements per PV. This time the element BW30-400 was used. The production capacity was the same as previous period after the reformed, but in this case the operating time was around 88,000 h. The aim of this work was to carried out a performance comparison between both periods. The evolution of the operating parameters such as feedwater conductivity, permeate conductivity, feed pressure, pressure drop, permeate flow, feed flow was shown. as well as the decline of the average water permeability coefficients in both cases

Keywords: Brackish water; Reverse osmosis; Long-term; Operating data; Performance; RO system design

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Off-grid desalination for irrigation in the Jordan Valley

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Groundwater resources in many regions of the world are becoming increasingly depleted and salinized. As aquifers typically straddle political boundaries, their ongoing depletion presents both a flashpoint for conflict and an opportunity for cooperation. A salient example is that of transboundary groundwater resources in the Jordan Valley, which are shared among Israeli, Jordanian and Palestinian residents. A desalination system is being developed for use by farmers in the West Bank. The system is based on a simple but efficient batch-reverse osmosis technology that incorporates energy recovery and brine recirculation to achieve 80% recovery and specific energy consumption < 1 kWh/m^3. It can be solar powered with minimal PV footprint. Because the system is built almost entirely from off-the-shelf parts, it is readily implemented with levels of engineering expertise available in many areas of the world. To test and upscale the solution and to propagate the knowledge about it, the system is being trialled at centres in the UK, Israel and Palestine. Participation of students internationally presents an opportunity for training and shared understanding of the regional challenges. The presentation covers technical aspects of the project and its outcomes. It also reflects on the challenges of implementation of the project and on its potential to further democratise the use of desalination technology and to promote regional cooperation in solving transboundary water problems in the Middle East.

Keywords: Groundwater, Solar PV, Batch-RO, High recovery, Transboundary resources, Regional cooperation

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Removal of chromium from aqueous system using synthesized and characterized encapsulated zero-valent iron by polymer

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Chromium is a common groundwater contaminant because of its widespread application in metallurgy, organic chemical syntheses, leather tanning, and wood preserving industries.[1, 2] In

aqueous environments, chromium usually exists in hexavalent (Cr(VI)) and trivalent forms (Cr(III)). Cr(VI) is acutely toxic and carcinogenic. It is also highly mobile in groundwater since it does not sorb strongly onto most soils.[1] Contrarily, Cr(III) is relatively nontoxic and an essential human nutrient.[3] It does not readily migrate in groundwater since it usually precipitates as hydroxides, oxides or oxyhydroxides.[4] Zero-valent iron (ZVI) has been proven to be an effective material for the reductive precipitation of Cr(VI),[4,5] Inside the reactive barriers, both Fe0 and the Fe2+ released from the anaerobic Fe^0 corrosion act as reductants to first chemically reduce Cr(VI) to Cr(III) followed by precipitation as chromium or chromium-iron oxides/hydroxides/oxyhydroxides on the Fe^0 surface.[6,7] Although At present, the most urgent problem to be solved in the application of ZVI is that the reactivity to the target contaminant in water is low and the sustainability is short. In this study, it was to develop a microcapsule-reactive medium containing ZVI with sustained release characteristics to maximize the stability and persistence of ZVI, a multifunctional reaction medium, redox-active contaminants are in the development of an optimal treatment process and purification system in water treatment.

Keywords: Encapsulated zero-valent iron, Chromium, Adsorption, Redox-active contaminants

Acknowledgment

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Retrofitting assessment of a full-scale BWRO desalination plant

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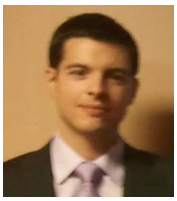

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Reverse osmosis is the most widespread technology in desalination of seawater and brackish water. In brackish water desalination, the use of energy recovery systems is not as evident as in the desalination of seawater, due among other factors, higher flux recoveries and lower specific energy consumption. In this work we studied the economic feasibility of installing energy recovery systems, interstage pump and RO membrane replacement by nanofiltration in a BWRO desalination plant with a feed capacity of 600 m^3/d. For this study. Experimental data from more than two years of operation were used in the current state of the plant, micro-filtration and antiscalant dosing as pre-treatment, RO system with two stages, 3 pressure vessels (PV) in the first stage and 2 in the second stage with 6 RO membrane elements each PV. The production of the plant is for agricultural irrigation. A study was made considering different scenarios with its influence on efficiency, permeate quality and economic viability.

Keywords: Brackish water; Reverse osmosis; Long-term; Operating data; Performance; RO system design

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Optimization of configuration and operation of remote water and electricity cogeneration plants (PV/WT/BS/RO systems)

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Facing the world`s challenges of the 21st century like climate change, population growth and excessive resource use, the design of water and energy supply play a crucial role for sustainable development. As a powerful application regarding water-energy nexus, Photovoltaic/Windturbine/Battery/Reverse Osmosis (PV/WT/BS/RO) systems are capable to perform water and electricity cogeneration in remote areas with access to sea or brackish water. High capital investment costs are the greatest obstacle for establishment of PV/WT/BS/RO systems, especially for poor communities. The combination of PV/WT/BS/RO brings along special features (complementarity of solar and wind resources, scheduled or flexible operation of RO, application of ERD for RO, fresh water

tank as indirect energy storage) which open up capabilities for cost reduction. These potentials can be enabled by optimization of the configuration and operation the system. In the present thesis, a configuration optimization tool for PV/WT/BS/RO systems is developed. The system model reflects stated features and allows various operation modes. Following recent optimization literature, the metaheuristic algorithm â€œParticle Swarm Optimizationâ€ (PSO) is applied on minimizing the total annualized cost (TAC) of water and electricity production under water and electricity supply security constraints (LPSP & LWSP). The optimization results of a heuristically designed system, of a PSO on constant RO operation and a PSO on scheduled RO operation are compared quantitatively and qualitatively. The findings feed into the development of a user-friendly, fast and accurate optimization tool which paves the way for planners, funders, operators and communities to establish sustainable water and electricity cogeneration.

Keywords: Off-grid, Renewable energy, Water and electricity cogeneration

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Economical and ecological advantages of nanofiltration techniques over different conventional well water treatment

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The report is devoted to modernization of existing membrane techniques aimed at development of versatile tools to remove iron, hardness, fluoride, ammonia and strontium from the well water.

A state of the art survey is presented that describes modern techniques used to remove iron, hardness and fluoride from well water. Main features of existing techniques are presented, as well as their advantages and disadvantages are described.

A new developed approach to use nanofiltration membranes to treat well water is described and its advantages over conventional techniques are presented basing on economical comparison of their main economical and ecological characteristics. Anew approach is described to minimize amount of discharged concentrate that uses a double stage treatment of concentrate streams with nanofiltration membranes.

These new membrane tools feature application of additional membrane unit to treat concentrate stream with high recovery (up to 0.9-0.95) .

Experimental research was conducted to determine main operational parameters of membrane units such as: recoveries, scaling rates, antiscalant doses and cleaning schedules. To determine required recovery values, relationships of iron, hardness and fluoride removal efficiencies versus recoveries were investigated.

Also calcium carbonate scaling rates in nanofiltration modules are determined to evaluate operational costs to control scaling. New types of "green" phosphorous-free antiscalants based on polyaspartic and polyacrylic acid salts were proposed. Results of antiscalant testings are presented that provided their efficient dosing values and scaling rates for different recoveries. PASP (polyaspartate salts, molecular weight 3000 Da) and PAK-4 (polyacrilate, molecular weight 4500 Da) were selected for industrial application to treat well water using new developed membrane techniques. Both chemicals are developed, produced and supplied by "Traverse Co" (Moscow).

The obtained data enables us to determine all operational parameters of membrane units as well as their operational costs. Results of operational costs calculations based on experimental testings are presented. All research testings and economical calculations were conducted for three typical well water compositions in the Podolsk region of New Moscow southwest area. Capital and operational costs are evaluated and compared for the cases of well water treatment using new developed membrane techniques and conventional techniques (such as: aeration/filtration, ion exchange softening, reverse osmosis).

Basing on results of experimental studies operational costs are calculated for the main cases of treatment of well waters with different chemical compositions. Various types of nanofiltration membranes with different rejection, pressure and flow characteristics were tested. Operational costs were determined using the computer program developed by the authors earlier.

The conducted calculations revealed that nanofiltration and reverse osmosis membranes efficiently remove calcium, iron and fluoride even at high values of recoveries (0.75-0.9). The obtained experimental plots show that rejection of multivalent ions (iron and calcium) remains high even at high values of concentration factoe during test runs. Therefore, when membrane unit is developed, nanofiltration membranes with lower rejection as well as with lower energy and chemical consumption should be preferentially used. This was demonstrated by experimentally obtained presented plots yielding dependencies of scaling rates on concentration factor and membrane rejection values. The obtained data confirms that nanofiltration water treatment units are more cost efficient compared to conventional techniques even for the cases when only iron is removed from well water.

Conclusions: Application of versatile membrane techniques with 10 cubic meter per hour capacity to treat well water demonstrated higher economical and ecological efficiencies than conventional techniques even for simple cases of iron removal due to smaller footprint, chemical consumption and wastewater discharge. Membrane units also offer simpler delivery, start-up, operation and service opportunities to embrace large territories for water supply.

Keywords: Well water, Iron and manganese removal, Water softening, Fluoride removal, Reverse osmosis, Nanofiltration, Reverse osmosis concentrate utilization.

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Monitoring adenosine triphosphate and bacterial regrowth potential along the pre-treatment of a seawater reverse osmosis plant

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Standard methods to monitor and predict biological fouling of seawater reverse osmosis (SWRO) membranes do not exist. Monitoring bacterial regrowth potential (BRP) of SWRO feedwater has

gained attention as it is directly related to the nutrients present in seawater. In this research, a new BRP method using indigenous bacteria consortium based on microbial adenosine triphosphate (ATP) was developed and used. The method to measure microbial ATP has been recently developed using seawater-specific reagents (developed by Promega, USA). Moreover, the new developed methods were applied (i) to monitor microbial ATP and BRP along the pre-treatment of a full-scale SWRO desalination plant in the Middle East and (ii) to monitor the performance of the first stage of media filtration. The pre-treatment line includes screens, inline coagulation, two stages of dual media filtration and cartridge filtration.

To measure BRP, seawater samples were pasteurized for 60 min and were inoculated with 1×10^4 intact cells/mL (measured by flow cytometry) using a natural bacterial consortium from seawater. The samples were incubated at 30°C and bacterial regrowth was monitored using microbial ATP method in seawater.

The new BRP method is fast (2-3 days) compared to the conventional BRP method using bacterial plate counting. The new methods were applied to monitor microbial ATP and BRP through the pre-treatment trains of an SWRO desalination plant in the Middle East. Significant reduction in microbial ATP and BRP were recorded through the RO pre-treatment. Microbial ATP declined from 500 ng ATP/L in raw seawater to 10 ng ATP/L in the SWRO feedwater and BRP reduced from 250 ng ATP/L in the raw seawater to 100 ng ATP/L in the SWRO feedwater.

Moreover, the performance of the first stage of dual media filtration was monitored based on microbial ATP and verified with other parameters including silt density index (SDI) and modified fouling index (MFI-0.45). A well optimized maturation time and good performance of backwashing were observed. During maturation (35 min), microbial ATP was declined from 190 to 35 ng/L which is very close to its value before backwashing. Typical similar tends of Microbial ATP, MFI, and SDI were obtained. However, microbial ATP showed a higher sensitivity and fast response during the intermittent chlorination.

Overall, the new methods are promising tools to monitor (BRP) and control pre-treatment (e.g., maturation period of DMF) of SWRO desalination plants with respect to biological activity.

Keywords: Desalination, Biofouling potential, Reverse osmosis, Microbial growth potential, Microbial adenosine triphosphate, Seawater.

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Limitation of reverse osmosis system projection program

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Reverse osmosis (RO) process is the most frequently applied process in the field of desalination. In order to design RO processes, RO projection software provided by the membrane manufacturers is used. If the software had incorrectly evaluated the performance of RO membrane, how can we find out? Thus, it is important to understand the limitation of RO system projection program. The best way is to compare the projection results with the real data. However, it is impossible to

obtain the real data for various design conditions to compare them with the projection results. Instead, the trends of the projection results are analyzed to find out if they are reasonable or not. Five pieces of RO system projection software (e.g., CSMPRO Ver 5.0, IMS Design -2016, ROSA 9.0, LG Chem NanoH2O, and Toray DS2) were tested in this work. We simulated RO systems with 10 different SWRO membranes (5 high flux and 5 low flux membranes) to elucidate the limitation of the RO projection programs provided by the manufacturers. In general, the RO projection programs show reasonable data patterns when tested with different design fluxes and temperatures. However, the changing rates of feed pressure and salt rejection with temperatures are quite different for different membranes. This should be investigated more specifically. In addition, most RO projection programs do not account for the dependence of salt rejection upon pH.

Keywords: Reverse osmosis (RO), RO system projection program, Limitation, Temperature

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Agenda for simultaneous enhancement of the performance and environmental soundness of pressure retarded osmosis hybridized with seawater reverse osmosis

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Pressure-retarded osmosis (PRO) has gained an attention as one of promising carbon-free energy generating processes since after the twenty-first century. Due to its thermodynamic feature, however, it was clarified that stand-alone PRO is little viable. To this end, PRO has been often hybridized with a seawater reverse osmosis (SWRO) to enhance the economics of PRO. However, almost every recent research concerned with SWRO-PRO has focused only on the energy saving efficiency. Considering that the electricity used to operate both SWRO and PRO is mostly generated by fossil fuel, the effect of fossil fuel-based electricity on SWRO-PRO should be also taken into account to ensure the environmental soundness of PRO. In this context, a series of numerical analysis was conducted in the current study, to observe the performance and environmental impact of SWRO-PRO simultaneously. The performance of SWRO-PRO was assessed with a pre-invented dimensionless index, which describes the ratio of the energy recovered by PRO to the energy consumed by SWRO, together with various membrane parameters and operational conditions. Subsequently, the carbon dioxide emission incurred by SWRO-PRO was simulated based on the results of performance assessment, and the scenarios made up of renewable energy demand and population trend in Republic of Korea. According to the simulation results, the carbon dioxide emission from SWRO-PRO was significantly reduced only when the water recovery of SWRO stayed below 50%, and the degree of reduction fell dramatically as the water recovery increases. Moreover, it was found that the hydraulic pressure of PRO can play a decisive role for both energy efficiency

and carbon dioxide emission of SWRO-PRO since water flux and energy recovery of PRO are in a trade-off relation. Since a complexion becomes even intricate if the performance and environmental soundness are considered at the same time, a delicate optimization on SWRO-PRO would be required to satisfy those two aspects. (Next pages contain several figures for the current study)

Keywords: Pressure retarded osmosis, Seawater reverse osmosis, Energy efficiency, Environmental sound process, Performance index

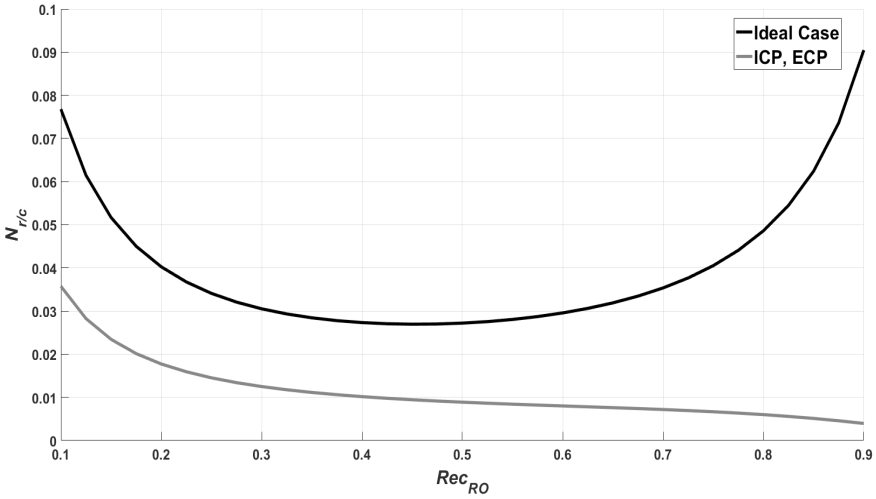
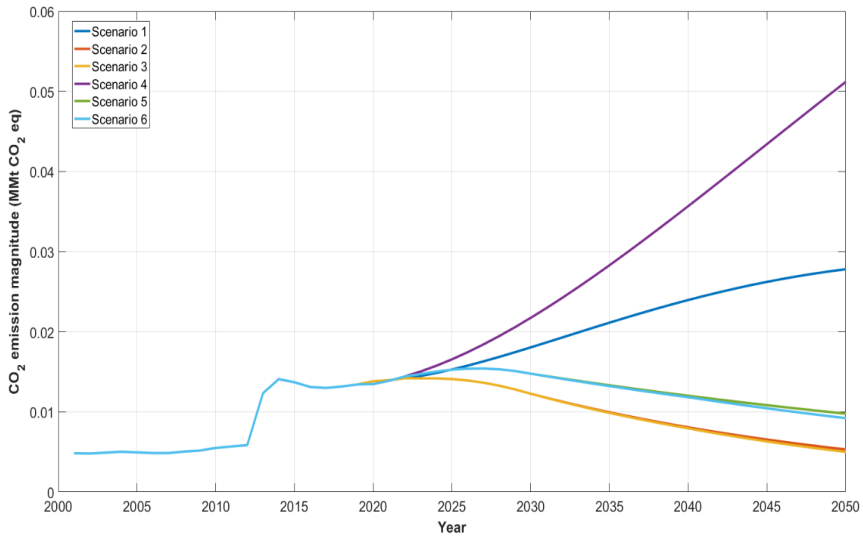


Fig. 1. A figure representing the trend of a dimensionless index for a SWRO-PRO hybrid process, , according to the total water recovery rate of SWRO. A graph with a black solid line represents an ideal model case (i.e. no concentration polarization in PRO), and a graph with a grey line represents a realistic model case reflecting the concentration polarization in PRO. Differently from the results of past studies, SWRO-PRO never shows a maximal energy efficiency around the 50% of SWRO water recovery. Rather, the energy efficiency gradually decreases as the water recovery of SWRO increases.



[Fig. 2] A figure depicting the magnitude of carbon dioxide emission of SWRO over next three-decades, resulting from six-different data-based scenarios. Each scenario utilized in the current simulation is formulated with the renewable energy demand and population prediction data provided by Korean government.

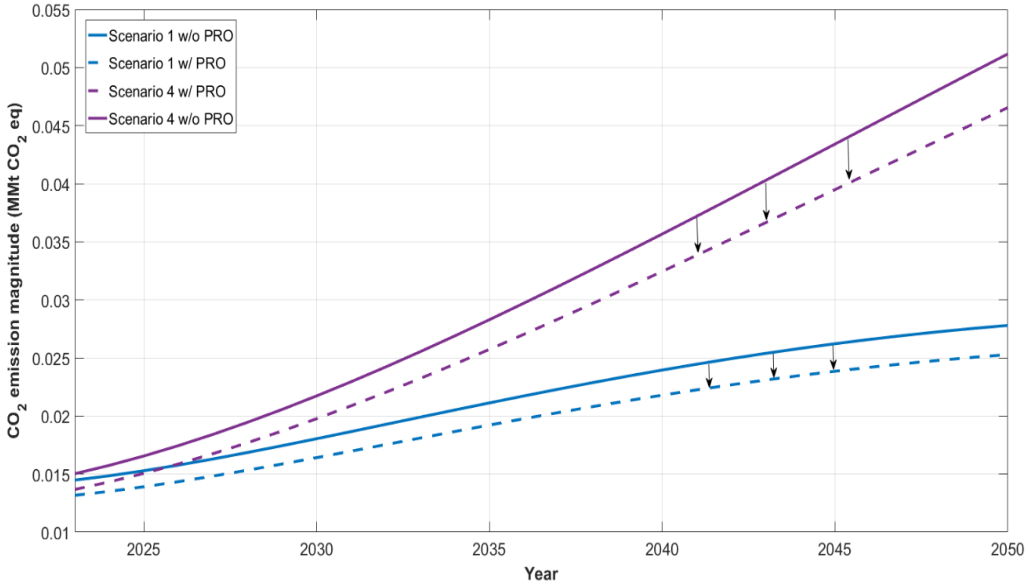


Fig. 3. A figure forecasting the reduction degree of carbon dioxide emission from SWRO. Here, the reduction degree of carbon dioxide is triggered by PRO. For the simulation, the simulation results of ideal model case from Fig. 1, and scenario 1 and scenario 4 results from Fig. 2 are respectively utilized.

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Does phosphate limitation control biofouling in membrane systems?

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Phosphate limitation in feed water has been suggested as a biofouling control strategy for reverse osmosis (RO) membrane systems. The objective of this study was to investigate the effect of phosphate limitation on RO biofouling and to give better insights into the biofilm morphology and composition that develops under phosphate-limiting (P-limiting) conditions compared to phosphate-dosed (P-dosed) conditions and subsequently the effect on membrane performance parameters. Even though no additional phosphate was added to the feed water for the P-limiting conditions,

a low concentration of phosphorus (~1 μg L^{-1}) was present in water. Results demonstrated that phosphate limitation resulted in a lower concentration of non-purgeable organic carbon (NPOC), adenosine triphosphate (ATP) and total cell count (TCC), but higher protein and phosphorus concentrations in the extracted extracellular polymeric substances (EPS) (Fig. 1). Faster development of pressure drop with time was observed under phosphate-limiting (P-limiting) conditions compared to phosphate-dosed conditions. The biofilm that developed under P-limiting conditions had a higher average permeate flux decline, therefore, a higher biofilm resistance. Optical coherence tomography (OCT) imaging was performed to investigate the structure of the biofilm grown in both conditions and analysis of the images highlighted significant differences: i) thicker more homogenous (lower roughness coefficient) biofilm developed on the membrane under P-limiting conditions, and ii) P-limiting biofilms have a higher biofilm coverage in the flow channel than P-dosed biofilms (Fig. 1). This study suggests that even at low phosphorus concentrations (below 1 μg L^{-1}) in the feed water, biofilm formation occurred and the impact on membrane performance parameters varied depending on the C:P ratio and P concentration in the system. Results from this study revealed that biofilm development occurred even at a very low concentration of phosphorus in the feed water. So, when considering phosphate limitation as a biofouling control strategy, a comprehensive approach should be performed, starting by determining the actual phosphorus concentration and C:P ratio in the system, followed by analyzing the biofilm composition and structure. This will help to come up with accurate removal techniques that maintain membrane performance indicators.

Keywords: Biofilm structure; Biofouling; Desalination; Non-destructive imaging; In-situ characterization.

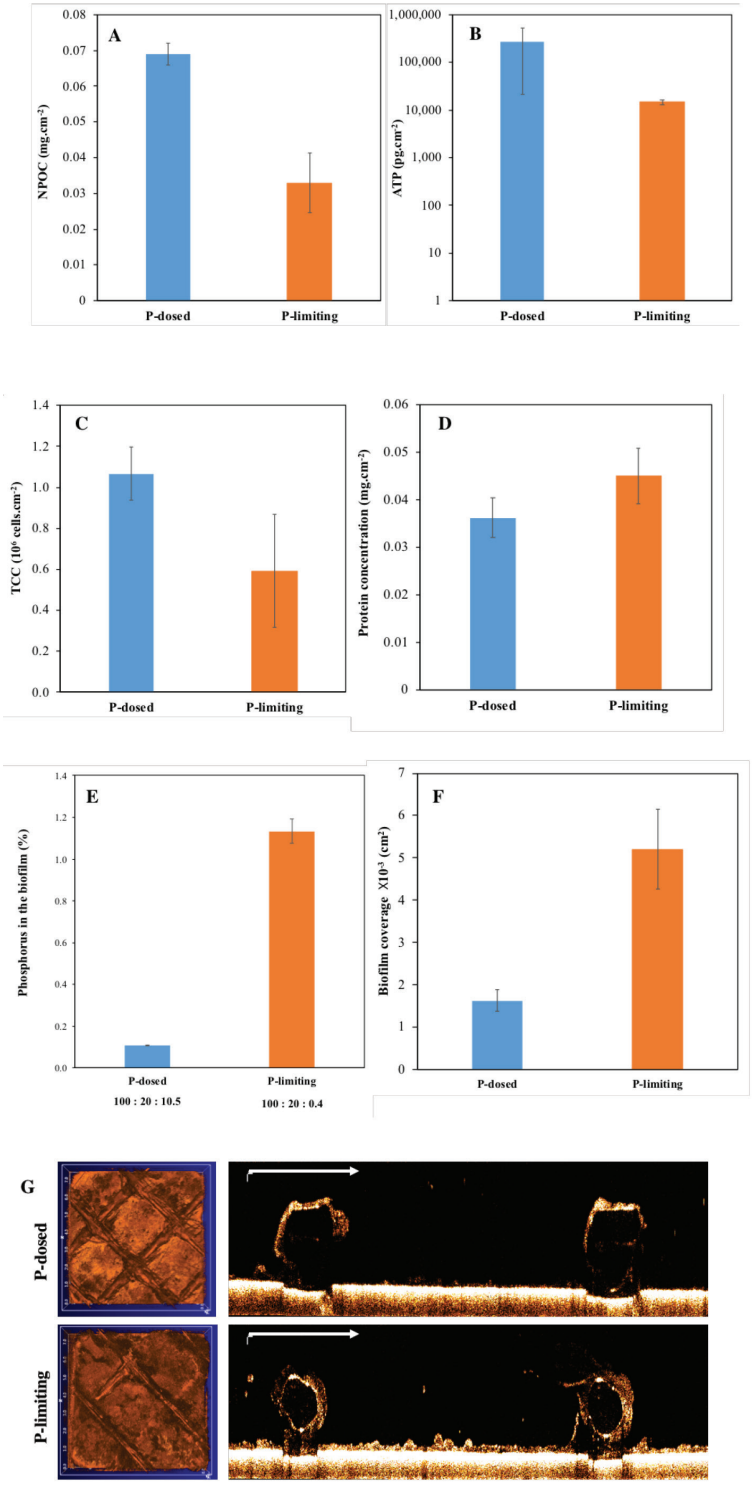

Fig. 1. (A) Non purgeable organic carbon (NPOC), (B) Adenosine triphosphate (ATP), (C) Total cell count (TCC), (D) protein quantification from the extracted exopolysaccharide (EPS) matrix, (E) percentage of phosphorus accumulated in the biofilm, (F) biofilm coverage in the cross-section of the flow channel, which is calculated from optical coherence tomography (OCT) images, (G) 3D and 2D OCT images of the biofilms developing in the flow channel under P-dosed and P-limiting conditions. All experiments were stopped once a normalized pressure drop increase of 150 mbar was reached. The arrow indicates the flow direction. N=2.

Autonomous reverse osmosis (RO) desalination system powered by a small photovoltaic (PV) system at an isolated Greek Islet - The Strongili Island Project

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TEMAK SA is a market leading company since 1972 with experience and perpetual presence in the Greek and International market, providing the most advantageous solutions in WATER TREATMENT applications.

We provide reliable water treatment solutions and manufacture complete water treatment systems with long-life, high endurance and minimum need for maintenance.

Water treatment systems applications include sea and brackish water desalination plants, water treatment systems for industries, tourism, hospitals, power plants, etc.

Our company contributes to the worldwide effort in developing innovative solutions and technologies for the production of water in arid areas and solutions that improve both the living conditions and environment.

TEMAK SA presents one of its innovative solutions in designing, manufacturing, producing and installing systems for the supply of fresh water for human use and consumption at an isolated islet of the Eastern Aegean Sea, named Strongili Island. More specifically, the main target was the supply and installation of a portable reverse osmosis (RO) desalination unit of a capacity of 20 m^3/d, pre-constructed, ready for operation and ergonomically containerized, autonomous and safe towards the environment and the personnel.

Strongili Island is a strategic area of the Hellenic Army Forces, since it marks the Eastern border of Greece. The islet is inhabited exclusively by soldiers who stay in Army Camps throughout the year, thus the infrastructures are vestigial (lack of port, energy supply etc) and the supply of fresh water becomes a big challenge. The minor requirements for such an application are:

- Reliability – Flawless technical design that minimizes the risk of technical problems as there is not an alternative water source
- Robustness – Robust construction that can endure in time under extreme conditions
- Reduced power consumption – the application must be powered exclusively by solar panels
- Flexibility – requirement of in situ assembly of the plant due to transportation difficulties (containerized solution is not an option –" no existing building available to install the equipment)

Our company, TEMAK S.A., responded effectively to the necessity of the Hellenic Army with its long-term experience in water treatment systems and hybrid-RO systems, providing the islet with a RO unit powered by a photovoltaic (PV) array. The capacity of the installed RO desalination unit is 20 m^3/ d. However, since the energy supply derives exclusively from the PV system, the RO desalination unit was designed for six hours of operation per day (producing 5 m^3 of fresh water), while it also includes an energy recovery system, aiming to the maximum energy saving. Therefore, the system is capable for a larger production if necessary (e.g. more personnel) or/ and water storage.

One big challenge of the current project was the fact that, since the islet lacks a port and similar infrastructure, the RO unit had to be pre- constructed, disassembled, transferred by boat and re-assembled on the islet. Moreover, since it is a stand- alone system on an isolated island, exposed

to the weather throughout the year, it dictates a high- quality equipment and careful and safe design and installation. TEMAK S.A. constructed a system featured by the steady and long-term high quality that governs all of our projects and guarantees a long- life, continuous, smooth operation, including a remote control and monitoring system. Additionally to that, considering the fact that up to 2012 (year of installation) the water supply to the islet was realized exclusively by bottled water transferred by boat (i.e. vulnerable to the weather and usually not available), our company offered a permanent solution and of lower cost, since water transportation was a big expense for the Hellenic Army and today the water cost is less than 0,67/m^3 .

The aforementioned project is awarded with :

- Second Global Water Award for the Innovative Project Award Category of the international "Mohammed Bin Rashid Al Maktoum Global Water Award" , 2017 in Dubai
- Gold Award at Best City Awards 2017 in Greece

Keywords: Water treatment systems, Desalination, Manufacturers, Sea and brackish water desalination plants, Renewable energy, Photovoltaics, Reverse osmosis, Solar energy

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Brackish water desalination in the Gaza Strip. Case study: Rafah small scale RO plant

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More than 95% of the population of the Gaza Strip depends on desalinated water for drinking purposes. Drinking water is being produced through 154 private and public desalination plants across the Gaza strip in addition to 10 MCM of drinking water received from Mekorot water company as a result of Oslo peace accord. This paper presents the details of the implementation of a medium scale brackish water desalination plant constructed in eastern Rafah – Gaza by Oxfam and its partner the Coastal Municipalities Water Utility to reduce the water stress in the Gaza strip and contribute to the provision of safe and clean drinking water.

Keywords: Brackish water, Desalination, Water pollution, Over exploitation, Water quality, Sustainable management

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Molecular composition studies on membrane biofilms

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Biofouling in membrane systems is one of the most persistent problems in water desalination. Extracellular polymeric substances (EPS) are a polymeric slime produced by bacteria which is composed of proteins, lipids, nucleic acids, polysaccharides and humic substances. EPS plays a sig-

nificant role in biofouling causing a performance decline of the system. The need to have detailed knowledge of the molecular composition and spatial distribution of EPS will lead to optimization of biofilm treatment.

Matrix Assisted Laser Desorption Ionization Imaging Mass Spectrometry (MALDI-IMS) has been widely used for studies of the spatial distribution of compounds on various bio-systems. The technology gives direct information about the molecular composition of different proteins, peptides, lipids, drugs, and metabolites.

This study aims to determine the compositional and spatial differences between biofilm EPS formed under different (i) systems, such as reverse osmosis, and aerobic granular sludge, and (ii) operational conditions by using MALDI-IMS. Different experimental approaches for EPS protein detection have been taken into consideration, such as embedding methods and material, sample thicknesses, type of matrix and concentration, freezing and slicing temperatures. By the optimization of the technique, proteins spatial distribution in the EPS matrix of biofilms were determined.

Biofilm EPS characterization using MALDI IMS is a challenging technique; nevertheless, it is viable for protein characterization. The limitations of the method involve thickness of the biofilm, embedding material and image resolution.

Keywords: EPS, Maldi-IMS, Biofilm, Characterization

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Non-rectangular flow-paths for brackish water electrodialysis

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In order to reduce the capital and operating costs of electrodialysis (ED) desalination, several authors have turned to optimizing geometry and operating parameters. These studies are broadly focused on either the millimeter-scale geometry of spacers [1,2] or component-scale considerations such as the length, width, and number of cell-pairs. With the latter, all recent continuous ED studies assume rectangular flow-paths [3-7]. Here, we specifically mean that the width of the flow-path is constant along its length. Commercial spacers, including the Suez Mark IV-2 spacer and IonTech sheet-flow spacer are also rectangular in the manner defined.

We instead investigated the potential energetic and cost savings facilitated by non-rectangular flow-paths for brackish water desalination. In particular, we identified the optimal flow channel geometry to minimize pressure drop (energetic savings) and membrane area requirements (capital cost savings) using simulation. Benchmarking against the SUEZ MkIV-2 indicated a potential 55% decrease in pressure drop at the same operating voltage of 0.62 V/cell-pair with minimal increase in membrane area (1%), by reconfiguring the geometry in the manner proposed (Fig. 1). Alternatively, by increasing the voltage by 18%, a tapered spacer reduced the membrane area by 17% for the same production performance specified in Fig. 1 with no additional pressure drop. Spacer thickness, membrane properties, and flow-rates remain unchanged in this comparison, and the same existing spacer manufacturing processes can be used. The effect of changing the flow-rate and recovery ratio

were also investigated in this study. The proposed spacer geometry provides a promising direction for reducing the cost of ED in domestic [8] and community-scale applications [9] where hydraulic and/or electrical staging is not feasible.

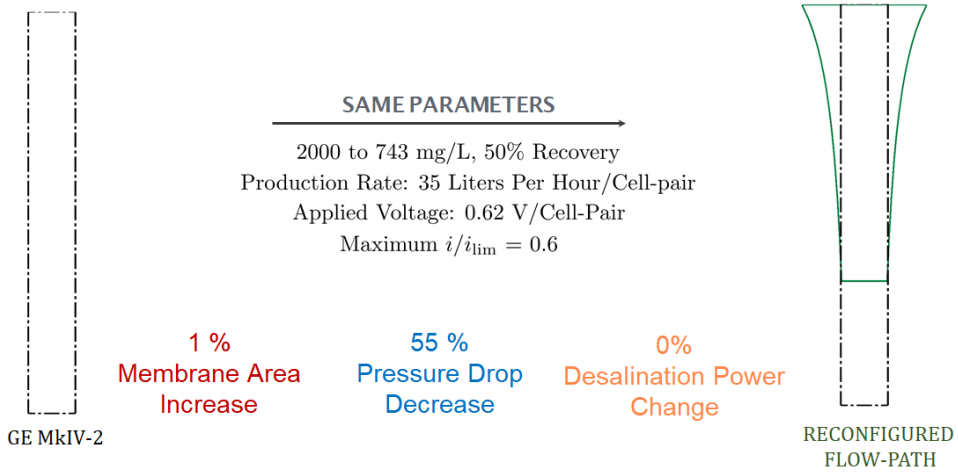

Fig. 1: Preliminary analysis indicates that SUEZ can decrease the pressure drop in their ED(R) MkIV-2 flow-spacers (black, dot-dashed) by 55% by implementing the tapered-flow path geometry shown (right, green, solid). Note that the MKIV-2 flow-path is shown here in an unwound state (normally U-shaped).

Keywords: Brackish; Design

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Establishing correlations between pore structure, surface roughness, compressive strength, and fracture toughness of ceramic water filters local to Rajasthan, India

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This paper discusses the material and strength characterization of local clay-organic (CO) ceramics used for household water filtration application in rural India. Local clay and sawdust were the raw materials for manufacturing these ceramics. Wet mix with specified volume fractions of these raw materials were hydro-plastically formed to square plates, dried and fired at 850°C. Once fired, these ceramics showed a prominent presence of silica, alumina, and oxides of iron. Quartz, potassium feldspar, and hematite are the major minerals in these produced ceramics. The family of ceramics has pore distributions with dominance of pores orthogonal to the surface. Surface roughness of the ceramics varies linearly with porosity of the mixture. The compressive strength is found to decrease linearly with increase in surface roughness. The fracture toughness is a polynomial function of the surface roughness of these porous ceramics. Models show that filtrate productions from square plate ceramic filters are better than those of cylindrical and frustum shapes at ambient conditions.

Keywords: Ceramic; Roughness; Porosity; Fracture; Compressive strength

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Optimized fit-for-use reclaimed oil and gas wastewater treatment by means of a smart decision support system

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The treatment of highly variable and complex industrial wastewater, particularly of those sectors that involve the use of large amounts of water, is an upcoming challenging concern, particularly in water scarce regions. The H2020 Integroil project aims at developing and demonstrating a robust and flexible integrated treatment solution for such water streams. It is based on innovative treatment technologies effectively arranged and optimized through a novel Decision Support System

(DSS), capable of producing fit-for-use reclaimed water, increasing the overall sustainability and competitiveness of those industries. The technologies that comprise this solution include dissolved air flotation (DAF), ceramic ultrafiltration (UF), advanced oxidation (AOP), catalytic wet air oxidation (CWAO) and reverse osmosis (RO). The Oil&Gas field has been selected as case study; however, due to the versatility of the integrated solution, it is expected to be applicable in other sectors.

A fully automatized 1.5 m^3/h pilot plant composed by the above-mentioned processes has been designed, constructed and is currently under operation. It is being tested in two demonstration sites corresponding to two water treatment scenarios within Oil&Gas: upstream, where water and crude oil or natural gas from the reservoir are extracted, and downstream, which corresponds to the water involved in the process of oil refining. Different final water uses have been considered, enabling water reuse for different purposes.

The five considered processes have been integrated into a centralized control architecture and the developed DSS adapts the pilot plant treatment scheme according to the changes in the influent wastewater characteristics and the selectable effluent water quality requirements, depending on its final use. Hence, this DSS is able to assess the possible configuration of the pilot plant given the influent wastewater quality parameters and the characteristics of each process and is able to select the best configuration (active processes) of the plant capable of fulfilling the final quality requested, minimizing the associated treatment costs.

The associated benefits of using the DSS during the operation of the pilot plant with respect to various KPIs will be shown. These will include the robustness (compliance 99% of the time), flexibility (less than 1 minute in plant reconfiguration time) and long-term performance by using big data and machine learning techniques.

Keywords: Decision support system, Wastewater treatment, Optimization, Oil and gas.

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Interactions between inorganic and organic fouling in forward osmosis process: impact on crystal formation and boron rejection

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The objective of this study was to understand the interactions between inorganic and organic foulants and their impact on boron rejection in forward osmosis (FO) process. Four parallel lab-scale FO systems were operated using model organic foulants (humic acid, bovine serum albumin, sodium alginate gypsum) and inorganic foulants ($CaCl_2$ and Na_2SO_4) with boric acid. The membrane performance (flux decline, salt rejection), physico-chemical properties of the fouled membrane (surface charge, roughness, hydrophobicity, morphology of fouled membrane), crystal formation (morphology, composition), and boron rejection were analyzed.

Significant differences in physico-chemical properties of fouled membranes and the crystal morphology were shown according to the type of organic foulants. The different morphologies of gypsum crystals and fouling layers on the membranes may be caused by the different interaction mechanisms between the foulants. However, the changes in properties of fouling layer showed a limited effect

on the membrane performance and boron rejection. The water flux decline and boron flux after two days were 8.9, 0.3, 8.8, 12.2% and 0.5, 1.3, 0.9, 0.4 mg/m^2/h under inorganic foulants (gypsum) with boric acid (GB), alginate with GB, BSA with GB, humic acid with GB conditions, respectively. Also, boron rejection was more influenced by water flux rather than physico-chemical properties of fouled membranes. This study showed that properties of fouling layer are significantly different depends on the foulant compositions, but it is not an essential factor to determine transport of boron in FO process.

Keywords: Forward osmosis, Inorganic fouling, Organic fouling, Crystallization, Boron rejection

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Demonstration of the efficiency and reliability of a seawater desalination pilot plant in the Arabian Gulf in views of a subsequent full-scale plant construction

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The assessment of water treatment schemes by means of pilot plants not only enables the performance verification of a full scale plant under design, but also the possibility of optimizing it beforehand to better calculate the associated CAPEX and OPEX, as well as the reliability of the process when facing challenging scenarios. In this study, a 30 m^3/h pilot plant consisting in dissolved air flotation (DAF), disk filters (DF), ultrafiltration (UF) and reverse osmosis (RO) to desalinate seawater was designed, constructed, operated and optimized. This pilot plant mimicked the 284.000 m^3/d full-scale plant water treatment scheme that was being constructed in the framework of the Umm Al Houl Independent Water & Power Project in Doha (Qatar).

The 1-year evaluation period enabled the assessment of the proposed treatment scheme under different conditions. In particular, influent turbidity ranged from 0.3 – 42.3 NTU, total suspended solids (TSS) 1.3 – 62.0 mg/L, conductivity 61 - 69 mS/cm, total organic carbon (TOC) 1.1 – 2.1 mg/L and SDI_{15} > 5 %/min.

Due to the operational problems that algae bloom may cause to seawater desalination plants, algae threshold tests were conducted. These enabled pushing the technology to its limits and characterizing its hydraulic and quality performance. The ULTRADAF® system was able to successfully deal with the challenging conditions faced and the feasibility of this process as pretreatment of UF systems for algae bloom events was demonstrated.

Optimal operational conditions, associated chemical consumption and water yield were defined per unitary process. Treated effluent quality of each unit was determined, demonstrating that the final permeate fulfilled the quality requirements during the whole operational period in a reliable way. Membrane autopsies and cleaning studies provided some insights to further optimize the

full-scale operation. The full paper will present the specific results obtained, demonstrating the suitability, robustness and efficiency of the treatment scheme proposed.

Keywords: Seawater desalination, Reverse osmosis, Dissolved air flotation, Ultrafiltration, Optimization, Reliability.

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Methodology to design cost-effective and sustainable solutions for reverse osmosis membranes cleaning

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Membrane fouling is a persistent problem throughout reverse osmosis systems that reduces plant efficiency and economics. 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 removing foulants. If the cleaning agents are not the appropriate ones, the desired effectiveness is not achieved or the membrane may be damaged. Membrane cleaning depends on the type of deposit affecting membrane performance. Knowing the nature of a membrane foulants will allow selecting the best cleaners and the most effective cleaning procedure. Membrane autopsy is the best method and the only reliable technique to identify the nature of foulants and the cause of poor membrane performance.

In this study, a methodology based on membrane autopsies has been successfully applied to determine the most cost-effective and sustainable solution for reverse osmosis membranes cleaning. The methodology used to identify and characterize the composition of foulants deposited on a membrane surface consists in 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). Membrane autopsies were performed on reverse osmosis elements derived from two different plants: a reverse osmosis seawater membrane and a reverse osmosis membrane used for leachate treatment. Both membranes surface were covered by a thick gelatinous deposit layer. The deposit layer had a dense and compact structure. More severe fouling was observed in the leachate treatment membrane. Fully developed biofilm was found on both membranes. This biofilm was the predominant form of membrane fouling and it was composed of bacteria and extracellular polymeric substances (EPS). CLSM analyses showed that three-dimensional structure and the composition of biofilms were different in each membrane. Analysis of the deposits also showed the presence of alumino-silicates (clay) and iron in a smaller proportion.

After determining the fouling behavior and mechanisms involved in membrane fouling for each element, 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 biofilms require a combined sanitization and cleaning procedure. Cleaning procedures included the use of non-oxidizing biocides and formulated powdered cleaners with the ability to fully penetrate, reach

and destroy internal biofilm layers. Cleaning programs also included effective cleaners to remove alumino-silicates and iron. Cleaning protocols effectiveness were tested in the laboratory using flat sheet membrane test cells to restore the performance of membranes to levels within the manufacturers specifications. Biocides and powdered cleaners effectiveness was evaluated in terms of normalized permeate flow and normalized salt rejection before and after cleaning. Comparative analyses of membranes before and after cleaning procedures were conducted using CLMS, ATR- FTIR and SEM-EDX techniques. The results demonstrated that powdered cleaners used in combination with non-oxidizing biocide restored both membranes performance to design specifications and removed bacteria and biofilm from membranes surface. Formulated powdered cleaners are effective at low doses so they reduce operating costs and minimize chemicals discharge to the environment. This study demonstrates that CLSM provides a valuable research tool to understand the effect of cleaning agents on biofilm structure.

Keywords: Reverse osmosis, Membrane cleaning, Formulated powdered cleaner, Biofouling, Membrane autopsy, Confocal laser scanning microscopy (CLSM)

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Auto-adaptive fouling control in UF during algal blooms

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Ultrafiltration (UF) is currently one of the leading treatment solutions for several municipal and industrial water treatment challenges including pretreatment for water desalination and wastewater reclamation. Here we describe a novel approach to maintain stable operation in UF system by employing digital pumps and sensors to optimize hydraulic cleaning and coagulant dosing in UF system. The key innovation is the development of auto-adaptive pump control algorithms - which consider real-time performance data from pumps and sensors - to optimize the hydraulic cleanings in UF system and inline coagulant dosing for timely fouling mitigation with minimal need for human intervention. The viability of this technique was validated in a bench-scale UF system treating algal bloom impacted seawater with highly dynamic quality. The algorithms demonstrated significant reduction in system downtime and operational cost for chemical consumption and sludge handling. This smart pump solutions do not require additional footprint as the algorithms can be installed with existing units via microcontrollers embedded in the pump, through the plant PLC or SCADA system, or remotely implemented via a cloud server. Further steps will consist testing the algorithms in a 10 m^3/h seawater desalination pilot plant located in the Mediterranean region.

Keywords: Ultrafiltration (UF), Algal blooms, Seawater desalination, Membrane fouling control, Smart pump solutions

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Limiting phosphate to control biofouling in seawater reverse osmosis

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Pre-treatment is crucial to reduce the biofouling potential of seawater and limit the use of cleaning chemicals in SWRO systems. However, if pre-treatment is not (fully) effective, severe biological/organic fouling may occur.

Previous research on freshwater revealed that limiting inorganic nutrients such as phosphorous and carbon can slow biofouling development in membrane systems. The required concentration levels of phosphorus are approximately 10 times lower than carbon as indicated by the molar ratio of carbon (C), nitrogen (N), and phosphorous (P), i.e.,~100:20:10 for microbial growth. The study of Jacobson et al., (2009) showed that in freshwater a phosphate concentration below 0.2 µg PO_4-P/L may limit biofouling in reverse osmosis membranes. Likewise, the study conducted by Vrouwenvelder et al, (2010) also suggested that phosphate concentration of ~0.3 µg PO_4-P/L in the feed fresh water restricted the increase in pressure drop in membrane fouling simulator studies (MFS). However, currently no analytical method exists that can detect such low levels of phosphate in seawater or freshwater.

Dissolved air flotation (DAF) in combination with ultrafiltration (UF) is gaining attention as a promising pre-treatment to reduce biofouling in SWRO membrane systems, particularly during algal blooms. The operation of DAF is always preceded by coagulant dosing (ferric chloride) to remove algae, organic matter as well as dissolved phosphate. Phosphates are known to form strongly bonded complexes with iron in the wide range of pH (Belelli et al., 2014, Tejedor-Tejedor et al., 1990). The application of UF downstream of DAF further enhances removal of small flocs that pass through DAF systems. However, (non-backwashable) fouling resulting from iron usually hinders UF operation during long term operation of these systems, which again increases the frequency of (chemically) enhanced backwashing and down time of the system.

Despite advances in pre-treatment, biofouling in seawater reverse osmosis is still a major problem as neither DAF nor UF are optimized to remove dissolved phosphate or other nutrients.

This study focused on (i) developing a method to measure low levels of ortho-phosphate in RO feed water for seawater nd freshwater (<0.3 µg PO_4-P /L), (ii) monitoring the removal of phosphate along pretreatment steps in plants prior to reverse osmosis to help optimizing its operation. The preliminary results showed that limit of detection of phosphate measurements in freshwater is ~0.3 ppb. While, limit of detection of phosphate measurements in seawater still under evaluation.

Secondly in this study, we will demonstrate and optimize the role of DAF and UF (with coagulation) in removing phosphate. The work will be conducted using lab scale DAF unit and lab scale filtration unit.

Keywords: Seawater, Phosphate, Biofouling, Dissolved air flotation, Ultrafiltration

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Real-time fouling visualization in spacer-filled reverse osmosis channel under intermittent operation

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Lack of available drinking water is currently one of the most significant global risks. Photovoltaic-powered, small-scale reverse osmosis (RO) units for brackish water desalination could be a practical solution to this issue in many remote communities. Such systems run intermittently depending on sunlight availability, which may lead to premature membrane fouling due to additional complexities in operation and maintenance. Previous studies evaluated this phenomenon in terms of flux decline; however, due to sensing limitations, they could not clearly explain the underlying fouling mechanisms. This work describes the development and integration of a real-time imaging technique with measurement of flux decline to further characterize the fouling dynamics during intermittent operation. Experiments were conducted for both continuous (21-h straight) and intermittent (7-h/d for 3 d) modes of operation using lab-mixed brackish groundwater. To assist in visualization, a custom-fabricated plate-and-frame RO module with a transparent polycarbonate window was used. During each experiment, a membrane area of approximately 22.3 × 14.9 mm^2 was scanned periodically at a resolution of 5184 x 3456 pixels, and then post-processed. In this step, consecutive images were aligned, filtered, adjusted based on intensities, and subtracted from a reference frame. Then, resulting images were converted to grayscale and enhanced based on contrast-limited adaptive histogram equalization so scaling on the membrane surface can be distinctly seen. Comparison between the visualization and flux decline showed good one- to-one correspondence. At the beginning of the experiment, scaling started quickly with a uniform foulant growth over the membrane surface. As time progressed, the foulant accumulation increased near the feed spacer boundary as predicted in literature. Analyses of the preliminary results also demonstrated a significant drop of the scaling intensity over the shut-off period of an intermittent cycle. This finding strongly supports the hypothesis that during the shut-off period, retaining permeate water in the RO module flows back to the feed side through osmosis, reducing the concentration on the feed side, and dissolving some scales leading to improved membrane permeability. Further experiments employing this visualization technique will help to define the critical parameters for intermittent RO operation and will aid in the development of robust small-scale RO systems for remote communities.

Keywords: Reverse osmosis; Intermittent operation; Scaling; Visualization; Feed spacer; Brackish water

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Early non-destructive fouling detection in spiral-wound and hollow fiber membranes using high magnetic field and portable low magnetic field NMR and MRI

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This talk will present an overview of recent research developments in the area of monitoring membrane fouling using NMR & MRI at the Fluid Science & Resources research group at the University of Western Australia. These developments include early detection of biofouling in spiral wound reverse osmosis (SWRO) and monitoring of fouling and its effects on flow maldistribution in hollow fiber (HF) membrane modules using low field and high field NMR & MRI. This work aims to improve understanding of the effects of foulants (e.g. biological matter) on the operation of membrane modules where complex interactions of foulants with flow field causes maldistribution of flow which ultimately deteriorates the performance of the membrane modules. A strength of using NMR & MRI is that it can non-invasively and non-destructively image the distribution of flow inside complex geometries while its myriad of contrast mechanisms (T_1, T_2 relaxation, diffusion, density, specificity to nuclei (e.g. ^{23}Na)) coupled with macroscopic measurements (e.g. permeate production rate, pressure drops etc.) allows for both complementary and rich new information about the effects of foulants on the operation of membrane modules beyond treating each module as a "black-box". An important area of use will be the interrogation of the effectiveness of cleaning strategies on long-term viability of membrane modules. Work on monitoring concentration polarisation in forward osmosis will be explored, where the ability of NMR to directly monitor ^{23}Na nuclei is exploited. Future directions of this research will be presented in the context of developments in mobile NMR technology towards industrial application.

Keywords: Membrane fouling; Spiral wound reverse osmosis; Hollow fiber membrane; NMR and MRI; Early detection.

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MRI and NMR investigation of the flow field in spiral wound reverse osmosis membrane modules during biofouling

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Membrane desalination is a significant consumer of energy and fouling incurs large operating costs due to increased flow resistance and deterioration in membrane performance which ulti-

mately results in replacement. Timely detection of fouling is key to efficient plant operation as early detection and remediation of biofouling are important in the control of biofouling proliferation in spiral wound membrane systems. In this work high field MRI and velocity images are used to monitor the flow field inside of an operating 2.5-inch commercial spiral wound membrane system. Incremental doses of a long chain polysaccharide (sodium alginate) are introduced to the system to mimic biofouling. This study demonstrates that a small amount of fouling material can have significant effects on the flow field within the membrane module and that the foulant tends to associate with spacer nodes (consistent with results from previous studies and autopsy observations). Changes in the velocity in each spiral leaf (end-to-end) and along the length of the membrane system are monitored showing significant increase in asymmetry once foulants are introduced. T_2 images before and after fouling show that the foulant accumulates at spacer nodes and that different regions (brine side, permeate side and membrane) are distinguishable using T_2 relaxation. This opens the potential for using T_2 relaxation as a contrast mechanism to monitor the extent of fouling inside operating commercial spiral wound membrane modules, presenting a useful contrast mechanism when using portable low-field NMR equipment for monitoring early onset fouling.

Keywords: Noninvasive inspection, Nuclear magnetic resonance, Membrane fouling, Membrane flow fields, Biofouling.

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Applying the new $MFI_{0.45}$ method and SDI in monitoring of seawater

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The SDI and MFI are standard methods by the ASTM. However, the MFI is relatively new and beginning to gain momentum in the desalination community. The MFI is also recognized as a better index in comparison to the SDI, primarily due to a linear correlation to the concentration of particles in the feed water and being based on a filtration mechanism, which makes it suitable to model rate of clogging or fouling. However, the effect of the experimental set-up (filter holder, geometry and filter type) to measure these indices are not clearly understood and the ASTM standard does not define all aspects of the test.

The aim of this research was to assess particulate fouling of North Sea seawater, by measuring the SDI and MFI values over a period of several months (still ongoing until one full year is completed) and by studying the effect of testing conditions like filter holder and filter material on SDI and MFI. In this study, seven different filter holders and three different 0.45 µm filter materials from various manufacturers were tested and the SDI and MFI measured.

Our preliminary results illustrate the effect of the type of filter support of the filter holder in MFI values and not in SDI values. The filter material also influences greatly the measured values for both SDI and MFI. Different SDI and MFI-0.45 values were measured with different membrane materials. The filter support affects the effective area of the filter and needs to be corrected when measuring the MFI-0.45. SDI is not affected. The results of monitoring North Sea water show that MFI-0.45 is a good tool for assessing changes in particulate fouling potential.

This research is of interest for scientist and practitioners dealing with monitoring of water quality, assessment of pre-treatment and monitoring of reverse osmosis systems.

Keywords: Particulate fouling, Reverse osmosis, Seawater, MFI, SDI

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Short-term energy storage in reverse osmosis desalination systems – theoretical investigation and experimental validation

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Desalination processes require considerable amounts of energy to separate salts from the saline water. The theoretical minimum energy required for desalinating seawater of salinity of 35,000 mg/L at 50% recovery rate, is 1.06 kWh/m^3. However, in practice much higher amounts of energy are required by the current desalination technologies. For instance, reverse osmosis desalination requires at least 2.5 kWh/m^3 in large scale systems with energy recovery devices and can reach the value of 25 kWh/m^3 for small-scale systems without energy recovery devices.

Renewable Energy (RE) powered desalination is a suitable solution for remote and decentralized areas away from the national electricity grid with low population density and lack of fresh potable water infrastructure. Such renewable energy powered desalination units contribute to about 1% of desalination capacity based on conventional fossil fuels.

One of the most important aspects of RE powered desalination units is the variable power supply from the RE systems and the need of steady operation of the desalination units. Introducing lead acid batteries as energy storage currently solves this problem. However, these batteries have proved to be one of the most expensive parts of a RES powered desalination system; furthermore, they are not environmentally sustainable if not properly recycled.

The current work investigates the possibility of introducing short-term energy storage device in the form of hydraulic pressure tanks that can keep the reverse osmosis (RO) unit under a pre-defined operational window of pressure and flow in periods with variable RE power supply. The paper presents the modeling of this short-term energy storage device and the experimental validation of the developed model. The results showed that the time of energy storage with the use of 3 hydraulic pressure tanks is about 40 min. In order to optimize the operation and energy management of the system (RE and RO), a smart control system based on computational intelligence techniques is implemented. This innovative RE powered RO unit can then be integrated in electrical smart grids configuration for better demand side energy management.

Keywords: Short term energy storage, Desalination unit, Hydraulic pressure tanks, Theoretical modeling, Verification, Variable operating conditions.

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High recovery in SWRO using a multi-stage multi turbo (MSMT) configuration: CAPEX, OPEX and SEC analysis for the concept and the case study of an early adopter

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The concept of Total Water Cost (TWC) involves capital (CAPEX) and operational expenditure (OPEX) and has gained traction in the latest discussions on the how to make desalination more affordable. Achieving the lowest TWC at a BWRO and SWRO plant without sacrificing process performance is a challenge most process engineers face. It is not uncommon to find a tendency in the desalination industry to analyze the cost of producing permeate purely from an OPEX perspective. Not including the CAPEX in the permeate production cost evaluation will have a significant impact on the commercial value of the special offer. Most of the SWRO projects, especially those with permeate production capacities above 5,000 m^3/d, involve capital amortization paid throughout the project's lifetime. Interest rates add a significant overhead sometimes unaccounted by process engineers at the moment of selecting a technical solution resulting in a less competitive offer.

Moreover, high recovery employing multistage skids is a widely used approach in BWRO to optimize the process and obtain the maximum amount of permeate for every drop of feed water. In most cases, attaining the highest possible recovery will bring savings in CAPEX and OPEX resulting in the lowest TWC. Recently, we have shown that employing the same design philosophy as the one used in BWRO allows achieving 60% recovery in SWRO plants using Multistage Multi Turbocharger (MSMT) configuration. Shifting from 45 to 60% recovery will lead to a 33% reduction in the feed flow, which in turn reduces the size of the pretreatment, intake, pumps, piping, instrumentation, valves, brine discharge, building footprint within many other parts of the plant that are closely tied to this parameter. Additionally, it also decreases chemical consumption making it a greener process.

This paper shows a real case study of Universal Water Treatment, an OEM headquartered in Mexico, that early adopted the MSMT concept. They constructed the first 360 m^3/d MSMT RO skid capable of achieving 60% recovery in both Atlantic and Pacific oceans water quality. This skid demonstrates that two turbochargers may operate in series resulting in each turbocharger developing the desired amount of pressure boost to balance the flux on each stage while extracting all available hydraulic energy from the brine stream. Additionally, the Specific Energy Consumption (SEC) for different plant production capacities is analyzed showing that the facility power consumption is similar to the values obtained when using Isobaric Chambers.

Keywords: High recovery, SWRO, Total water cost, SEC, Specific energy consumption, Turbocharger, FEDCO, MSMT

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Combined membrane and thermal desalination processes for the treatment of ion exchange resins spent brine

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The production of polluted brines in several industrial processes is becoming a critical environmental issue. For this reason, it is necessary to develop new treatment solutions to purify the brines before injecting them into the environment, or to remove the pollutants and recover the valuable materials.

This work is focused on the treatment of waste brines coming from the regeneration of spent Ion Exchange resins (IEX) employed for water softening in a demineralization plant. The regeneration is performed via a NaCl-water solution and it produces an effluent containing NaCl at a lower concentration, magnesium and calcium ions. The treatment aims at recovering the NaCl-water solution (brine), re-usable in the next regeneration cycle, and Mg^{++} and Ca^{++} in the form of hydroxides. For this purpose, a treatment chain has been developed within the framework of the EU-funded project Zero Brine, whose aim is to build pilot plants to treat different types of industrial brines and to recover raw materials from them. The chain provides a nanofiltration (NF) stage, in order to concentrate the bivalent cations in the retentate, which is sent to a two-step crystallization, in which Mg^{++} and Ca^{++} precipitate via the employment of an alkaline reactant. Conversely, the nanofiltration permeate is fed to a multi-effect distillation (MED) plant, where the required salinity of the regenerant solution is restored.

For each of the three accounted processes, a techno-economic model was implemented and the models were interconnected in an integrated simulation environment. In this way, it was possible to assess the feasibility of the whole chain via the estimation of a novel performance parameter, the levelized brine cost (LBC): a measure of the cost of the brine produced via the treatment chain.

Firstly, the performances of the single processes were evaluated varying several parameters including the nanofiltration membrane properties, the number of effects of the MED plant, the quality of the supplied heating steam and the presence of a thermo-vapour compressor coupled with the MED. We found that the nanofiltration membrane properties affect dramatically the performance. Membrane properties are responsible for the ion rejection influencing the overall amount of recoverable minerals. The availability of waste heat at a low cost plays also a key role, since it radically reduces the operating costs of the MED plant. In particular, depending on the quality of the available heat and on its cost, the optimum number of effects was assessed. Then, the feasibility of the whole chain was evaluated, varying the nanofiltration recovery and taking into account the optimum MED configuration with a low pressure waste heat. It resulted that the LBC increases in the whole range of nanofiltration recovery because the reduction of the produced brine prevails on the variation of the annualized cost, which presents a minimum at an intermediate recovery (65%). Finally, we found that the revenues resulting from $Mg(OH)_2$ and $Ca(OH)_2$ production and the cost of the alkaline reactant have the most prominent role in the definition of the LBC.

On overall, the described treatment chain for the waste brines produced by the regeneration of spent ion exchange resins results competitive for a wide range of operating conditions and it allows reducing the environmental impact of the industrial process and promoting the recycle of waste streams and waste heat.

Keywords: Industrial brines, Nanofiltration, Crystallization, Multi-effect distillation, Techno-economic analysis, Circular economy

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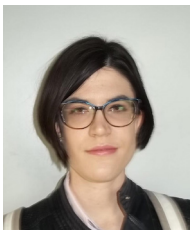
Adsorption of phenol with resin technology: phenol removal and resin recovery



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The wastewaters of the heavy petrochemical and oil refining industries carry important amounts of organics that include aromatic hydrocarbons, phenolic compounds and short-chain organic acids. The conventional oil separation systems typically operated in these facilities often fail to remove them consistently. Phenolic compounds are amongst the most common and problematic within this organic fraction. They are hazardous to human health and toxic to aquatic environments with long-lasting effects even at low concentrations. Therefore, they are currently classified as priority pollutants by the United States Environmental Protection Agency (USEPA) and the European Union (EU). Their concentration usually not only exceeds the levels for safe discharge, in keeping with current regulations, but also the levels of organic content recommended for other more sensitive downstream technologies for water treatment such as reverse osmosis membranes. Therefore, such wastewaters with large organic content typically need to be treated for phenol removal. Adsorption is an established method for removing phenol from water streams that can achieve very low concentration in the effluents. Most adsorbent materials however, have a challenging recovery. This paper studies the adsorption of phenol with DOWEX OPTIPORE™ L493 Adsorbent, a polymeric adsorbent designed for easy desorption and regeneration under mild temperature conditions. Equilibrium adsorption and desorption studies have been carried out. The results obtained show that temperature has a great impact on contaminant adsorption, indicating that resin recovery through thermal desorption is possible. Experiments in different conditions have showed that the regeneration of the resin is can be achieved with demineralized water at 100°C and 1 bar (≥ 97%), without the use of solvents of chemical solutions.

Keywords: Phenol removal; Adsorption; Polymer resins; Regeneration

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Direct renewable energy powered desalination (DrepD)

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All current reverse osmosis (RO) desalination plants powered by renewable energy operate by first generating electricity and then using this electricity to power a conventional RO desalination plant. However, directly pressurising seawater rather than producing electricity has the potential to improve reliability, reduces costs and energy loss through conversion. On the other hand, this complicates the design as traditionally RO desalination plants are intended for operation under unvarying power, unlike that produced by renewable energy. These conditions may be detrimental to product quality, quantity and membrane structure. A variable speed RO laboratory rig has been built to study the restrictions of this process. Volumetric flow and pressure variations produced by wave, wind and tidal energy can be replicated on the test rig to investigate the feasibility of directly driving an RO plant. The DrepD project compares RO performance under different intermittent energy sources, using a variable speed motor and an actuated valve to control flow and pressure, respectively. The experimental design allows for the constant monitoring of performance, energy input to output ratio, as well as product salinity. This is used to formulate the feasible range of variations in the feed. Adding appropriate control equipment to the model of a device can account for deviations from the suitable range. Through the physical experiments and numerical model of the plant, different configurations can be tested, in order to devise a robust and efficient design. This study is on-going and preliminary results will be presented.

Keywords: Reverse osmosis, Desalination, Marine energy, Variable operation

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Impact of permeate flux on biofilm development in forward osmosis membrane systems

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In membrane-based water treatment, biofilm formation on the membrane surface is a major problem. Current physical and chemical cleaning strategies are not successful in biofilm removal in most of the cases. A better understanding of the biofilm morphology and mechanical properties may lead to more effective biofilm control strategies. The objective of this study was to investigate

the morphological and mechanical changes of the biofilms under different water fluxes (through the biofilm) in membrane systems and the impact thereof on membrane performance. The impact of permeate flux on biofilm thickness and structure were investigated in-situ with *Optical Coherence Tomography* (OCT). To characterize the deposited biomass, total cell number, cell viability, adenosine tri-phosphate (ATP), total organic carbon (TOC), and extracellular polymeric substances (EPS) concentrations were analysed. Based on the results an increase in water permeate flux resulted in (i) higher EPS concentration in the biofilm, (ii) thicker biofilm, but (iii) no significant difference in membrane performance decline. OCT imaging provided useful structural information on biofilms developed in membrane systems under various operating conditions. Biofilm formed under high flux condition tend to be thicker and more heterogeneous than the biofilm formed under the low flux. These insights may lead to better understand the biofilm formation in membrane systems and more effective knowledge-based biofouling control strategies.

Keywords: Biofouling; Biofilm mechanics; Spiral wound membrane systems

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The impact of geothermal water RO concentrate volume minimization on the possibility of comprehensive further use

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Reverse osmosis (RO), as one of membrane processes, is well-known technology increasingly applied for providing fresh drinking water around the world, due to high efficiency, low energy consumptions and other improvements in energy recovery systems made over past years. Moreover, RO technology is becoming a useful method of desalination geothermal waters which often contain elevated concentrations of specific macro and microelements potentially valuable for reuse. Using membrane processes, especially RO, to concentrate geothermal waters can provide to obtain good quality new products, such as permeates possible to use as drinking waters and concentrates. Optimal selection of process parameters and recovery values of permeates and concentrates will directly influence on theirs compounds and possible comprehensive further reuse.

RO concentrates are conventionally are treated as waste and are disposed of by several means, which is disposal to surface waters, sewers, via deep injection, disposal in evaporation ponds and land application of concentrate. However recently, RO concentrates are also considered as a valuable resources for production mineral salts or solutions, metals, precious chemicals and other products for cosmetology, balneology and other industries.

The suitable hydro-geochemical composition of recovery geothermal water concentrates will strictly determine applicable management and reuse. Additionally, curative properties of natural geothermal water can be concentrated by use membrane processes to produce curative solution or crystalline salt used for therapeutic treatments and in cosmetic industry.

The work presents the results of the assay oriented towards examine the influence of recovery value of geothermal water on the quality of concentrate obtained by means of reverse osmosis process. The survey was carried out on the example of geothermal waters extracted from wells

located in Poland area. They exhibit elevated concentrations of magnesium, potassium, sodium, sulphates, silica and other components significant for therapeutic industry. Conducted RO processes in laboratory-scale have allowed for a detailed recognition of the influence of the concentrate volume minimization, in adopted process parameters of desalination, on theirs composition. The research was established for 50 and 75% permeate recovery.

The study results revealed that concentrates gained from RO tests with 75% recovery of permeate are characterized with significantly higher value of total dissolved solids and due to the concentration of the desired and undesired ingredients, can be a potential source of mineral solutions in different industries.

Keywords: Concentrate, Desalination, Reverse osmosis, Balneology, Mineral recovery

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Mechanical properties of microorganisms that comprise membrane biofouling using using bio-force spectroscopy

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Biofouling is still considered as one of the main hurdles for efficient operation of all membrane-based technologies. Biofilm often comprise a complex microbial community that includes microalgae and fungi as well as heterotrophic and autotrophic bacteria. To date, much research has been done to define biofilm characteristics under various physicochemical conditions. Yet, limited information is available in respect to the effects of hydraulic pressure on biofilm consortiums. In this study we carried dynamic experiments using gram positive and gram negative bacteria as well as cyanobacteria and microalgae in which mechanical properties of each organism were measured *in-vivo* under various pressures using bio-force spectroscopy. Our results show that under pressure of 10 nN and 15 nN, gram positive bacteria compressed by 139.8±43.8 nm in one, stable step. Differently, gram negative bacteria compressed by 165.2 ± 80.4 nm under pressure of 10 nN and by 219 ± 113.8 nm under pressure of 15 nN. The deformation of these gram negative cells was achieved gradually over time (~55 sec.). In addition, gram positive deformation did not change once pressure was relieved, while gram negative bacteria structure was partly (88%) recovered. Cyanobacteria, similarly to gram positive bacteria were also found to deform in one single step by 800 ± 100 nm under the same pressure conditions. Our results provide new insights over the impact of pressure on the structure and mechanical properties of microorganisms that comprise membrane biofouling. We surmise that these insights will enable new developments in pretreatment technology and biofouling control.

Keywords: Membrane biofouling, Mechanical properties, Atomic force microscope

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New approach for concentrate utilisation obtained during geothermal water desalination

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The use of geothermal energy plays an important role of renewable energy utilisation. Worldwide, geothermal water offers significant resources that are widely available and use to generate electricity in power stations, for heating purposes, greenhouses, agriculture, for generation of warm water, therapeutic and recreational purposes. In physical and chemical terms, the geothermal water present in the structures examined exhibit different properties. There are both fresh waters, in which total dissolved substances (TDS) are below 1.0 g/L, brackish waters (TDS from 1 to 10 g/L), saline waters (TDS from 10 to 30 g/L) and brine (TDS more than 30 g/L). All kind of geothermal waters are used for heating purposes, but low mineral content and fresh geothermal waters are especially made available for both heating and leisure purposes. The objective of this article is to present concept for multidirectional use of waste geothermal water, used in traditional manner. The Author previous research done on a semi-production scale showed that waste geothermal water can be purified by membrane processes (ultrafiltraion/nanofiltration/reverse osmosis) and after that re-used as drinking water. In these processes concentrate is generated as a by-product of the separation of the minerals from the source water used for desalination.

The paper presents two innovative approaches, but both of them based on geothermal water treatment processes. First, presents the result of research of the use of concentrate as a new product for therapeutic, balneological purposes and/or a source of medicinal raw materials. The analysis was based on the result of 21 concentrates which including: macroelements and specific therapeutic components, potentially toxic elements (heavy metals), radioactive elements. The research showed that the concentrations of potentially toxic metals in most concentrates do not exceed the limits recognized as safe for human health, independent of the way of contact with its body. These concentrates can be used: 1) for inhalation of the airways and rinsing the nose and mouth for the purpose of loosening and removing mucus and relieving inflammation; 2) for cosmetic purposes in the form of cleansing and moisturizing liquids; 3) for bathing both individual in baths as well as recreational or rehabilitation pools. The second innovative approach is related to energy harvesting from the salinity gradient. The objective of this conception is to clean geothermal water and also extraction of energy created by mixing of effluents with various salinity. RO process results in discharge of concentrate brine that can be considered as source of salinity gradient energy (SGE). In these cases two methods are considered: reverse electrodialysis (RED) and capacitive mixing (CAPMIX).

Keywords: Concentrate, Membrane processes, Human health, Salinity gradient; Energy

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CFD study of the vapor route within MED evaporator for seawater desalination plants

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This work aims to perform a thermal and fluid flow analysis of the vapor route of the transporting vapor from one effect to another in multiple effect distillation evaporators (MED). Two configurations of MED evaporator are considered. The thermal losses encountered in the vapor route along with the vapor uniformity at the entrance of the next tube bundle are analyzed. The effect of demister numbers and orientations for both configurations are investigated under different process recovery. Steady state 3D and 2D CFD simulation are performed using COMSOL Multiphysics non-isothermal two-phase flow package on a MED pilot scale.

The CFD analysis showed that, the side vapor box (MED-S) configuration with three inclined demisters records slightly better uniformity than the back vapor box (MED-B) configuration with one inclined demister; however, the footprint of MED-B is 40 % lower the MED-S configuration. The lower footprint reflects a lower evaporator layout space and consequently lower capital cost. Therefore, a tradeoff between the better uniformity and the capital cost would dictate the superior of MED-B to the MED-S configuration.

Keywords: Desalination; MED; Thermal losses; CFD; Vapor route; Vapor box

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The change of membranes properties during desalination of water

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The objective of this study was to investigate the effects mineral foulants on the membranes properties. Experimental tests were performed using a nanofiltration and riverse osmosis membranes (new membranes and used for water purification). The analysis the changes of membranes properties were performed using an optical tensiometer. The contact angle of the membranes was tested. The study showed the change hydrophobic and hydrophilic membranes properties.

Keywords: Membranes, Water pollutants, Desalination, Optical tensiometer

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Design of experiments in water treatment processes — data reliability

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The ultimate purpose of testing the quality of waters is always a decision on e.g. chemical status of water or the effectiveness of the treatment method used.

The effectiveness of the treatment process is monitored on the basis of the results of chemical analyses of raw waters, retentate and permeate. It is therefore important that these results be highly reliable. Obtaining sufficiently certain and reliable measurements of chemical parameters of water in practice entails the need for the laboratory to implement quality assurance/quality control (QA/QC) procedures.

The water treatment processes are highly dependent on many factors (i.a. treated water quality or process parameters). Therefore, apart reliable data, it is important to use well planned experiments, with the optimum conditions.

Experimental design is "statistical technique for planning, conducting, analysing, and interpreting data from experiments" (VIM). Statistically designed experiments allow to collect appropriate data during relatively small number of measurements, which may be analysed by statistical methods resulting in valid and objective conclusions.

Paper presents the example of design of experiment which was aimed at evaluation of effectiveness of nanofiltration process used for treating of geothermal water. The QA/QC procedure was implemented into the experiment. JMP Software was used to planning experiment. Data analysis (and verification) was done using PS IMAGO system (based on IBM SPSS Statistics software).

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Keywords: Design of experiments, QA/QC, Water treatment

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Experimental and theoretical investigations on performance evaluation of different spacers on a DCMD process

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This study provides a more comprehensive and systematic understanding on the fundamental characteristics of heat and mass transfer in direct contact membrane distillation (DCMD) process that employs different types of spacers in feed, permeate or both flow channels. Detailed theoretical investigations were carried out to demonstrate the effect of spacers on heat and mass transfer enhancement in the DCMD with a PTFE/PP composite membrane, complemented with experimental data for model validation. Thus, this work aimed on proposing and demonstrating heat transfer correlation for spacer-filled channels to more reliably predict the heat and mass transfer improvement by non-woven net spacers in the DCMD process. The results showed that the permeate flux enhancement by the spacers were 7% – 19% only for the spacer-filled permeate channels and 21% – 33% only for the spacer-filled feed channels even at higher flow rate, indicating lower flux enhancements in the spacer-filled permeate channels. This was because the influence of spacers on flux improvement became more evident at higher temperatures with a high temperature polarization. In this study, the maximum flux enhancement was at about 43% with the spacer having a hydrodynamic angle of 90° and a spacer porosity of 0.86 at both feed and permeate channels.

Keywords: DCMD, Spacer, Temperature polarization, Heat and mass transfer, Desalination

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Effect of size and concentrations of bead immobilized *Chlorella vulgaris* on wastewater nutrients removal

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Excess discharge of nitrogen and phosphorous from wastewater treatment plants (WWTPs) leads to eutrophication and poor water quality in water bodies [1]. Microalgae have been attracted as an alternative biological treatment to remove nutrients from WWTPs. Compared with conventional activated sludge process, microalgae offers more advantages, such as reduction of aeration cost and consumption of carbon dioxide, due to their photosynthetic metabolism [2]. The use of immobilization is an interesting technology for a successful microalgae cultivation. In particular, *Chlorella vulgaris* has been widely used to treat wastewater. Nutrients removal efficiency by immobilized *C. vulgaris* could be affected by numerous factors such as light penetration and substrate diffusion. Nevertheless, there is little information available for nutrients removal by immobilized *C. vulgaris*. The aim of this study was to determine the alginate bead size affecting nitrogen and phosphorus removal rates. The nitrogen and phosphorus removal rates were examined under various diameters of alginate gel beads (2, 4, and 6 mm). The effective thickness was measured by confocal laser scanning microscopy (CLSM) and SYTOX Blue dye in alginate beads, which enables to evaluate both viability and total counts of *C. vulgaris*. The optimized cell immobilization technology would accelerate nutrient uptake rate for high efficiency treatment system.

Keywords: Microalgae, Chlorella vulgaris, Nutrients Removal, Alginate bead, Encapsulation, Wastewater Treatment, Optimization, Immobilization, Removal efficiency, Bead size

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Degradation of triclosan and reducing by-products formation using non-transfer arc plasma

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It is well known that micro-pollutants cause various problems in securing safe water because they are concentrated in aquatic eco-systems. In particular, Triclosan [5-chloro-2-(2,4-dichlorophenoxy) phenol; TCS] is commonly detected micropollutants in surface waters, wastewater treatment plant effluents. TCS is an antimicrobial that is globally being used as disinfectants, soap, and detergent. Previous studies showed that TCS is toxic to aquatic eco-systems. It has also been reported that the transformation of TCS by photochemical or ozone treatment can cause a biological toxic effect. Therefore, it is important to effectively remove or degrade them.

In this study, TCS is treated by non-transfer DC arc plasma directly into the water. It is one of methods in advanced oxidation process and it shows different patterns of decomposition in various organic materials containing TCS depending on plasma generation types. At different voltages and currents, temperatures and pHs, non-transfer arc plasma treatment was operated. As treatment time increases from 0 to 5 min, degradation rate and byproducts of TCS were measured.

It shows new method of non-transfer arc plasma in micropollutants treatment for securing safe water and applicability to areas where micropollutants can cause environmental problem, such as water reuse and algal toxin control.

Keywords: Plasma, Arc, Micro-pollutants, Triclosan, AOP

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Identification of major factors affecting the fouling in cartridge filters prior to SWRO membrane

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Reverse osmosis (RO) membrane fouling results in water flux decline and frequent membrane cleaning in desalination plants. To overcome these problems, a good quality pre-treatment process

is essential for the successful operation of a seawater reverse osmosis (SWRO) plant. In general, deep bed filters or ultrafiltration (UF) membrane are employed as pre-treatment systems, they can minimize the reaching foulants to the SWRO main system [1]. Also, cartridge filter (CF) has been widely used to prevent RO membrane fouing and to extend the lifetime of the RO membrane. Nevertheless, research on CF fouling has not been reported in the SWRO system due to low replacement costs of CFs. The purposes of this study were to identify the major foulants and evaluate the performance of CF with respect to fouling and removal efficiency. Seawater was taken from the reservoir tank prior to RO process to conduct CF fouling experiments. The fouling experiments of CF with pore size of 5 μm were systematically investigated upon constant flux (60 L/m^2/h) filtration of the seawater. The CF surfaces were observed by scanning electron microscope (SEM)-energy dispersive spectrometer (EDS) to verify the deposition of foulants on CF surfaces. Permeate samples were analyzed by total organic carbon (TOC), liquid chromatography organic carbon detection (LC-OCD), and inductively coupled plasma mass spectrometry (ICP-MS) to evaluate the filtration performance. This study can contribute to the understanding of fouling behavior in CFs, which enables to improve desalination performance.

Keywords: Cartridge filter, Fouling

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Effect of charged surfactants on nanoparticles in feed solution of forward osmosis membrane system

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Forward osmosis (FO) is an osmotically driven membrane process in which the driving force for separation is the difference in chemical potential between a concentrated draw solution and a broad range of aqueous solutions, including contaminated wastewater.

Surfactants are deadly toxic substances in fish, causing endocrine disruption, affecting the growth rate and metabolism of algae in the water system, inhibiting photosynthesis, causing protein denaturation and skin disorders in the human body. Despite these problems, research on surfactants in the FO process is still insufficient. Among the fatal problems of the FO process, in addition, pore

clogging is a phenomenon in which voids are clogged by the particles, which reduces the life of the membrane and lowers the whole process efficiency. The similarity between these substances is that they all have electrostatic force, which results in a cohesion. Electrostatic force is known to be one of the factors causing the change in performance of the membrane. Other pressurized membranes have been shown to utilize this electrostatic force to improve the process performance of the membrane [1,2]. It is expected that the electrostatic properties of the two substances will increase the removal efficiency and permeability of the membrane.

In this experiment, we investigate the characteristics of the mixtures composed of nanoparticles and surfactants having different polarities. The effects of such nanoparticles and surfactants on the membrane and its performance are also examined. It is expected that the materials having the same polarity as the membrane have positive impact on the removal efficiency, helping reduce the membrane fouling.

Keywords: Surfactants, Nanoparticles, Forward osmosis, Membrane, Desalination

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Evaluating the impact of flux and recovery on reverse osmosis elements treating wastewater

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Increased demand in the water markets focuses the latest innovation researches on developing new products with improved characteristics and fouling resistance capabilities, that help to reduce the chemical and energy consumption, lower the fouling rates, increase recovery rates and achieve higher removal of dissolved contaminants.

The new DOW FILMTEC™ FORTILIFE™ CR100 reverse osmosis (RO) element is designed to address the most challenging fouling situations limiting water treatment plants. This element has an optimized design to improve its fouling resistance characteristics. This paper will present case studies where DOW FILMTEC™ FORTILIFE™ CR100 RO elements are benchmarked under difficult fouling conditions. Feed water was pre-treated with DOW™ Ultrafiltration to ensure high quality filtrate water for the RO system. The operational data from the municipal wastewater reclamation plants, show the reduction on overall pressure drop and chemical cleanings that the element can offer compared to previous generations of fouling resistant products.

This research proves that RO systems with DOW FILMTEC™ FORTILIFE™ CR100 elements can offer a reduction in the cleaning frequency of 40–50% per year. Less chemical cleanings results in higher system availability, productivity and membrane lifetime. It also offers a low feed-concentrate pressure drop during the long term operation, which represents energy savings for the system, thanks to the 53% reduction in pressure drop achieved.

Keywords: Flux, Recovery, Fouling, Wastewater, Membrane, Reverse osmosis

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Decomposition of phenol from aqueous media by electrocoagulation technique using bi-polar aluminum electrodes: investigation of adsorption isotherm and kinetic models

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Phenols are toxic carcinogenic compounds can cause mutagenic and teratogenicity defects to human beings. Due to its harmful effects on health, phenol is on the USEPA priority pollutants list, and represents as one of the most challenging classes of pollutants requiring urgent removal from water bodies and waste streams. Several technologies such as oxidation, adsorption, biological treatment, precipitation, distillation, solvent extraction, ion exchange, membrane processes, reverse osmosis, and electrochemical methods are used to remove phenolic pollutants. In the present study, the electrocoagulation (EC) process is used to remove phenols from aqueous media using aluminum electrodes. The effect of several experimental parameters of the EC treatment, such as initial phenol concentration, initial pH, number of electrodes, type and quantity of supporting electrolyte and the distance between the electrodes were investigated. A complete removal of 100 mg/L phenol was achieved within 10 min at pH of 2, 0.5 g NaCl, 750 rpm, 9 sheets, and 25°C. Amongst the studied adsorption isotherms models, Langmuir and Dubinin and Radushkevich were the most applicable ones. The kinetic of adsorption of aluminum hydroxide during the EC operation was studied by using the pseudo-first order, pseudo-second-order, and intra particulate diffusion models. The performed energy dispersive X-ray spectroscopy (EDAX), scanning electron microscopy (SEM) and Fourier transform infrared spectroscopy FTIR analyses to the flocs and aluminum sheets indicated that the phenol compound was completely decomposed and only aluminum hydroxide species was the main component in the flocs and on the sheets. Accordingly, it seems advisable to use the EC technique in the removal of phenol rather than any other applicable techniques.

Keywords: Electrocoagulation, Phenol, Bipolar aluminum electrodes, FTIR, SEM, EDAX

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Water Master Plan. The San Luis Case

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Under the premise of considering water resource as the basis foundation for the environment, productivity and provincial development, a Water Master Plan was implemented, positioning itself as the only Argentinean state having a tool that allowed to carry on a series of programs such as studies, land planning and strategic designs in the construction of dams, everything that has been a continuous improvement in quality of life.

The water reservoir system is composed by 20 dams, totaling 470 hm^3 of water reserves for 490.000 inhabitants. Local water policy allows having strategies to face the current challenges for growing population and food provision in a world requiring of new productive matrices.

The reservoir system, exclusively through summer rainfall, has doubled its storage volume increasing it in more than 50% in the last years, ensuring the resource provision for human, industrial and agricultural-livestock use, for the whole province and for decades. Over 4.000 km of aqueducts and canals were built to transport this water from the central mountains to the rest of the province. In this natural setting, creating an artificial reservoir, has necessarily responded to a strict planning in response to a focused State Policy in the Peace between Progress and Environment Treaty.

The commitment to democratize water access to the whole community is solved in San Luis via the Water Master Plan, covering a complex water system integrated by many reservoirs; a groundwater harvesting system and public wells, plus a great technology and infrastructure investment.

Keywords: Water policy, Strategic planning, Reservoirs increase.

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Role of non-Newtonian behavior in effecting complete desalination of simulated seawater by the emulsion liquid membrane technique

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In the present work it was managed to desalinate simulated seawater (35% sodium chloride solution) on a bench-scale work, by applying the emulsion liquid membrane technique in one single

stage resulting in the removal of 99% of the NaCl under specified conditions. Different factors were examined, which included: the effect of quantity of emulsifier, quantity of mobile carrier, type and quantities of sequestering agent and type and quantity of selected polymers which was added to the liquid membrane phase to improve the percent extraction, and to effect desalination in one stage only at room temperature (20°C). It was found that the polymer improved desalination, and that an optimum quantity of emulsifier existed which assisted in stabilizing the emulsion and improved desalination. In addition, an optimum quantity of the selected mobile carrier existed which enhanced mass transfer and that the presence of sequestrant was required to sequester the NaCl within the receptor phase. Finally, it is worth mentioning that only in the presence of specific quantities of the aforementioned reagents together, that 99% desalination could be achieved in a single stage.

Keywords: Desalination, Emulsion liquid membrane, Dibenzo-18-crown-6, Mobile carrier, Emulsifier, Span 80, Sequestering agent, Soluble starch, Chlorobenzene, Polymer.

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Different membrane technologies for potable water production from surface water

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Surface water

The quality of surface water is determined by hydrodynamic, biological, chemical, physical and meteorological processes. Intensive rainfall and flood in the catchments area can cause quite considerable degradation of the surface water quality. Surface waters contain inorganic and organic particulate substances. Inorganic particulate constituents are amongst others clay, silt and minerals. Organic particulate substances can include microorganism like viruses, bacteria and protozoan. One of the major problems of using surface water as source for drinking water is the high content of natural organic matter (NOM). NOM can cause odour, can influence the taste and can increase corrosion and biofilm growth in the distribution network. Furthermore NOM could be a source for the formation of disinfections by-products when water is disinfected. Hence, NOM removal is one of the most important treatment requirements for the production of drinking water.

Introduction

In recent years, surface water purification with membranes has become an attractive alternative to conventional clarification. No or less need of chemical agents, good quality of produced water independent of feed water quality, good removal efficiency towards microorganisms, less production of sludge, compact process, and easy automation are some of the advantages of ultrafiltration compared to conventional treatment. Originally, ultrafiltration was used to remove turbidity and microorganism from good-quality surface water. Nowadays the main goal is to improve this technology and to apply it to worse quality sources for the removal of microorganisms, natural organic matter (NOM), dissolved organic matter (DOC), disinfection by-products (DBPs), and other components.

An alternative technology is spiral wound nanofiltration membranes. Although this has the potential for addressing high organic content without the need for upfront coagulation, it has major draw backs:

- Spiral wound membranes require extensive pretreatment, even to the extent of upfront coagulation. This means that this technology is not replacing existing technology but is merely an additional 'polishing' step.
- Nanofiltration removes ions, such as calcium, magnesium and bicarbonate, that preferably should not be removed.
- Spiral wound membranes have problems in addressing microbiology. It cannot be tested and repaired and is therefore not accepted as microbiological barrier.

This paper describes the use of ultrafiltration with coagulated feed water (direct coagulation) and a newly developed hollow fiber nanofiltration membrane that addresses the disadvantages of traditional spiral wound membranes.

Direct coagulation

In drinking water production coagulation as a pre-treatment process for membrane filtration (UF/MF) can enhance significantly the efficiency of the filtration process, resulting in a higher flux level and increasing NOM removal. Common coagulants are salts from trivalent iron and aluminium ions as well as pre-hydrolysed products, such as polyaluminium chloride (PACl). The main objective of coagulation process is to aggregate small water ingredients to larger ones. Thus the removal of such substances by following applications is possible and easier respectively:

- • Advanced removal of colloidal and suspended matters
- • Removal of dissolved organic matter (DOC), especially humic acids.
- • Removal of inorganic trace metals and phosphate

In the application of ultrafiltration the coagulation can furthermore reduce fouling on the membrane and enhance the efficiency of the process This paper gives an technical overview of existing potable water production plants in Scandinavia where the technology is already applied:

- Seljord (Norway)
- Kvarnagarden (Sweden)

Hollow fiber nanofiltration

This paper describes a hollow fiber nanofiltration membrane specifically designed for removal of dissolved organics from water with low mineral content. This membrane exhibits high rejection for dissolved organics (up to 90%) and low rejection (around 20%) for dissolved inorganics.

Benefits over spiral wound membranes are:

- Chlorine resistant and a wide pH range for cleaning
- Backwashable, easier to clean
- Open feed channels, no blocking of feed channel spacer
- Capability for Direct Integrity Testing according to the membrane filtration manual
- Repairable, confirmed 5+ LRV rating for bacteria and viruses

This paper gives an technical overview of existing potable water production plants in Australia where the technology is already applied:

- Ringarooma (Tasmania)
- Rosebery (Tasmania)

Keywords: Ultrafiltration, Nanofiltration, Hollow fiber, Natural organic matter (NOM), Coagulation

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Designer probiotics model: novel strategies for controlling and combating membrane biofouling by using beneficial bugs

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If your reverse osmosis membrane in desalination plant does not seem to be working correctly, this system called leaky system " biofouling membrane " Leaky membrane is perceived by its effect on process performance or product quality and quantity.The bacterial populations on leaky membranes were herein focused due to their significant involvement in biofilm formation .Biofilm development commonly cause biofouling in nanofilteration and reverse osmosis water microbiome is the very strong network architecture structure from bacterial population of water colonized in membrane layers causing microbial bio-fouling The effect of biofouling on membrane operation including a reduction in a flux, increase in pressure drop, salt passage and potentially membrane degradation and failure

This review explores the strategic process how to survive with biofilm, biofouling , biocorrosion and maintain their outcome under the level of crossing point in the most resourceful way.

Keywords: Water treatment membranes, Cleaning, Biofilm, Biofouling, Probiotics

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Comparison of scale formation between inside-out and outside-in hollow fiber membrane distillation (MD) modules

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Recently, hollow fiber membrane distillation (MD) modules have drawn attention as a novel approach due to its advantages such as high packing density, potential for scale-up, and lower module cost per membrane area. However, relatively few works have been done in hollow fiber MD modules, leading to challenges in their system design and operation. One of the issue is the selection of flow direction because hollow fiber MD modules may be operated either inside-out or outside-in modes. Preliminary works revealed that their performances are similar under no fouling conditions. Nevertheless, little information is available on the performances of such modules under severe fouling conditions.

Accordingly, this study focused on the comparison of inside-out or outside-in MD modules under the conditions where fouling due to scale formation occurs. Experiments were carried out using a laboratory-scale direct contact MD setup. Synthetic feed water containing NaCl or $CaSO_4$ was used as well as the reverse osmosis (RO) brine from a desalination pilot plant. In-house MD mini modules were fabricated for these tests.The rate of fouling due to scale formation and the recovery

ratio of membrane permeability after physical cleaning and chemical cleaning were examined using the inside-out and outside-in MD modules. Results showed that the flux and thermal efficiency of the inside-out MD module were higher than the outside-in MD module under no fouling conditions. However, a more severe fouling due to scale formation occurred in the inside-out MD modules in a long-term operation compared with the outside-in MD modules. The cleaning efficiencies were also lower in the inside-out MD modules than in the outside-in MD modules, suggesting that different guidelines for the feed waters for these modules due to their different configurations.

Keywords: Membrane distillation (MD), Hollow fiber membrane, Scale formation, Inside-out and outside-in MD modules

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Understanding oily wastewater treatment via membrane distillation

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Membrane distillation (MD) is an emerging green technology, but very few reports are available on its use for treating oily feeds, despite produced water representing a significant source of oily wastewater. Accordingly, this study was targeted at understanding the primary impediments of oily water MD by systematically investigating the influence of the key components (namely, oil-in-water emulsion, surfactant and salt) in such feeds. When the feed contained all three components typical in produced water, the MD performance severely deteriorated in terms of permeate flux and quality. Interestingly, for feeds containing oil or SDS or NaCl alone, the MD performance was reasonable, which indicates each component on its own did not impact the MD process sig- nifi- cantly. Furthermore, the performance was also reasonable when the feed contained oil and NaCl, and improved when the feed contained oil and SDS. The adverse impact on the MD process was thereby traced to the combined presence of SDS and NaCl. Even in the absence of oil, increasing the concentrations of SDS and NaCl in the feed progressively deteriorated the permeate flux and quality. Therefore, to use MD for treating oily feeds necessitates a pre-treatment step to remove or significantly dilute either the surfactant or the salt. More understanding of the interaction between NaCl and SDS via molecular dynamics simulations would be useful to not only provide information on the interaction strength but also on means to circumvent such issues.

Keywords: Membrane distillation; Surfactant; Salt; Oil-in-water emulsion; Membrane wetting; Membrane fouling

Application of nanomaterials in desalination, agriculture and wastewater remediation: A review

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Clean water is an essential requirement for all life. Scarcity of fresh water is an increasingly serious problem around the world due to growing populations and diminishing supplies of fresh water. Despite that over 70 per cent of the Earth's surface is covered by water, most of it is unsuitable for neither human nor animal consumption. Lakes, rivers and underground aquifers represent only 2.5 per cent of the world's total freshwater supply. The demand for fresh water has no doubt increased tremendously, with agricultural, industrial and domestic sectors consuming 70, 22 and 8% of the available freshwater, respectively. Desalination could help alleviate these shortages, but it has traditionally been an extremely expensive process. Recently, the application of nanotechnology (NI) has emerged as a fascinating area of interest for removal of various contaminants from wastewater effluents. NT will play a great role in averting future water shortages. But, hoping that the 'magic' of NT will solve all water problems, is still far away to be true, since the basic problems of accessibility to technologies, affordability, and NT-based applications are still in the R&D stage. None of them has been scaled up to industrial levels yet. Nevertheless, desalination should not be used as a quick solution to our water shortage problems. Recycling and conservation programs are usually much less expensive and less risky alternatives to building desalination plants. The use of NT in water could be in monitoring, desalinization, purification and waste water treatment. It would provide novel opportunities to develop more efficient and cost effective nanostructured and reactive membranes for water purification and desalination. NPs can be functionalized with various chemical groups to enhance their affinity toward a target contaminant. Consequently, NPs provide high capacity/ selectivity and recyclable ligands for various toxic contaminants in wastewater. They can also be employed as adsorbents and/or catalysts for efficient water clean-up. Agriculture is an area where new technologies are often applied to improve the yield of crops. Today, application of agricultural fertilizers, pesticides, antibiotics, and nutrients is typically by spray or drench application to soil or plants, or through feed or injection systems to animals. Delivery of pesticides or medicines is either provided as "preventative" treatment or is provided once the disease-causing organism has multiplied and symptoms are evident in the plant. In this context, NT offers a great opportunity to develop new products against pests. NT improves their performance and acceptability by increasing effectiveness, safety, patient adherence, as well as ultimately reducing health care costs. The employment of NPs in agriculture will impart some beneficial effects to crops. The emergence of NT and the development of new nanodevices and nanomaterials (NMs) open up potential novel applications in agriculture. NMs have a number of key physicochemical properties that make them particularly attractive as separation media for water purification. On a mass basis, they have much large surface areas than bulk particles. They can also be functionalized with various chemical groups to increase their affinity toward a given compound. They can also serve as high capacity/selectivity and recyclable ligands for toxic metal ions, radionuclides, organic and inorganic

solutes/anions in aqueous solutions. NMs also provide unprecedented opportunities to develop more efficient water-purification catalysts and redox active media due to their large surface areas and their size and shape-dependent optical, electronic and catalytic properties. NMs are also being used to develop chlorine-free biocides through functionalization with chemical groups that selectively target key biochemical constituents of waterborne bacteria and viruses. NT would provide novel opportunities to develop more efficient and cost effective nanostructured and reactive membranes for water purification and desalination. NMs which could be used in water purification and desalination include metal and metal oxide NPs, graphene and carbon nanotubes. For combined water desalination, solar energy and NT, NT could enhance the performance of solar concentrator which collect the solar energy and focus the light into the target. Also, NMs could absorb light efficiently and transfer it into solar heat. The application of nanotechnology in wastewater remediation can be summarized as follows: employing the NPs as nanoadsorbents for adsorbing pollutants by sequestration, applying NPs as nanocatalysts to oxidize and breakdown contaminants, merging NPs with membrane filtration techniques, using NPs as nanosensors for rapid detection and identification of pathogens and viruses. Nanoscale devices are envisioned that would have the capability to detect and treat an infection, nutrient deficiency, or other health problem, long before symptoms were evident at the macro-scale. This type of treatment could be targeted to the area affected with a greater awareness of the hazards associated with the use of synthetic organic insecticides, there has been an urgent need to explore suitable alternative products for pest control.

Keywords: Nanotechnology, Water purification, Desalination, Nanoparticles, Nanomaterials

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Desalination by sweeping-air pervaporation with modified cellulose-based membranes

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Scarcity of fresh water is nowadays posing serious threats to mankind all over our planet Earth, due to several reasons including global warming which has caused a reduction in rainfall and desertification, as well as the rapidly increasing population across the globe. Man needs fresh water for drinking, irrigation and industrialization, accordingly numerous desalination techniques have been developed throughout the years to overcome this critical situation, of which pervaporation is only a young member of those methods which rely on the use of membranes. In this context, the present work deals with the fabrication of hydrophilic asymmetric modified cellulose-based membranes by the phase-inversion method and used to desalinate simulated seawater by sweeping-air pervaporation in a specially designed and constructed set-up. Numerous variables were investigated for their effect on the flux and salinity of the pervaporate, which included as the major variable the addition of each of caprylic-, capric-, lauric- and palmitic- acids in definite quantities to a cellulose acetate

casting dope; the pervaporation temperature; cooling temperature; saline water and air flowrates. The performance of each membrane was compared to a standard membrane free from any additive, and the membranes were examined by SEM and FT-IR and their thicknesses determined. Results showed that the membranes exhibited superior performance relative to the standard membrane, with very high salt rejections and fluxes that reached 10 L/m^{2}h in some cases, and that they were all asymmetric and superhydrophilic.

Keywords: Desalination, Pervaporation, Cellulose acetate, Fatty acids

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Desalination by humidification-dehumidification using a novel green packing material

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Humidification-dehumidification (H-D) is a non-traditional desalination process which involves vaporizing water from a saline liquid stream into an air stream, then condensing the vapor to form purified water. In nature, sea water gets heated by solar irradiation and evaporates into the air thereby humidifying it then the humidified air rises to form clouds, which eventually dehumidify as rain which in turn falls over land to be collected for human consumption. This is known as rain cycle. The man-made version of this cycle is called H-D desalination cycle. The latter has received great attention in recent years and many researchers have investigated the intricacies of the technology. In the present work, the H-D process has been critically reviewed, followed by experimental work in which a simple set-up was devised and constructed consisting of a humidification column followed by a condenser in which, the humidified air is dehumidified to produce fresh water. A novel unique packing material was used in the humidifier which consists of a cellulosic plant which is grown on the banks of the river Nile. In all previous work, the main problem was the type of packing material which could provide intimate and uniform contact between the aqueous stream and air stream. Accordingly, this novel packing material proved to be extremely suitable in terms of hydrophilicity and interconnectivity. Different variables including mass of packing of each stage, number of stages, air and saline water flow rates, saline water concentration and temperature of inlet saline water and condensation temperature, were investigated for their effect on the fresh water production and its salinity.

It was found that a high production of fresh water could be produced by this present set-up which can be coupled with solar heating to make the process cost-effective and competitive compared with other commercial processes.

Keywords: Desalination, Humidification-dehumidification, Packing material

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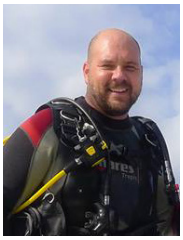
Shifting the discharge mind-set from harmful to habitat: Exploring inventive designs and benefits of underwater discharge structures



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The effects (or lack thereof) of desalination concentrate vary widely. It is not only site dependent, but also subject to the marine organisms around the discharge area (the biotic community), the type of the concentrate, and to what degree it is been disperse. From an environmental point of view, the design of the particular discharge structure must be adequate so that the effluent discharged adheres to the receiving water guidelines (ambient standards) beyond the mixing zone, and also to ensure that critical salinity limits will not be exceeded at the boundary of the regulatory mixing zone. Commonly, limits apply at the boundary of the regulatory mixing zone, depending on the significance value and depth at the discharge area (normally to a maximum distance of 100 m). However, the habitual benefits of underwater discharge structures have often been overlooked, as a result of a predominant focus on the discharge limits (e.g. temperature and salinity) and regulatory compliance.

We certainly can't change ambient conditions, but together with selecting the most suitable discharge location, the obligatory salinity reduction can be achieved through sufficient near field hydrodynamic mixing, achievable through appropriate outfall/discharge design. This paper therefore aims to contribute in shifting the 'typical mind-set' that discharges and associated structures are *always* detrimental to the environment. The traditional approach (typically focused on minimizing the environmental (and operational) impacts only)) often overlooks the opportunities that could be associated with discharge- stream (dilution) and underwater structures (habitats). As part of a collaborative effort, we propose different methodologies that combines natural processes, discharge matrices and possible environmental benefits of underwater structures.

Keywords: Desalination, Concentrate discharge, Underwater discharge structures, Habitat, Environmental impact assessment

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A smart and innovated membrane distillation crystallization technique for zero liquid discharge

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Scarcity of fresh water is a worldwide problem that has recently emerged as a significant challenge to human life on the planet, due to the continual increase in population around the globe together with the gradual change in the environment due to global warming resulting from rapid industrialization and spreading wars. As a result, shortage of potable water has been remedied by desalination of seawater either by thermal means or by membranes. The most widely established membrane technique is reverse osmosis, in which the water recovery is in the vicinity of 40%, while the remaining concentrate is dumped back into the seawaters, which causes a gradual rise in salinity thereby causing a threat to aquatic life and endangering the ecosystem.

Accordingly, the present work aims at solving this critical situation by recovering most of the lost water in the brine instead of wasting it, together with its contained salts, by a novel technique named membrane distillation crystallization (MDC) which is not limited by high concentration of feed as is RO, and in which hydrophobic membranes are used instead of hydrophilic ones.

A set-up of the air gap membrane distillation configuration was initially devised and constructed for conducting the experiments. Hydrophobic polytetrafluoroethylene membranes of four different pore sizes purchased from STERLITECH-Corp, USA, were used for comparison. Numerous factors were investigated for their effect on the flux and salinity of the desalinated water, and these were: membrane pore size, initial feed solution concentration and temperature, cooling water temperature, difference in temperature between the two streams, feed flowrate along the membrane surface, and air-gap distance. Results indicated that very high fluxes and extremely high salt rejections were obtained when intermediate pore sized membranes were used; flux is inversely proportional to feed solution concentration; flux varies directly with feed solution temperature, with temperature difference between the two streams, and with solution flowrate, and that a smaller air-gap distance leads to higher flux.

It was also found that MD using the membranes in question produced almost deionized water, in some cases, which suggests their application in the production of ultrapure water for medical purposes, from ordinary tap water or otherwise. The technique was applied successfully to both distilled water, and actual brine from RO units, then MDC was effected by introducing a crystallization step within the retentate loop, by which a mixture of salts were harvested concommittantly with the desalinated water, each from a different outlet stream. Finally, a complete design of a smart MDC desalination unit is proposed, which is to be energized totally by solar energy. In this way,

operating costs will be nullified, and only the fixed cost will be needed. Therefore, the proposed method will present an altogether smart and cost-effective MDC process.

Keywords: Desalination; Membrane distillation crystallization; Zero liquid discharge; Hydrophobic membranes; Reverse osmosis brines; Ultrapure water; Pore size; Solar energy.

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Ultrasonic-assisted cleaning for inorganic scales on high salinity wastewater treatment using membrane distillation

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Although reverse osmosis (RO) is widely used for desalination of seawater and brackish water, its application is limited by the total dissolved solids (TDS) of feed water. If the TDS exceeds 60,000 g/L, it is not practically possible to apply RO to produce fresh water. Accordingly, other desalination techniques have been explored to overcome this barrier, including membrane distillation (MD). MD is a thermal membrane separation, which performance is not affected by the osmotic pressure of the feed water. This allows to use MD for the treatment of feed waters with high TDS. Nevertheless, fouling due to scale formation may occur during the concentration of such feed waters, leading to the limit of MD application. Since the scale formation is highly irreversible, it is not easy to recover the performance of the fouled MD membranes by conventional cleaning methods including physical cleaning (i.e. flushing) and chemical cleaning (i.e. use of acids or chelating agents).

In this study, we focused on ultrasonic-assisted cleaning of MD membranes fouled by inorganic scales during the treatment of high TDS feed waters. The conditions for the ultrasonic application were optimized to maximize the cleaning efficiency and to minimize physical damage of the membrane. First, fouling tests of MD were carried out using synthetic feed waters with various TDS. After the fouling tests, cleaning experiments were performed by immersing the membrane cell into an ultrasonic generator and operated with a citric acid solution. The recovery of membrane permeability, liquid entry pressure, and ion rejection were measured as well as the visual observation of membrane surface using scanning electron microscopy. Response surface methodology was also applied to optimize the cleaning conditions. Results showed that the ultrasonic-assisted cleaning was effective under the optimum condition. However, since the excess application of ultrasonic resulted in serious damage, it appears that the accurate prediction of cleaning efficiency and membrane damage is crucial to apply this method.

Keywords: Ultrasonic, Membrane distillation, Inorganic salts, Membrane cleaning, Ultrasonic assisted acid

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Voltage regulation of solar-powered EDR systems for brackish water desalination

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This work presents a novel approach to substantially reduce the capital cost of photovoltaic (PV), batch-operated electrodialysis reversal (EDR) systems for community scale applications. By operating the ED stack in a time-variant manner, the system accommodates the variability of both the power source (solar energy) and load (ED stack). As a result, the power consumption of the PV-EDR system can be varied in sync with the solar power available, and directly utilize more power compared to constant voltage operation. We show that time- variant operation increases salt removal rate and the number of batches for a given solar- powered EDR system design. This suggests that PV-EDR systems can be made less expensive by down-sizing the power system and the batteries and still achieve the daily production target through time-variant operation.

The presented study builds upon earlier investigations, both at lab and pilot scales, on solar-powered EDR systems for brackish water desalination as a cost-effective way to meet potable water demand for small communities ([1], [2], [3]). The recent drop in PV power cost has motivated our research on accurate modeling and cost optimization of PV-EDR systems. In particular, by coupling robust parametric models of both ED [4] and solar behaviors, a full PV- EDR model has been built and demonstrated to accurately predict energy consumption of batch PV-EDR systems in the field [5]. This enabled Bian et al. [5] to co-optimize the PV power and ED subsystems in a constant-voltage, batch system, achieving a 42% cost reduction compared to existing design practices for a community-scale PV-EDR system. A drawback of the resulting design is that 38.7% of the solar energy available to the system is redundant and not captured for desalination.

Our work shows both theoretically (by simulation) and experimentally (by lab-scale experiments) the benefits of varying the voltage applied to the ED stack versus constant voltage operation to better utilize available solar power. We investigated voltage-regulated single batches, where allowing for increased power consumption at the beginning of the batch reduces desalination time. Additionally, the voltage-regulated batch model was coupled to a variable solar daily profile to assess the performance of time-variant operation in tracking the solar variance and increasing daily water production. We defined and implemented control rules for the voltage applied to the ED. The instantaneous voltage maximizes salt removal rate while ensuring that current density does not exceed 80% of limiting current density, and power consumed cannot exceed the available solar power. We simulated the behavior of a reference, small-scale system under such operation. It was used to generate the optimum voltage profile (both for a single batch and during a solar day) to be applied to the ED stack and predict the corresponding power consumption evolution and PV-EDR performance. We validate the feasibility of voltage control and the validity of our time-variant model with a bench scale setup controlling voltage in real-time for a single batch first, then a full mimic solar day.

Both simulation and experimental results show that a 30% reduction in single batch time can be achieved for a water volume of 1 L desalinated from 1500 mg/L to 300 mg/L when changing voltage on the ED stack every 10 s (Fig. 1). Simulations of the daily time-variant operation with con-

strained solar power predicted that 12.5 batches of 0.7L each can be desalinated in one simulated solar day at the lab scale, which we confirmed experimentally (Fig. 2). This simulation indicates a 50% increase in water production during hours with sunlight, and a 58% increase in solar energy that is directly utilized through variable voltage regulation compared to the direct-drive, constant voltage case. These results also show that a direct drive system can potentially reduce battery capacity by ~70% to achieve a typical daily production requirement at the lab-scale. Motivated by these preliminary findings, we are planning to use the lab-scale validated model to investigate the effect of voltage-regulation to reduce cost in community-scale PV-ED desalination systems both theoretically and experimentally.

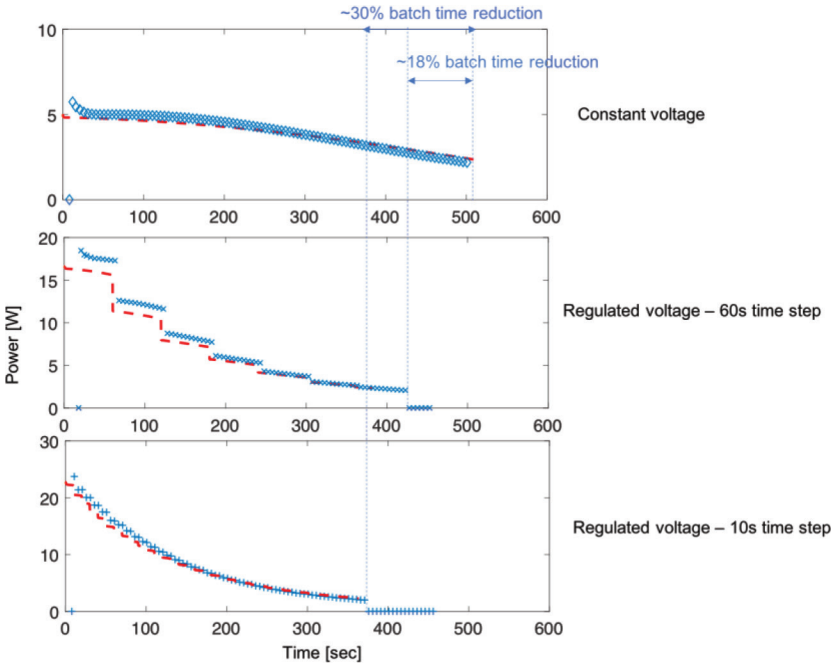

Fig. 1. Power consumption during a single batch at lab scale, with three different voltage control frequencies (constant voltage, 60 s time step, and 10 s second time step). Experimental parameters: 1 L batch size, 68 LPH flow rate, 71% recovery, initial concentration: 1500 ppm, target concentration: 300 ppm.

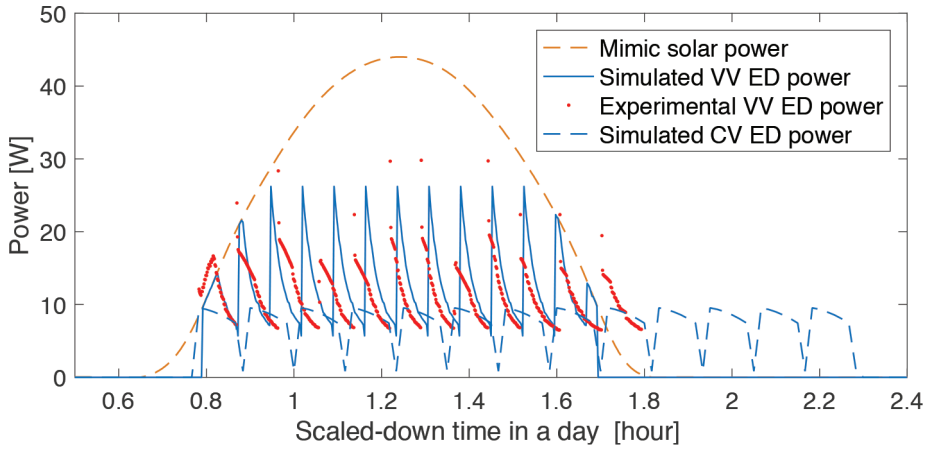

Fig. 2. Provided solar power and pump+ED power consumption during one mimicked day for two distinct cases: constant voltage with batteries and direct drive variable voltage. Experimental parameters: 0.7L batch size, 68 LPH flow rate, 71% recovery, initial concentration: 1500 ppm, target concentration: 300 ppm.

Keywords: Renewable energy for desalination; Brackish water desalination; Photovoltaic electrodialysis-reversal (EDR) system; Direct-drive system; Voltage-regulated ED batch; Solar to desalination energy efficiency

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Renewable energy powered desalination in SIDS – opportunities and challenges in the Caribbean Region

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The issue of water security continues to be a global issue as millions of people have dire challenges accessing secure, adequate sources of potable water. As the global population continues to increase steadily, the need for fresh water will continue to increase. These issues continue to plague Small Island Developing States. The SIDS located in the Caribbean Region are in close proximity to the oceans and possess a wealth of Renewable Energy Resources. The cost of electricity in these SIDS tend to be very high and the islands often face water scarcity issues. As such, therein lies the ideal opportunity to use renewable energy resources to power desalination processes in these SIDS. In this paper, the status and perspectives of developing coupled renewable energy systems with desalination units in SIDS are reviewed. Moreover, keys opportunities and challenges across the various islands are discussed.

Keywords: Desalination, Renewable energy powered desalination, Solar energy, Small island developing states, Renewable energy

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MPPT with robust fuzzy control of squirrel-cage induction generator

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When connecting to power grid, Squirrel-cage induction generator (SCIG), whose stator connected with grid directly, is very sensitive to voltage variation and has limited ability to resist to

drop of grid voltage. Supervising the uncertainity and intermett ance in wind speed and grid faults is a major challenge to agree with the modern grid code requirements. The objective of this study is the extraction of the maximum wind power (M PPT) by robust fuzzy controller for nonlinear systems which is reconized enough to stabilize a nonlinear system with parametric uncertainties and wind disturbance. The systems in question are Takagi-Sugeno type characterized by a nonlinear representation and the corresponding algorithm uses the local system models. This is obtained from the around operating points and is established by human expertise in the form of IF-THEN rules type. The algorithm was developed with a Squirrel-cage induction generator (SCIG) as shown by the model of the wind energy systems to illustrate the effectiveness of the proposed method. The proposed algorithm maximizes power output and maintain a stable system in the parameter uncertainties.

Keywords: Wind turbine, Energy, SCIG, MPPT, Fuzzy controller, Parameter uncertainties.

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Nanofiltration polishing membrane process for fluoride removal

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Despite their harmful effects, several industrial wastewater effluents are still rejected to the marine environment. It is necessary to treat this effluent in order to respect the environmental standards before discharge into the sea. Several techniques have been developed for fluoride treatment in effluents. A neutralization associated to a membrane process can achieve this goal when the concentration of fluorides are very high such as for some industrial effluents. Each step requires an optimization to get the best overall result.

The objective of this study is to investigate the removal efficiency of nanofiltration (NF) membranes to reduce fluorides from a real industrial wastewater adequately neutralized with lime.

This study demonstrated that the neutralization with hydrated lime using excess of about 36% at pH 6-7 led to fluoride removal rates higher than 98.7 %. The effect of several operating parameters on the permeate quality was determined. As a result, an optimum operating pressure must was choosing when using NF for treating the effluent. The best removal conditions of fluorides were identified.

Keywords: Industrial wastewater; Fluoride; Treatment; Neutralization; Nanofiltration; Optimization

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Influence of vapor compression cooling with packing on the dehumidifier performance in (HDH) desalination process

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This work investigates the effect of using an external heat transfer area inside the dehumidifier tank with different packing materials on the performance of the dehumidification section and the overall unit productivity. the investigation was carried out under different conditions such as: type of packing material on the humidifier trays, adding external heat transfer area inside the dehumidifier tank, temperature and flow rate of feed water, the flow pattern of inlet vapor to dehumidifier and the dehumidifier temperature. The results show that using high temperature and flow rate of feed water have increased the productivity of HDH unit, while presence of Raschig ring of copper or polyethylene as a packing material have decreased the productivity of the unit. In the dehumidifier section, it was also found that one inlet feed vapor stream in the middle of the tank and adding the coil inside the dehumidifier tank were preferable to the unit performance. It is also found that decreasing the temperature of humid air nearer to the zero-degree using vapor compression cycle approximately doubled the unit productivity. The average productivity of this unit under optimum conditions was found out to be 0.3356 L/h.

Keywords: Humidification-dehumidification, Desalination, Vapour compression cycle, Packing

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Microbial desalination cell: the golden MIDES low energy desalination technology

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Microbial Desalination Cell (MDC) is the integration of a MFC and an electrodialysis (ED) cell in order to treat wastewater and desalinate seawater [1]. By using the energy provided by the oxidation of organic matter, contained in the wastewater, this system drives the migration of ions and the desalination process.

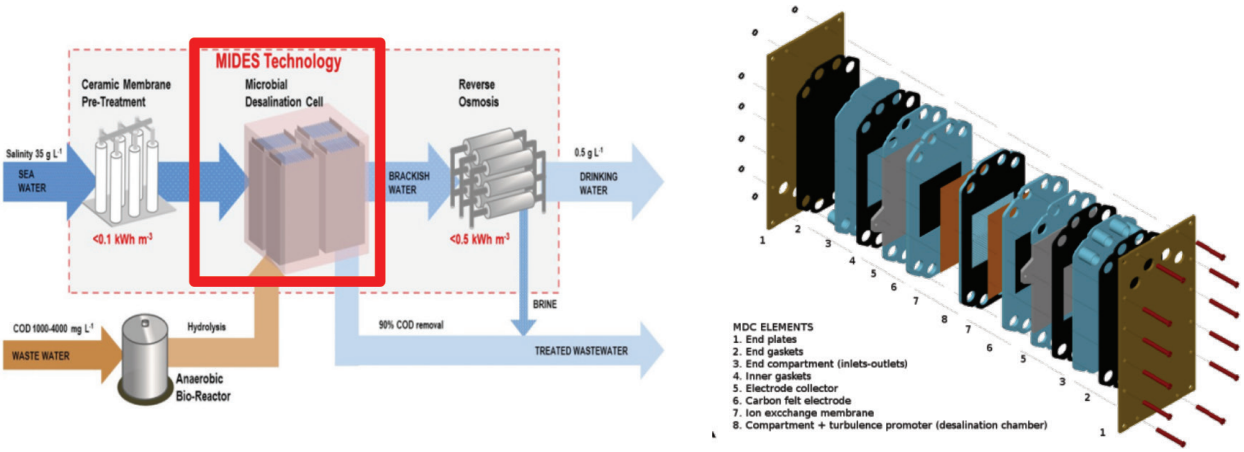

Fig. 1. A) MIDES overall process and B) Lab-MDC configuration.

Thus, MDC technology is able to desalinate saline water without consuming electric or thermal energy and allowing the use of the energy for any other processes. In this sense, MDC technology could be employed to save energy and avoid the greenhouse gases related to the conventional processes (seawater RO produces 1.78 kg of CO_2 per m^3 using 600 g CO_2 kWh^{-1} in the average European Union (EU) energy mix). The versatile and simultaneous applications of MDC have made it a real and feasible alternative for both desalination and wastewater treatment.

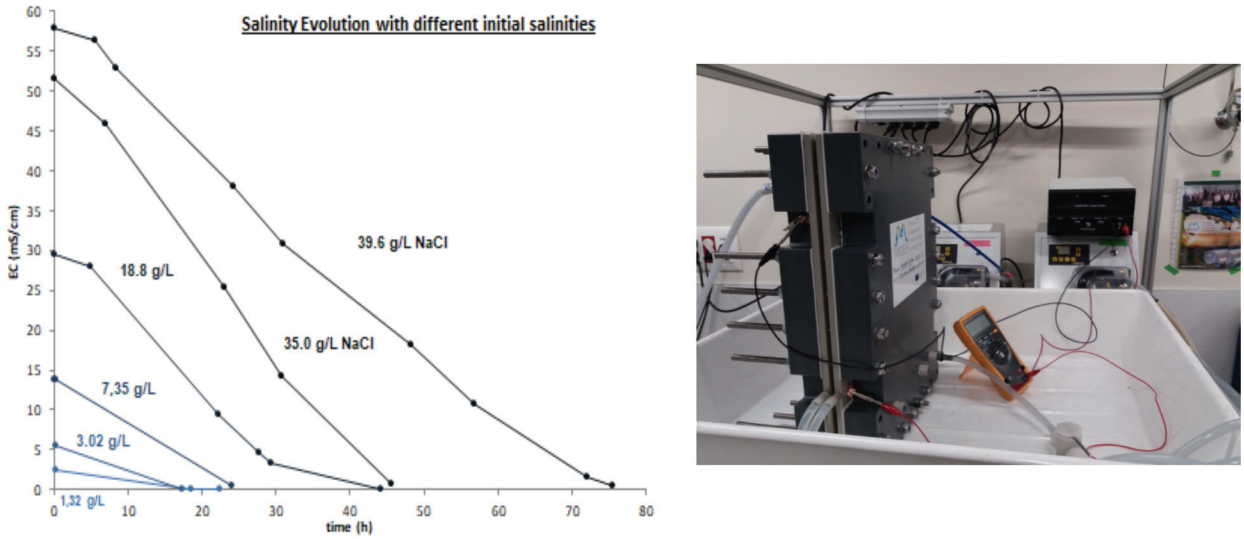

Fig. 2. Left) Desalination curves for different saline streams. Right) MDC pre-pilot system (unit cell, 550 cm^2 cross section).

In this sense, the merge of microbial electrochemical cells with ion exchange membranes could bring new processes and concepts in the field of waste water treatment and sustainable desalination, opening the chances of integration of such technologies with other biotechnological processes. In this communication, a rational discussion on the future applications of such technology is presented as well as results related to the performance of the technology for different saline streams

Keywords: Microbial desalination cell, Desalination, Wastewater treatment.

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Acknowledgement

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Performance evaluation of a novel vacuum-enhanced air-gap membrane distillation module for regeneration of salinity gradients

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Membrane distillation (MD) technology is studied as a thermal regeneration step in a salinity gradient heat engine based on reverse electrodialysis in a closed-loop system. A very low thermal energy consumption is required for the process to produce electricity with acceptable energy efficiency (a target specific thermal energy consumption of 45 kWh/m^3 is estimated in order to reach about 4-8% efficiency). Current MD technologies at pilot scale show generally higher values of specific thermal energy consumption (STEC). Spiral-wound modules with long channels for improved internal heat recovery have shown to be the ones with the best heat efficiency. Values of specific thermal energy consumption as low as 107 kWh/m^3 have been measured using spiral-wound modules in air-gap MD configuration with 5 m channel length for seawater feed. Two main improvements of that particular technology are considered in this evaluation. The first is the operation of the modules in vacuum-enhanced air-gap MD configuration. Suctioning the air from the gap minimizes mass resistance of vapour diffusion and decreases conductive heat losses. A novel system to achieve this suction with a minor impact on electric consumption has been devised by Aquastill and was used in this work. The second is batch operation of the module, which allows reusing the sensible heat of the feed when increasing its concentration. According to model predictions, this can result in up to 7% savings of thermal energy consumption compared to multi-stage operation. Both improvements were evaluated in experimental tests at pilot scale using two spiral-wound modules from Aquastill: one with total surface area of 24 m^2 and 5 m channel length, and another with total surface area of 7.2 m^2 and 1.5 channel length. Experiments were performed with different solutions optimized for the reverse electrodialysis process (aqueous solutions of NaCl and KCH_3COO), at increasing concentration values from 0.5 to 4 molar. Different operating conditions of feed temperature and velocity were used to characterize their influence and to identify the most favourable cases for improving the thermal efficiency of the process. The maximum concentration that both modules can reach with each solution was determined, as well as the corresponding thermal performance.

Keywords: Membrane distillation; Vacuum-enhanced air-gap membrane distillation; Pilot-scale experiments; Energy efficiency

Acknowledgements

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Membrane processes for valorization of agro-industrial effluents including water recycling

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Throughout Europe more than 700 Mton of Agricultural Wastes, Co-products and By-products (AWCB) are produced annually [1], constituting a serious environmental issue. AWCB effluents mainly originate from processing of various agricultural commodities; e.g. in olive oil and table olive production, fruit and tomato processing, fruit-juice and wine production, etc. [2]. Such effluents are characterized by high organic content, including significant concentration of valuable bio-active compounds. Integrated valorization of AWCB is currently pursued, including extraction of valuable marketable compounds and further processing leading to bio-energy and bio-fertilizers production as well as clean water for reuse. Conventional wastewater treatment technologies are clearly unfit for such integrated effluent processing. However, as shown in this presentation, membrane-based processes are most appropriate for valorization of such streams. Most of these results have been obtained in the context of AGROCYCLE, a three-year H2020 project aiming to develop, demonstrate and validate novel processes, practices and products for the sustainable use of AWCB. The authors Laboratory at CERTH is a major participant in this project, dealing with the development and demonstration of such novel processes. Results from three membrane-based processes will be summarized as follows.

Winery wastewater from cleaning red wine tanks, containing polyphenolic substances with anti-oxidant activity, was treated in bench-scale dead-end filtration test cells and in a lab-scale cross-flow filtration pilot unit, for separation and recovery/concentration of polyphenolic compounds. Both UF and NF commercial membranes were tested concerning their polyphenolic rejection efficiency and flux performance. Results show that NF membranes of typical pore size approx. 1000 Da, exhibit the best selectivity for polyphenolic compounds, combined with very good fluxes. More than 70% of polyphenols were recovered in the NF concentrate stream that possessed enhanced anti-radical activity.

For fruit-juice wastewater valorization, a two-stage scheme, involving anaerobic wastewater treatment followed by an aerobic MBR for final polishing, was tested in a lab-scale pilot unit. Two experimental campaigns were carried out, for treating either low- or high-strength Fruit Processing Wastewater (FPW) representative of the seasonal production variability. In both cases the removal efficiencies of organic matter and the biogas production were satisfactory. The treated effluent resulting from the final stage of aerobic MBR was of very good quality, and its characteristics met the strict standards for irrigation, suggesting that valorization of this waste stream is possible with

water reuse.

Aerobic membrane bioreactor (MBR) technology was selected as an appropriate technology for developing an effective table olive processing wastewater (TOPW) treatment method. TOPW is particularly difficult to bio-degrade mainly due to the presence of polyphenols. Systematic long-term studies in a lab-scale MBR proved effective in substantially biodegrading TOPW, after appropriate biomass acclimatization. Average total organic carbon removal was 91.5%, whereas nitrogen and phosphorus removal were also satisfactory. The membrane exhibited stable performance at moderate biomass concentration (e.g. 8.0 g/L), with a tendency to deteriorate at higher biomass concentration. Fouled membrane permeability could be fully restored by implementing usual chemical cleaning protocols [3].

The proposed technologies appear to have notable attributes. Further, their performance and economic feasibility will be assessed in a full-scale demonstration unit for the case of TOPW, and in an industrial-scale pilot plant for the case of FPW; these pilot facilities are currently under construction.

Keywords: Valorization of agro-industrial effluents, Water recycling, Membrane-based processes, Recovery of valuable bio-active compounds, Anaerobic-Aerobic MBR treatment

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2 Patsios et al. (2017), A methodology for estimating AWCB during fruit processing in European Union: Implementation in six ftuits of Greek interest, 11th National Scientific Conference of Chemical Engineering, Thessaloniki, 25-27 May 20017. In Greek.
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Novel methodology for RO membrane fouling and scaling predictions and monitoring - Beyond indices

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At present, predictions on the membrane fouling and scaling propensity of feed-water to RO/NF desalination processes are made through indices (SDI, MFI for fouling – Langelier, other for scaling) that have well-known drawbacks. Considering that fouling/scaling evolve in time with significant spatial non-uniformity throughout the pressure vessels (comprised of multiple SWM modules), the main weaknesses of these indices are as follows :

- They provide a single value, corresponding to fluid composition and conditions of the particular test; thus, no predictions of spatial-temporal fouling/scaling evolution along a vessel can be made.
- There is weak (if any) physical foundation underpinning most of these indices. Therefore, they

provide poor (or unreliable) representation of the fouling and scaling processes.
- The data on indices (collected over the years) have not been formally correlated with the main process variables; therefore, such data are of no archival value and are essentially wasted.

In general, fouling and scaling predictions, at the plant design stage, are dealt with separately and inadequately, in a manner (particularly for scaling) that does not allow optimization of process parameters and of chemical additives used for fouling/scaling control. The above-mentioned limitations of present practices (involving indices) also hold regarding RO process monitoring for fouling/scaling. Indeed, despite the development of some novel techniques to detect fouling/scaling on RO/NF membranes, there is lack of a generalized methodology to properly adapt these techniques and permit reliable monitoring.

The novel methodology, presented in this lecture, involves: a) Laboratory studies of fouling and scaling phenomena, under conditions representative of those prevailing in SWM modules, to select and determine the most appropriate parameters for each case (i.e. the specific cake resistance for fouling, the rate of mass deposition for scaling). b) Correlation of such parameter data with key RO process variables (i.e. flux) and fluid composition characteristics (i.e. foulants concentration, supersaturation ratio of scale-forming compounds), thus developing generalized expressions akin to constitutive relations of the phenomena involved. c) Integration of these relations into an appropriate comprehensive modeling framework, implemented in a computer-aided simulator, that permits projections of the fouling and scaling temporal evolution throughout the membranes along the pressure vessels of RO plants.

The typical cases of organic fouling and scaling will be discussed in the context of the aforementioned approach. Appropriate experimental techniques will be presented for determining representative parameter values for fouling and scaling. The effect of process conditions and fluid characteristics on these data will be assessed, that can lead to generalized correlations for fouling and scaling parameters. The latter can be integrated in an available modeling/simulation framework of SWM module performance for making projections; some typical examples will be presented for membrane fouling and scaling. Potential applications of this novel approach, remaining challenges to fully develop it, as well as related R&D work, will be discussed.

Keywords: RO membrane desalination, Methodology for fouling/scaling predictions and plant monitoring, Comprehensive modeling of RO process performance, Determination of appropriate fouling and scaling parameters

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Polishing membrane process for fluoride removal: nanofiltration vs. reverse osmosis

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In recent decades, industrialization, domestic and agricultural activities, and other environmental changes have constantly increased the pollution of the marine environment. This problem has re-

inforced the efforts to treat the effluents in order to respect the environmental standards before discharge into the sea. For this reason, several techniques have been developed for fluoride treatment in effluents. When fluoride concentrations are very high, a neutralization with lime associated to a membrane process could be an appropriate approach for dealing with industrial wastewaters.

The main objective of this study is to investigate the removal efficiency of reverse osmosis (RO) and nanofiltration (NF) membranes to reduce fluorides from a real industrial wastewater optimally neutralized with lime.

This study demonstrated that the neutralization with hydrated lime using excess of about 36% at pH 6-7 led to fluoride removal rates higher than 98.7 %. The effect of several operating parameters on the permeate quality and the optimal pressure for membrane process treatment were determined. The best removal conditions of fluorides in accordance with the Tunisian standard NT 106 002 were identified.

Keywords: Industrial wastewater; Fluoride; Treatment; Neutralization; Reverse osmosis; Nanofiltration; Optimization

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Ceramic filtration as a pretreatment for reverse osmosis in industrial wastewater treatment and reuse

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The robustness of ceramic membranes drives their use in demanding applications, dealing with complex and highly variable wastewaters under difficult operational conditions. Reverse osmosis (RO) installations require high quality feed water to ensure stable operation, as a result of which there is an increasing demand for ceramic ultrafiltration (UF) technology as a pretreatment stage, especially when dealing with industrial effluents.

The Oil&Gas industry is considered one of the eight most water-intensive sectors, and efficient water/wastewater management - focused at reuse – is one of the biggest challenges in the sector. In this scenario, the H2020 Integroil project aims at developing and demonstrating a robust and flexible treatment solution for both the upstream and downstream sectors in the Oil&Gas industry, where ceramic membrane filtration is one of the technologies applied before the final RO process.

Based on the foregoing, the work presented is related to the experimental results related to the implementation of ceramic membranes in the following scenarios:

i Ceramic UF for the treatment of the so-called produced water, which is the oily wastewater generated during Oil&Gas exploration and production activities.
ii Ceramic membrane bioreactor (MBR) for the treatment of the industrial wastewater generated during the oil refining process.

Treatment of produced water has been studied and optimized at both laboratory and pilot scales. It has been concluded that ceramic UF allows removing the highly stable emulsified oil and

obtain an effluent which is free of turbidity, solids and bacteria. This effluent presents optimum quality for being subsequently treated by RO or other polishing technologies such as advanced oxidation processes.

Treatment of refinery wastewater is addressed by ceramic membranes with a completely different approach. This effluent contains significant amount of biodegradable organic matter and biological treatment is applied as a general rule. When a final desalination stage is required for salt removal the MBR process brings major benefits by coupling the ceramic ultrafiltration to the biological reactor. In this way, high-quality ultrafiltered water is produced, which can be directly fed to the RO system without the need for further pretreatment.

Keywords: Ceramic membranes; RO pretreatment; Oil and gas; Ultrafiltration; Membrane bioreactor.

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Development of a new integrated textile wastewater treatment and hydrogen production system with bipolar membrane

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Bipolar membranes have been used for many years to generate organic and inorganic acid, base and desalinated fresh water in various industries. A bipolar membrane is generally composed of anion- and cation exchange membrane layers and can split water at the junction point of these membranes into hydrogen ion and hydroxyl ion under the applied electrical field. The electrodialysis process with the bipolar membrane (BPMED) is a proven technology for the treatment of textile wastewater with high salt concentration (40-80 g/L) while producing acid and base[1]"ISSN" : "21680485", "abstract" : "In this work, textile wastewater is explored for resource recovery in a hybrid loose nanofiltration (NF. However, a high dye concentration content of textile wastewater causes fouling to the membranes and decreases the ion transfer efficiency of the bipolar membrane electrodialysis process. The color of the wastewater should be removed before the BPMED process to prevent membrane fouling. The hardness of the wastewater is considered another problem that causes membrane fouling in the BPMED system, and it has to be removed before the BPMED process. Since many studies reported different color removal methods [2]metal coagulation, (ferric chloride and alum, ion exchange process is an effective and cost-saving treatment method prior to the BPMED process. The strong base anion exchange resins are capable of removing dye solution from wastewater while releasing Cl- and OH-ions into the wastewater[3]. Also, other anions that might be present in the content of the wastewater can easily be removed. In this way, the possibility of contamination of the produced acid can be prevented. The other advantage of the anion

exchange process is the ability of hardness removal from wastewater with the precipitation of Ca^{2+} and Mg^{2+} by the help of OH^- ions that are released from ion exchange resins.

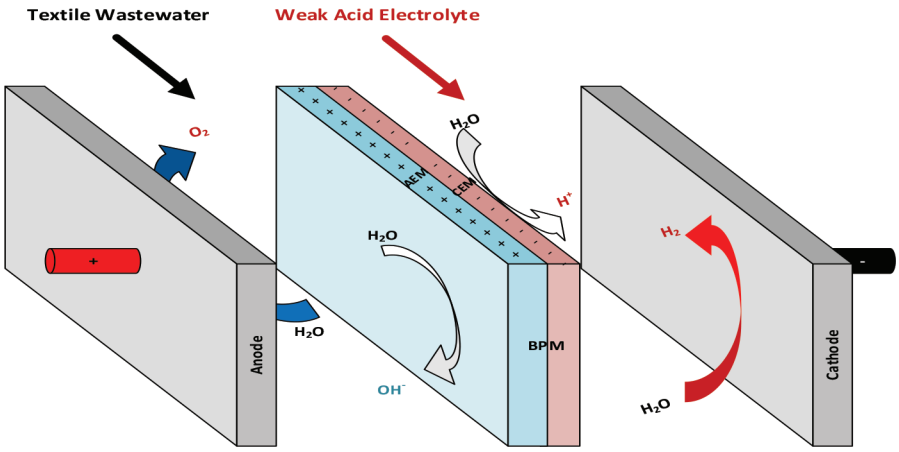

Fig. 1. Water splitting hydrogen production cell with bipolar membrane.

Hydrogen is an environmental-friendly alternative fuel source which can potentially be used in various industries as gas or liquid. The water electrolysis is known as the most common hydrogen production method that decomposes the water into hydrogen and oxygen gas. The electrolysis process is composed of anode and cathode compartments. The placement of the bipolar membrane between anode and cathode side will increase the pH of anolyte and decrease the pH of catholyte (Fig. 1) while producing hydrogen gas at the cathode side and oxygen gas at the anode side [4]. This change in pH can increase the hydrogen production efficiency and decrease the required energy consumption.

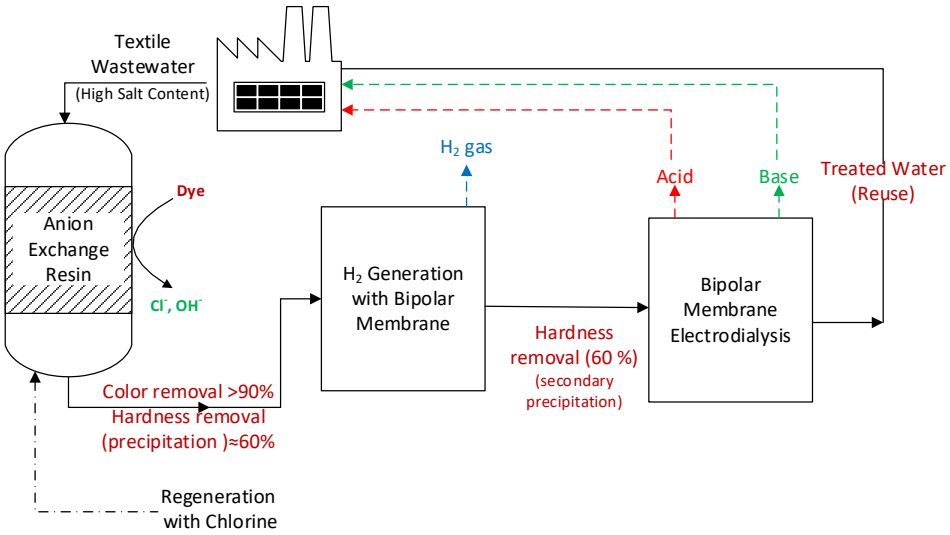

Fig. 2 Integrated hydrogen production and textile wastewater treatment system flow diagram.

In the present study, an integrated hydrogen production and the treatment of textile wastewater is investigated conceptually and experimentally with an aim to achieve zero waste discharge (Fig. 2). The textile wastewater is treated with a strong base ion exchange resin inside the ion exchange column to remove the color of the wastewater. Also, after the ion exchange process with the increase in pH of the textile wastewater is resulted in a decrease of the hardness causing ions (Ca^{2+}

and Mg^{2+}) concentration. After ion exchange process, the hydrogen gas is generated from the textile wastewater by using the bipolar membrane in the electrolysis process. Finally, the textile wastewater is treated with the BPMED process to remove salt from the wastewater while producing acid, base and clean water that can be reused in the wet textile processes. Numerous performance parameters, such as current efficiency, limiting current efficiency, current utilization efficiency, hydrogen production efficiency, and the water quality parameters, such as color, conductivity, absorbance, pH, chemical oxygen demand (COD), etc. are monitored while running all integrated processes. It can be concluded that the proposed hydrogen generation and wastewater treatment system is a promising method that can generate hydrogen while treating the wastewater.

Keywords: Hydrogen production, Textile wastewater treatment, Bipolar membrane, Electrodialysis

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The miracle of chitosan as a biosorpent in desalination, wastewater treatment and biomedical engineering—a review

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Man needs water throughout his life. Without water there would be no life on planet Earth. Man needs water for various purposes including drinking, agriculture and industrial processes as well as for sanitary purposes. Despite that water is renewable, yet the growing populations around the world, together with their concomitant needs have led to unavoidable water shortages in many areas across the globe. In addition recently, global warming has been posing a serious threat to mankind due to changes of environment, and wars everywhere, which both contribute largely to this change, and have resulted in scarcity of rainfall.

Accordingly, to solve this water deficiency problem, scientists have sought for alternative solutions which can overcome this drastic situation, by either desalinating saline water such as seawater and brackish underground water, or reclaiming wastewater (WW) from various industries, municipal WW or from irrigation. In this regards, health and aesthetics, come as the principal reasons for WW treatment. Acute waterborne diseases, such as typhoid and cholera, spurred the development of chlorination and filtration plants, in the early 1900s. Then more elaborate pretreatments to enhance disinfection resulted, upon subsequent identification of additional diseases and contaminants in WW. Diversified unit operations such as filtration, adsorption, sedimentation, biosorption, and

many others, have been used in removing different contaminants from WW. Granular activated carbon has been used as the main commercial adsorbent of choice for several decades , however, scientists have been searching since then, for other cheaper and easier to prepare adsorbents, that might be more ubiquitous in nature, of which chitin and , the by-product in the seafood industries and its derivative chitosan, have been lately used in different forms in the remediation of organic and inorganic contaminants in WW, such as toxic heavy metals, dyestuffs, pesticides, phenols, etc….

In the present paper, the different applications and modification of chitin and chitosan have been reviewed in removal of heavy metals, nitrate, dyes, desalination, as well as in the application to blood and biomedical engineering.

Keywords: Applications of chitosan; Modification of chitin and chitosan; Desalination; Biosorption; Chitin; Wastewater treatment; Biomedical engineering; Heavy metals; Dyestuffs; Pesticides; Nitrate; Blood.

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Role of tight ultrafiltration on reducing fouling potential of SWRO feed water

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The failure of conventional pre-treatment to provide acceptable feed water quality for seawater reverse osmosis (SWRO) during algal blooms underlines the significance of robust pre-treatment systems. This study investigated the effectiveness of tight ultrafiltration (10 kDa) membrane as pre-treatment in delaying the onset of organic/biological fouling in SWRO feed water during algal blooms. The proof of principle experiments were performed in laboratory and pilot plant using various MF/UF membranes and algal organic matter (AOM) produced by *Chaetoceros affinis* as a feed solution. The feed and permeate of MF/UF membranes were analyzed in terms of biopolymer concentration, and bacterial regrowth potential (BRP). Furthermore, biofouling experiments were also performed using membrane fouling simulators (MFS) to simulate biofouling in spacer-filled RO membrane channels.

Results illustrated that the rejection of algal biopolymer produced by Chaetocerous affinis was 3–4 times higher with tight UF (10 kDa) compared to the high molecular weight cut off MF/UF membranes. The lower biopolymer concentration in permeate coincide with the lower bacterial regrowth potential. The relationship between the bacterial regrowth and biopolymer concentration was found linear with $R^2 = 0.88$. Moreover, no substantial difference was observed in measured net bacterial regrowth in permeate collected from tight UF (10 kDa) and standard UF (150 kDa) from pilot experiments. It could be attributed to the contribution of passage of low molecular weight organics from both UF membranes. The biofouling experiments performed using MFS monitor fed with permeate of 150 kDa and 10 kDa UF at a cross flow velocity of 0.2 m/s also showed no substantial increase in the feed channel pressure drop in the MFS monitor. Moreover, the result of membrane autopsy showed biomass accumulation of 860 pg ATP/cm^2 in MFS fed with 10 kDa

UF permeate, which was 2 times lower than in MFS fed with 150 kDa UF permeate. Overall, the results illustrated the potential of tight UF membranes towards delaying the occurrence of biofouling in SWRO membranes. Nevertheless, the non-backwashable fouling rates development after each succeeding CEB cycles were approximately 1.5 times higher for 10 kDa UF compared to 150 kDa UF. Therefore, it is still important to improve the backwashability performance of the tight UF membrane for the better future application. It is expected that improving the surface porosity of the membrane can better remove the cake/gel layer formed on the membrane surface during backwashing/CEB and improves the backwashability of the membranes.

Keywords: Membrane fouling, Tight ultrafiltration, Conventional ultrafiltration, Algal blooms, Algal organic matter

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Alternative energies in desalination – present status and future prospects

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Continuing depletion of energy, in the form of fossil fuels, has lately become a problem of great concern all over the globe. Accordingly, continual research in optimal techniques by which to tap alternative energies such as solar, wind, geothermal, ocean, tidal and wave energies, are taking place by scientists worldwide. Concomitantly, shortage of potable water in many areas around the world, such as the Middle East and North Africa (MENA) region, has been posing a threat to life as a whole, and lack of fresh water for drinking, irrigation and industrialization due to environmental changes, as well as increase in world population, has necessitated desalination of seawater and ocean waters, as a solution to this critical catastrophe which endangers life altogether on our planet.

Accordingly, in the present paper, numerous diversified applications of different types of alternative energies in desalination, accompanied with various explanatory figures, have been thoroughly reviewed. The paper presents an in-depth coverage on different types of solar stills such as multi-effect and double-effect basin type stills, vertical stills, tubular-type stills, various designs of wick-type stills, as well as other alternative energy-driven desalination technologies. Future prospects of the alternative energies in desalination are also outlined.

Keywords: Desalination; Alternative energies; Solar energy; Wind energy; Wave energy; Geothermal energy; Ocean energy; Tidal energy; Solar still; Wick-type still; Basin-type still; Vertical still; Tubular still; Multi-effect still.

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Solar-powered desalination for irrigation in the Jordan Valley

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Irrigation in the Jordan valley is becoming more difficult due to increasing salinity in its underground aquifers. Palestinian, Israeli, and Jordanian farmers living side-by side share the same depleted water resources. All parties have a common interest in finding sustainable solutions to irrigation in this arid area where traditional cultivations of some of the crops have declined drastically due to lack of good quality water supplies.

Aston University, the Arava Institute and the Palestinian Wastewater Engineers Group have begun a project that brings Middle Eastern and UK students together to develop technical and social solutions to the farmer's wells issue. This project is aimed to help the students to develop a sustainable develop solar desalination system that will provide irrigation to the farmers in the Jordan valley. On the 2nd phase of the project, the Arava Institute students started building and running the system side-by side with Aston University students for educational purposes as a prototype system located on the Arava Institute campus with conducting some water analysis tests for the system's permeate. Besides that, some mechanical tests were done to confirm the efficiency of reducing the power consumption of the system.

The assembly system (prototype) needs to be scaled up in order to increase the capacity to be more suitable for installation in a farm as 3rd phase of this project.

Keywords: Solar desalination, Jordan Valley, Desalination

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Multi-stage analysis of pressure retarded osmosis for scale up operation

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A global trend toward the renewable and sustainable sources of energy has been increased due to greenhouse gas emissions. Pressure retarded osmosis (PRO) can be considered as a renewable source of energy released from the mixing of freshwater with saltwater using a semipermeable membrane. A model of a scaled up multi stage PRO power plant is presented in this work. The effects of reverse salt flux, concentration polarization, flow and pressure drop along the membrane have been investigated. To maximize the power density and reduce the irreversible energy loss multi-stage PRO systems have been introduced in large scale. For a system in co current opera-

tion with a river and sea water solutions with the loss considerations we compared the thermodynamic efficiency of single and multi-stage systems with the same membrane area used. In this model the hydraulic pressure applied in the draw side and water flow rate has been optimized. In spite of other dual stage PRO studies which have been conducted in laboratory scale, the scale up considerations like pressure and flow drop along the membrane area and salinity change have been taken into account in our study. The effect of spacers in pressure drop and mass transfer in both draw and feed side have been investigated. Furthermore, we compared the effectiveness of multi-stage PRO system with the single stage one with consideration of the same membrane area. With the new description of the efficiency and using the optimum operating conditions, the results indicate that overall performance of the system can be improved significantly in the case of multi-stage PRO in large scale.

Keywords: Pressure retarded osmosis, Multi stage configuration, Thermodynamic efficiency, Power density

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One year operation of integrated ultrafiltration and reverse osmosis system for challenging industrial wastewater from chemical industry

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This presentation will show the first year of operational experiences of a combination of ultrafiltration (UF) and reverse osmosis (RO) for treatment of challenging industrial wastewater. The feed water of this pilot operation is coming from the chemical industry and represents a high challenge both for UF and RO due to high fouling and scaling potential and high variability regarding the composition.

The configuration demonstrated in the pilot operation includes one DOW IntegraFlux™ SFP-2880XP module, which contains PVDF fibers with a nominal pores size of 30 nm being operated in out-in mode. Part of the pilot operation was a study for optimization of operating conditions and cleaning strategy. For improving the cleaning efficiency, influence of parameters for backwashing are being studied. Optimization potential for the chemically enhanced backwash and the cleaning in place are being investigated. Additionally, an alternative cleaning strategy, in which the chemically enhanced backwash us replaced by periodical short cleanings-in-place is being studied.

For the RO operation, 4 inch prototypes of the fouling resistant DOW FILMTEC™ FORTILIFE™ CR100 elements are being tested. These elements show high resistance especially against biofouling and a low differential pressure along the feed channel. The pilot configuration for RO consists

of a first stage with six reverse osmosis elements and a second stage with three elements. Due to high fouling and scaling potential, the RO operation was started with very conservative conditions. Flux and recover are being increased stepwise. Prevention of scaling is studied using anti-scalants.

Keywords: Ultrafiltration, Reverse osmosis, Industrial wastewater

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Continuous solar desalination unit (CSDU): design and performance investigation

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Desalination techniques –to remove salts from water – have been used widely around the world, to reduce the water crisis, since there are nearly 1 in 10 people lack access to safe water. Solar desalination is one of the most promising technique among all of other desalination techniques especially in remote areas that suffer from lack of fresh water.

Most of the available solar designs are batch which gave commonly low productivity, therefore, this project aims to design and build a continuous solar desalination unit (CSDU), and study the effect of environmental and operational conditions on its productivity where rotating belt, suction fan and compressor were added and classified into five cases.

The solar still has been experimentally tested for three months. Promising results were achieved, the productivity was measured along several days during February to April. The maximum and minimum evaporation fluxes achieved were 11.4 and 6.9 ($L/m^2.d$), respectively, while solar irradiation at those days were (5.03 and 4.11 $kWh/m^2.day$), respectively. The average productivity for conventional solar stills was (3-4) $L/m^2.d$, which lower than CSDU's average productivity that reach approximately 9.73 $L/m^2.d$, where 64.02% enhancement is obtained.

The tested results confirmed that running the apparatus with rotating belt, compressor, and fans at average solar radiation= 5.65 kWh/m^2 has a high significant effect than running the unit while they are turned off. The improvement was 86%, which mean that integrating of these enhancements will improve the productivity of solar still.

In addition, results indicate that the evaporation rate was highly affected by weather conditions. Since the evaporation rate increases with increasing solar radiation and temperature and decreases with increasing the relative humidity. These prove that the constructed apparatus is working in the right way.

Keywords: Desalination, Solar desalination

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Process modeling and simulation of a SWRO desalination plant: Case study of Gijang SWRO desalination plant in Korea

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Recently, an operator training simulator (OTS) is essential for a cost effective training in an identical operator environment and accumulation of operation and maintenance (O&M) know-how in a SWRO desalination plant. In this study, a dynamic process model replicating the Gijang SWRO desalination plant in Korea was developed as key elements of OTS with a distributed control system (DCS) control logic. The entire process model includes all the unit process model such as a dissolved air flotation (DAF), a dual media filtration (DMF), an ultrafiltration (UF), and a reverse osmosis (RO) with an energy recovery device (ERD), which are components of the plant. All the properties of unit processes were based on the actual design values of the plant. As a result, it shows good agreement between the simulation values of the developed process model and designed performance values of the plant. Also, both the increases of different pressure (DP) and cleaning activities such as backwash, chemically enhanced backwash (CEB), and cleaning in place (CIP) at DMF, UF, and RO unit process, respectively, were well simulated with a decay rate according to the process time. Collectively, the process model developed in this study can be firstly applied to develop an OTS system of Gijang SWRO desalination plant and furthermore it can be used for digital twin technology of a desalination plant after improving it more in detail

Keywords: Seawater reverse osmosis (SWRO), DAF, DMF, UF, RO, Process modeling, Operator Training Simulator (OTS)

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Performance evaluation of a multi-effect distillation unit with a polymer tube heat exchanger

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The high capital costs of multi-effect distillation (MED) plants are mainly due to the evaporator tubes existing in each cell. Cu-Ni evaporator tubes are the most frequently used in the industry due to their heat conductive properties and low cost compared to others (e.g., titanium). However, they are sensitive to corrosion and scaling, which make the heat transfer and therefore the distillate production decrease with operation time. The idea of replacing these metal tubes by cheaper ones

made of polymer materials has been already discussed in the scientific literature [1,2]. However, standard polymers have poor heat conductive properties, which would lead to a huge increase of the required heat exchange surface, making this option unprofitable.

Technoform Kunststoffprofile company (Germany) has developed a thermally conductive compound which is based on polymers with a large amount of thermal conductive filler. This compound is processed by extrusion to form heat exchanger profiles in any shape that can deliver the required properties in terms of corrosion resistance and heat transfer. They have very good chemical resistance and a confirmed long term operating temperature of 80°C [3,4]. In order to check the behavior of those polymeric tubes in a real MED plant, experiments have been performed in a pilot plant located at Plataforma Solar de Almería. The specific thermal energy consumption (performance ratio) and distillate production of the plant were investigated by replacing one of the Cu-Ni 90/10 evaporator cells with the polymeric cell developed by Technoform. The replacement was initially done in the third cell and experiments were performed for different external energy source (hot water) temperatures (65, 70 and 75°C), different feed water flow rates (6, 7 and 8 m^3/h) and different vapor temperatures (30, 35°C). The results were compared with those performed with a Cu-Ni 90/10 cell and it was observed that the distillate production was higher in all cases with the polymeric evaporator (about 10% at inlet hot water temperature of 65°C and last effect vapor temperature of 30°C, 15% at inlet hot water temperature of 70°C and last effect vapor temperature of 35°C, and about 17% at inlet hot water temperature of 75°C and last effect vapor temperature of 30°C). Regarding the performance ratio, it was always lower in the case of the MED plant with the polymeric cell (between 3-9% lower). After the test campaign, the polymeric cell was removed to check the scaling on the tubes. It was observed that the amount of salt precipitated over the tubes was considerably lower than in case of a Cu-Ni 90/10 cell. Moreover, the cleaning procedure required for the former was much easier than for the latter (the polymeric one was cleaned simply by a brush, while the metal cell had to be cleaned by the required acid cleaning). Another test camping was performed changing the position of the polymeric cell to the last effect in order to avoid its influence over the rest of effects. These experiments were carried out keeping the inlet hot water temperature and the last cell vapor temperature at 70°C and 35°C, respectively, and changing the feed water flow rate from 6 to 8 m^3/h. The results found were even better than in the previous test campaign, obtaining an increase percentage of 25% with the polymeric cell compared with the metal one at a feed water flow rate of 6 m^3/h (24% in case of 7 m^3/h and 16% in case of 8 m^3/h). In this case, the performance ratio was higher with the polymeric cell for feed water flow rates of 6 m^3/h (3% higher) and 7 m^3/h (7% higher), but lower for 8 m^3/h (5% lower). More experiments at different operating conditions should be performed in order to check the goodness of polymeric cells against traditional metal ones.

Keywords: Polymeric tubes; Multi-effect distillation; Performance ratio; Distillate production

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Spiral wound electrolysis modules of Archimedean and non-Archimedean form

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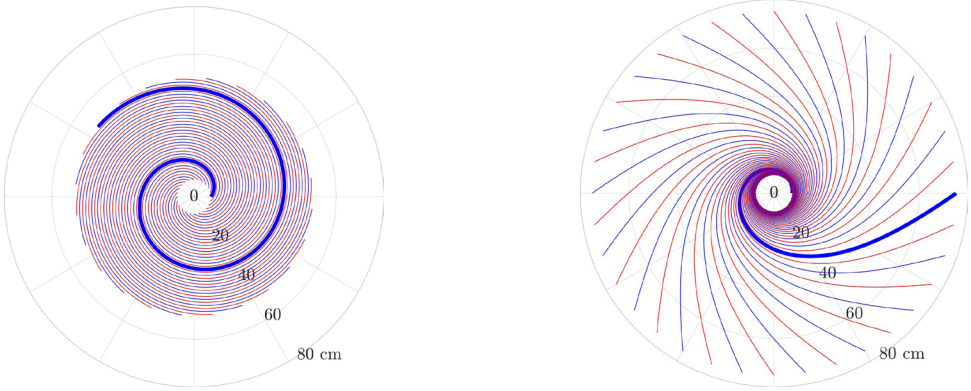
This work proposes methods of reducing the cost of electrodialysis brackish water desalination systems, as motivated by use in rural India, where 60% of the groundwater is too saline to drink. First, a robust model that predicts desalination rate and total energy consumption (desalination plus pumping) previously developed by the authors is used within an optimization routine to determine the lowest cost operating mode and stack design, assuming existing, flat-stack architectures. Common operating modes including constant-voltage batch and multi-stage continuous systems were considered alongside novel operation modes, including voltage-regulated batch and hybrid batch-continuous systems. For the production and desalination rates required for a village-scale application, a voltage-regulated hybrid system that is fully optimized for membrane width, length, and channel thickness reduces the 10-year total cost and capital cost of the system by 37% and 47%, respectively, in comparison to a commercially available stack optimized under the same operation modes.



(a) Achimedean Spiral (b) Ideal Spiral

Fig. 1. Representation of the spiral pattern in the optimized Archimedean and ideal spiral. In both cases the design in which equal importance is placed on total cost and capital cost is presented and 1/15th of the total cell pairs are shown for visual clarity.

By matching the applied current density as closely as possible to the limiting current density at any given location in a stack, the voltage-regulated batch operation minimizes the required amount of membrane area required, reducing capital cost. However, this requires a potentially costly DC power supply and control system. As a result, this work proposes a constant-voltage, continuous

system that uses a spiral-wound electrodialysis module such that the diluate stream flows from an inner electrode to an outer electrode along a spiral path, achieving the same matching effect. In this configuration, the effective membrane area increases causing the applied current density to decrease, as the concentration in the diluate stream and associated limiting current density also decrease. Both a standard Archimedean spiral (as spiral reverse osmosis modules are wound) and an ideal non-Archimedean spiral shape are presented. The ideal spiral shape would reduce the 10-year total cost and capital cost by 21% and 39%, respectively, in comparison to the Archimedean spiral, and is cost-competitive with the optimized hybrid voltage-regulated flat-stack design.

Keywords: Electrodialysis, Brackish desalination, Spiral-wound modules

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Membrane technology for water treatment in Malaysia – a new entry point

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Membrane applications in water treatment in Malaysia have seen more setback than success. Its early applications in few location encountered operational problems which had seen many system ceased operations due to membrane fouling due to poor raw water quality that entered the membrane. There also experiences of high operation and maintenance costs for electricity and spares which are by large more than conventional system operations.

In few European countries there has been wide awareness of high raw water quality which has not been a concern in the developing nations like Malaysia. There have been extensive efforts to produce high raw water quality for treatment at the water treatment plants. It is evident that raw water quality in Europe is as good as treated water quality adopted by the developing nations. Hence the introduction of membrane in the water treatment plants in this poor raw water quality is considered oxymoron and had always been futile. There is a need to change the paradigm. A new entry point is needed.

Based on the standard of raw water set in the developed countries, it is imperative that developing nations need to raised water quality standards by introducing utilising high quality raw water by prior treatment either through natural process or forced, physically or chemically.

Downstream reservoir, river bank infiltration and radial well system have been applied independently in several projects in Malaysia and had successfully resulted in high quality raw water at its exit point. However it has always been restricted from being implemented fully due to financial constraints. Hybrid off-river storage (HORAS) implemented as interim measure to improve raw water quantity had indicated prospect of improving raw water to reach the European standards.

This paper will compare the raw water quality of the non-conventional raw water abstraction, discuss and demonstrate the possible entry point of a cost effective membrane system in Malaysia.

Keywords: Raw water, Membrane, Quality, Treatment, River bank filtration

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Water security in Libya and the ability of the Man Mad River Project to provide Libya›s water needs

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Due to of the increase in the population in recent decades and the increase in demand for water with limited resources and sometimes non-renewable and the large change in the demand for water for drinking and agriculture and the industry, etc. To increase the consumption of stored water, Resulting in much loss of surface water resources more than underground for easy accessibility.

The urgent need to provide water of quality and cost suitable for a country such as the size of Libya is large and the difficulty of access to surface water, although Libya has almost 2000 km on the sea, who is little used desalination because of the high costs of producing large quantities of clean water, This led to the implementation of the Man Mad River Project, which is one of the most important strategic projects in the world, which worked on the transfer of water from the south the richly water availability to the north, For majority of the population of Libya and less clean water, Implementation and Success of this project requires a set of Procedures and measures to ensure the supply of water and realize water security, Then water flow continuous without interruption despite difficulties and risks , This is what the paper concludes.

Keywords: Water security; Risks; Aspirations; Failures; Man Mad River Project

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Coagulation effectiveness comparison for turbid water treatment using Medicago sativa and its blended mixture

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Environmental friendly natural coagulants are favorable for turbid water treatment because they are safe for human beings and environment. The aim of present study was to identify and study the applicability of locally available pure natural coagulant (*Medicago sativa*) and its blended mixture with the most commonly used chemical coagulant (alum) for turbid water treatment. By mixing different proportions of *Medicago sativa* and alum, the blended mixture was prepared. Maximum turbidity removal efficiencies of pure natural coagulant and its blended mixture were then compared with each other. At optimum dosage and pH for pure natural coagulant and its blended mixture, the maximum turbidity removal efficiencies achieved were 96.8% and 98.5% respectively. Also FTIR (Fourier Transformed Infrared) analysis was employed for characterization of natural coagulant. Protein specific functional groups identified in natural coagulant were medium 1o amines, medium aliphatic amines group and medium, strong and broad 1o and 2o amines groups, responsible for

coagulation phenomenon. Micro photographic analysis was also performed to observe floc sizes produced after coagulation of natural coagulant and its blended mixture, indicating floc sizes of upto 22 μm and 35 μm respectively whereas the charge neutralization phenomenon was observed for both coagulants. The blended mixture of *Medicago sativa* was proved as a very potential coagulant for turbid water treatment.

Keywords: Alum; Coagulation phenomenon; Medicago sativa; Turbid water

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Temperature and thermal stress distribution of high concentrator solar cell under different environmental conditions

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A three-dimension thermal model of the typical Triple-junction solar cell was performed in finite volume software. Depending on the 3D model, the temperature distribution of the cell layer and thermal stresses were analyzed and simulated. The effects of meteorological conditions such as wind speed and ambient temperature on the local temperature and thermal stress distribution of solar cell were examined. The temperature and thermal stress contours showed that the solar cell layer possessed the highest temperature and thermal stress at the solar cell center. The effect of wind speed on cell performance was very limited when it increases from 0 to 15 m/s compared with the effect of ambient temperature. The results elucidated that the low ambient temperature conditions enhanced the heat dissipation that improves the electrical efficiency of the Triple-junction solar cell.

Keywords: High concentrator photovoltaic, Simulation, Temperature distribution, Thermal stresses

The REvivED water project: Electrodialysis for advanced desalination concepts

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Approximately two billion people live in areas of water scarcity†. If the efforts to combat climate change are not intensified, by 2025 two thirds of the world's population could be under water stress conditions‡. The desalination industry has responded well to the increasing demand and is constantly evolving by reducing the costs and improving the reliability of producing high-quality water. Despite remarkable progress so far, the high costs and energy requirements are still critical factors preventing the wider adoption of desalination. Continuous innovation is necessary to make the desalination technology more affordable.

REvivED water, a European Commission-funded pilot project led by Fujifilm Manufacturing Europe BV, is focusing on the potential of electrodialysis for desalination applications. The logos of all partners are shown in Fig. 1 and more information on them and the project is available on www.revivedwater.eu.

Fig. 1. The partners of the REvivED water proejct

The project builds on the progress achieved in the performance and cost of ion exchange membranes. This allows the industry to benefit from the inherent advantage of electrodialysis, whereby only the ions (salt) flow through the membranes, rather than the water.

The application of these innovative ion exchange membranes will allow for the use of electrodialysis to desalinate seawater. The REvivED water project will go one step further, applying a reverse electrodialysis (RED) unit as a pre-desalination step, for sites where a low salinity water stream (such as treated wastewater) is available. The RED pre-desalination step can also be used in (existing) reverse osmosis plants.

If there is no treated water available, a simple electrodialysis system can be added to reverse osmosis plants to pre-desalinate the sea water. The hybrid system with electrodialysis as a pre-desalination can increase the water recovery of reverse osmosis systems, producing more drinking water from the same amount of seawater at low energy consumption and at affordable costs.

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‡ UNESCO, the 4th edition of the UN World Water Development Report (WWDR4), 2012, http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/wwdr/wwdr4-2012/

The REvivED water project is also addressing the brackish water desalination field, where it brings together past experience and new technological developments in solar powered system targeting remote areas in developing countries that are threatened by water stress.

Finally, the project tests the application of the electrodialysis principle for water softening.

Several pilot projects are developed around the world to demonstrate the role of electrodialysis in the provision of drinking water for the world's growing population. All system configurations described above will be tested in real conditions, demonstrating the operation of electrodialysis in different settings and for various applications. The seawater desalination solutions will be tested in Europe. The brackish water systems powered by solar energy will be tested in remote locations of developing countries in Africa and in Asia.

Keywords: Ion exchange membrane; Electrodialysis; Reverse electrodialysis; Seawater, Brackish water, Pilot plants.

Acknowledgements

This work has been performed within the REvivED water (Low energy solutions for drinking water production by a REvival of ElectroDialysis systems) projects, Horizon 2020 programme, Grant Agreement no. 685579, www.revivedwater.eu.

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Impact of pretreatment of seawater and impaired water on fouling of ionic exchange membranes in reverse electrodialysis systems

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Reverse electrodialysis (RED) is an electrochemical membrane technology that has received significant research attention for pre-desalination of seawater/brines. the use of impaired water (e.g. secondary treated wastewater) has been suggested as an appropriate option as a low salinity stream for RED processes. Although electrochemical membrane systems (i.e., ionic exchange membranes-IEMs) are less prone to fouling compared to pressure-driven membrane systems, an adequate pre-treatment would be required for both low and high salinity streams. In the current study, robust pretreatment strategies were performed on secondary-treated wastewater (i.e., river bank filtration-RBF, rapid sand filtration-RSF, or 100 mm cartridge filtration) and on seawater (RSF, bead filtration, and UV disinfection); where their performances were compared to RED efficiency without pretreatment (Reference), during six weeks of experiments, using commercial Fujifilm IEMs type-10. Also, a microscopy study was conducted on fouled membranes to assess the efficiency of pretreatments.

Both 100 µm filtration and RSF significantly reduced fouling on IEM surfaces, resulting in lower pressure drops, lower frequency of cleanings, and a higher permselectivity (Fig. 1). RBF showed no improvement compared to Reference, possibly due to the difficulties in reproducing this technology on a lab-scale and the nature of the feed water (i.e. wastewater). Pretreated seawater also considerably reduced fouling on IEMs. The gross power density was comparable for all pretreatments and

slightly decreased during experiments. The pressure drop had an impact in the net energy. Specifically, the pumping energy increased 22-fold over the course of the experiment for the reference stack, while only 5-fold and 4-fold after RSF and 100 μm filtration, respectively. Also, membrane autopsies were conducted on all IEMs. ATP (adenosine tri-phosphate) and carbohydrates concentrations were considerably higher on reference samples and inlets, indicating favorable conditions for biofilm formation. Quantitative nanomechanical analysis (atomic force microscopy) of the foulant layers were conducted. At the microscale, foulant layers covered from 14-37% and 3-15% of membranes subjected to reference and pretreated-feeds, respectively. At the nanoscale, the morphology and nanomechanical properties of foulant layers highly differed from those of virgin membranes; indicating stiff, low elastic, and highly adhesive fouling layers (i.e., high Modulus, dissipation energy, and adhesion force, respectively) (Fig. 2). The presence of these foulants after extended operation and chemical cleaning and their high adhesion would be a nanoscale evidence of irreversible fouling.

This study provided insights into simple, robust, and inexpensive treatment methods and their ability to ensure a stable long-term RED operation, which is valuable information considering any type of application using ion-exchange membranes with natural water.

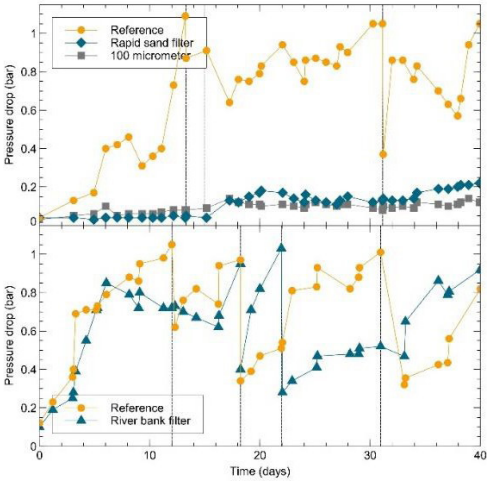

Fig. 1. Pressure drop over the wastewater compartment in RED following the different pre-treatment options

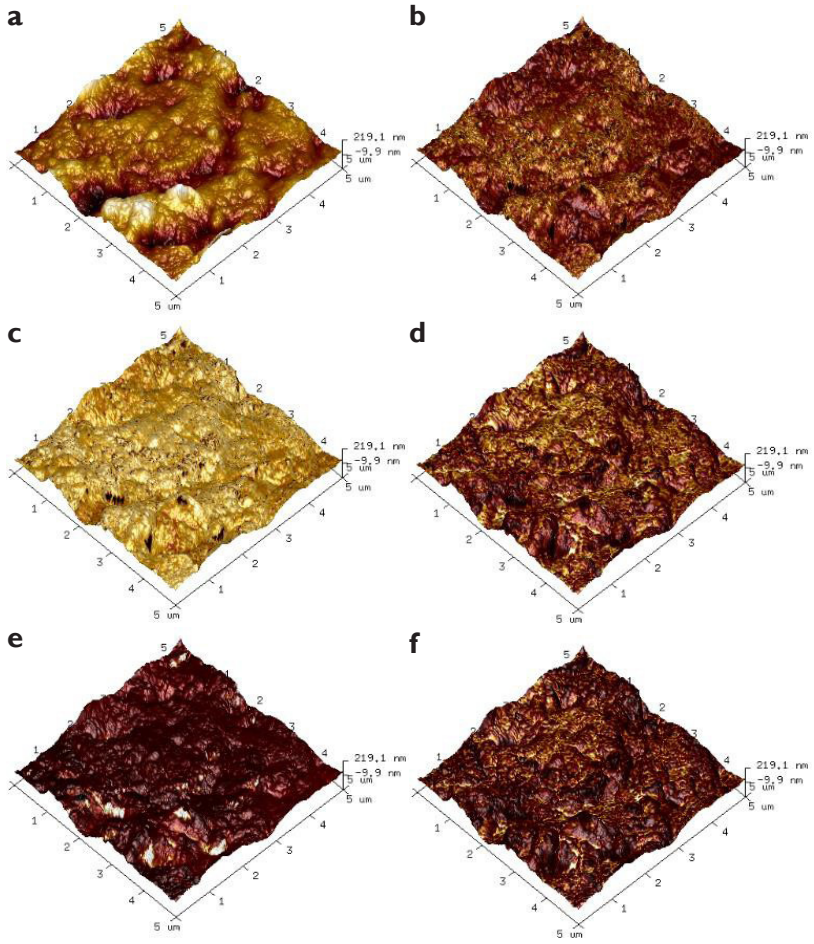

Fig. 2: a) Height sensor, b) DMT modulus, c) Log DMT modulus, d) Adhesion, e) Deformation, and e) Dissipation of reference cation exchange membrane-seawater.

Keywords: Ion exchange membrane, Reverse electrodialysis, Fouling, Nanomechanical properties

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This work has been performed within the REvivED water (Low energy solutions for drinking water production by a REvival of ElectroDialysis systems) projects, Horizon 2020 programme, Grant Agreement no. 685579, www.revivedwater.eu.

Donnan dialysis for tap-water softening

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Hard water is a problem in both domestic and industrial applications and is caused by an excess of calcium and magnesium ions. It significantly decreases the lifetime and efficiency of equipment which has negative technical and economic consequences. Existing water softening technologies have several disadvantages, such as a high chemical use (crystallization, ion exchange), water and energy consumption (nanofiltration). A promising technology for the softening of tap water is based on Donnan dialysis (DD). DD is a separation process with which divalent cations can be removed from tap water using cation-exchange membranes (CEMs) and a concentrated salt solution (receiver). No external driving force is used in DD, ion-exchange is only due to a chemical potential gradient across the CEMs. In this study, a technical and economical assessment is made to create more insight into the potential of DD to become a competitive water softening technology.

The technical assessment consisted of the optimisation of a lab-scale setup for DD, the investigation of operational parameters that influence the hardness removal and ion fluxes and the theoretical modeling to make predictions possible. Accumulation of divalent ions in the CEMs was discovered, therefore a conditioning step was required to have the same starting point in every experiment. In contrary to theory, it was observed that higher salt concentrations in the receiver did not improve the performance, it even deteriorated at high concentrations. The influence of the receiver composition showed that up to 8.4 g L^{-1} Ca^{2+} can be added before replacing of the solution is necessary. The driving force remains high enough to move Ca^{2+} against its concentration gradient. Corresponding to the theory it was observed that a decrease of the recovery and an increase of the flow rate both resulted in an increase of the removal. Different types of Fujifilm CEMs were examined. The electrical resistance (ER) and permselectivity (PS) of the CEMs were found to be crucial as they directly determine the ion flux, a higher ER results in a decrease of the ion flux. Influence of water permeability (WP) was not noticed due to the fact that the experiments performed with a relatively short residence time. The DD process can soften hard water in one pass through the system if sufficient CEM area is available. Theoretical modeling enables to predict equilibrium and ion fluxes, these ion fluxes were validated by experimental results.

The economical assessment in terms of CAPEX and OPEX showed that further improvement of DD is necessary to compete with other water softening technologies. Relatively high amount of salt usage comparing to the ion-exchange resin is the biggest issue that needs to be solved first.

Keywords: Donnan dialysis, Water softening, Cation-exchange membrane

Acknowledgements

This work has been performed within the REvivED water (Low energy solutions for drinking water production by a REvival of ElectroDialysis systems) projects, Horizon 2020 programme, Grant Agreement no. 685579, www.revivedwater.eu.

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RevivED Water: Small-scale ED desalination systems for brackish water Experiences from field test in Somaliland

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One of the electrodialsyis based solutions developed by the REvivED water project are small-scale desalination units powered by off-grid solar systems for the use in developing countries.

In 2017 a first prototype for the desalination of brackish water based on capacitive electrodialysis has been developed.

For the first pilot plant the project partners of Ghent University, Deukum GmbH, Fujifilm Manufacturing Europe B.V., Phaesun GmbH and the University of Palermo worked on improving and scaling up all system components. The complete system was constructed and tested in laboratory in April 2018. It includes the following modules:

A) Pre-treatment unit: slow sand filter and active carbon
   ⇒ The slow sand filter technology and activated carbon was chosen out of seven pre-treatment options due to its robustness, simplicity, and economic viability.

B) Capacitive electrodialysis (CED) desalination unit
   ⇒ A desalination unit with capacitive electrodes, new generation of ion exchange membranes and innovative stack design that is able to run three operation modes (single pass, batch, feed & bleed) was developed.

C) Post-treatment: chlorine cartridge
   ⇒ A chlorine treatment of the out-coming water and for the system's cleaning purposes was chosen as the most viable option.

D) Concentrate disposal: evaporation pond for brine
   ⇒ The salt concentrate water as waste product of the system is being collected in an evaporation pond.

E) Solar power supply
   ⇒ The PV system to serve all power needs of the system was sized with the further developed EasySizing RevivED software.

F) Control and user interface
⇒ The remote monitoring and control software is in the process of being implemented in the system to offer the possibility to transfer data via GSM from all parts of the world.

For the first field test a salted well in the desert of Somaliland was selected. The PV powered pilot plant was installed in May 2018 at the site in the village Beeyo Gulan to collect data from the operation under the Somali sun.

The presentation will give an insight into the technology used, the performance of the first pilot run in the field and the experiences collected during the preparation and operation of the field test.

Also information will be provided on the plans and progress for the other pilot units that will be tested under real conditions in Asia and Africa within the REvivED water project.

Keywords: Desalination, Electrodialysis, PV power, Stand-alone, Brackish water

Aknowledgement

EU Disclaimer

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Fluid-structure interaction in electromembrane processes: modelling of membrane deformation, fluid dynamics and mass transfer

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In recent years, water and energy supply issues have boosted a noticeable interest in the scientific community on electromembrane processes such as electrodialysis and reverse electrodialysis. In order to gain an important place in the industrial market, technological challenges on various aspects are involved for the optimization of these processes. In this context, profiled membranes exhibit interesting performances and offer countless geometric alternatives. However, the mechanical behavior of the membranes and its interaction with fluid dynamics has been poorly investigated so far.

In membrane-based processes, a trans-membrane pressure (P_{tm}) between the different solutions flowing through a module may be a design feature or may arise for various reasons, including flow arrangement and differences in physical properties, flow rate or friction coefficient. This leads to local deformations of membranes and channels, affecting flow and mass transfer characteristics, thus causing uneven distributions of flow and mass fluxes, which worsen the process performance.

In this work, we developed an integrated model for the numerical simulation of local mechanical deformations and of fluid dynamics and associated mass transport phenomena inside deformed channels. Two diverse profiled membrane types ("overlapped cross filaments", OCF, and "round

pillars", RP) were simulated under conditions representative of (reverse) electrodialysis and under the assumption of perfectly elastic behaviour. 3-D simulations of a couple of membranes and of the interposed fluid were conducted by the unit cell approach (periodic domain). *The Ansys Mechanical 18 (Workbench)* and the *Ansys CFX 18* software was used.

The selected geometries were simulated under P_{tm} ranging from -0.4 to +0.4 bar, computing expanded and compressed configurations. Then, CFD simulations of the deformed channels were performed, showing significant effects of the deformation on fluid flow and mass transfer. The influence of P_{tm} was to increase friction under compression conditions (up to ~2.2-2.5 times) and to reduce it under expansion conditions (but to a lesser extent, i.e. up to ~50-60%). Overall, compression enhanced mass transfer and expansion reduced it, but with smaller and more complex effects than on friction. The influence of the flow attack angle was negligible for friction, but more significant for mass transfer.

In future works the same simulation approach will be adopted in order to compute also the Ohmic resistance in deformed configurations. The simulation results will be implemented in the form of correlations into higher-scale models, in order to study distributions of flow, mass transfer and Ohmic resistance in whole channels. The method proposed can be extended to other membrane applications with minor modifications.

Keywords: Ion exchange membrane; Electrodialysis; Reverse electrodialysis; Membrane deflection; Fluid-structure interaction; CFD.

Acknowledgements

This work has been performed within the RED-Heat-to-Power (Conversion of Low Grade Heat to Power through closed loop Reverse Electro-Dialysis) and REvivED water (Low energy solutions for drinking water production by a REvival of ElectroDialysis systems) projects, Horizon 2020 programme, Grant Agreement no. 640667 and 685579, www.red-heat-to-power.eu, www.revivedwater.eu.

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New innovative thermal system for improving the performance of HCPV cell and its application in solar desalination system

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High concentrating solar cells technology is one of state of the art solar energy technologies, which recorded an electrical conversion efficiency up to 43%. The high concentration photovoltaic

(HCPV) has the potential to abandon the expensive normal photovoltaic material with lower cost optical components which also augment the overall yield. The main challenge of HCPV in producing electricity proficiently is maintaining the cell under the recommended operating temperature by applying an efficient cooling to allow peak performance in all situations. Furthermore, availing and collecting of the waste heat to enhance the overall system efficiency also stills challenging. Overcoming these two challenges will prompt more economical, effective and reliable high concentrating photovoltaic systems.

The high concentration photovoltaic combined with thermal systems (HCPV/T) were implemented in the current work to take the advantage of rejected heat at the same time maintain the PV under the permitted operation conditions and propose the solution of the main challenges of HCPV. The main objective of the current work is to investigate the probability of different cooling techniques to maintain triple-junction solar cell under the recommend range and enhance the electrical performance under high solar concentration and different weather conditions. The triple junction III-V solar cells were selected as they are more efficient and have a good response to high concentration. To increase the overall convergence efficiency of HCPV/T a solar still desalination unit can be attached to HCPV/T as a subsystem to utilize the rejected heat from HCPV/T. The proposed system gives a promising solution for several Egyptian regions which endure from the lack of fresh water and electricity. For carbon savings, these units can eliminate many tons of CO_2 every year.

A three-dimension thermal model of the typical Triple-junction solar cell was performed in finite volume software. From on the 3D model, the temperature distribution of the cell layer and were analyzed and simulated. This model had a thermal model for the current state-of-the-art triple-junction solar cell integrated with a thermo-fluid model for four distinct designs of confined jet impingement heat sinks. The results revealed that increasing the coolant inlet mass flow rate, improved the cell electrical efficiency. It was observed that low-temperature distribution non-uniformity can be achieved by the jet impingement configurations. Additionally, the use of jet impingement configurations consumed a very slight pumping power, which accounted for 1% of the generated power in the solar cell. Exergetic analysis shown that the single confined jet impingement heat sink attained the maximum total exergy efficiency.

Keywords: Photovoltaic/thermal systems, Water desalination and triple junction III-V solar cells

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Operational efficiency and benefits of using positive displacement pumps and isobaric energy recovery devices for SWRO

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Based on the SWRO technology and different setups depending on plant size, this presentation will describe the operational efficiency and benefits of using high pressure positive displacement pumps and energy recovery devices from Danfoss.

Among several desalination techniques, the SWRO technology has emerged as the preferred method.

Considering energy saving and reduction of CO_2 emission, the desalination industry is looking for more efficient pumps.

About 50-60% of the energy consumed in the SWRO plant is from HP pump, so it is important to reduce the consumption of the high pressure pump to the maximum.

For that reason, the high pressure positive displacement pump from Danfoss is a perfect choice.

The focus of energy consumption has also led to world wide acceptance of using Isobaric energy recovery device (ERD) resulting in an average power reduction of 60%. Here Danfoss offers a competitive solution with its range of iSave isobaric ERDs.

Keywords: Operational efficiency, Energy saving, retrofit, Energy cost, Uptime

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The application of composite GO/PAN membranes for removing surfactants from laundry wastewater

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Domestic and industrial laundry wastewater (LWW) is relatively 'clean' in comparison to other industrial effluents but it does not mean that there is no need to process them. Treatment of laundry wastewater can be cleaned by the following methods: biological, electrocoagulation, advanced oxidation processes, photoelectrochemical and electrochemical processes. Membrane processes are very suitable for LWW treatment.

The paper presents the possibility of removing anionic and non-ionic surfactants from laundry wastewater on ultrafiltration membranes (UF). For the research, prepared composite membranes based on polyacrylonitrile (PAN) modified with graphene (RG) were used. The content of anionic surfactants in LWW was tested using the MBAS (methylene blue active substances) method, whereas the content of non-ionic surfactants was determined by CTAS (cobalt thiocyanate active substances) method. The tests have shown that GO/PAN composite membranes can be successfully used for cleaning LWW from detergents.

Keywords: Laundry wastewater, Ultrafiltration, Composite membranes, Polyacrylonitrile, Graphene oxide

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Electrophoretic deposition of graphene oxide on copper pipe for corrosion prevention

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Copper and its alloys are widely employed in water desalination plants as it has excellent thermal properties. One of the main challenges of copper metal is the high corrosion especially under non-inert environment, such as seawater and rich oxygen media.

The current work introduces innovative corrosion resistant coatings for copper pipes which can be utilized for high saline media applications. The electrophoretic deposition (EPD) technique was implemented during the current work. Graphite oxide was produced from graphite powder by chemical oxidation of graphite using modified Hummers' method. An aqueous colloidal suspension of graphene oxide (GO) nanoplatelets were prepared by exfoliation of the graphite oxide via ultrasonic treatment. GO coatings were deposited on copper pipes through EPD from stable GO aqueous suspension. The EPD parameters such as voltage, time and GO concentration were optimized to obtain uniform GO coatings. The optimal EPD conditions for well-formed deposits were observed when the operating voltage was equal to 20 V and 90 s deposition time.

Different characterization methods were applied for the final coating. Fourier transform infrared spectroscopy (FT-IR) spectrum confirmed that GO was partially reduced during the EPD process itself due to the removal of oxygen containing functional groups. The corrosion resistance of GO-coated samples was evaluated by electrochemical measurements under corrosion condition in NaCl solution. The GO coatings are promising techniques for protecting copper from corrosion as the corrosion potentials reduced significantly in the GO-coated pipes when it was compared with the non-coated pipes.

Keywords: Desalination, Coating, Graphene oxide, Electrophoretic deposition

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The fallacy of energy efficiency for desalination processes comparison

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The major concern of desalination industry is the inadequate approach in energy efficiency of diverse seawater desalination processes by omitting the grade of energy supplied. These conventional approaches would suffice if the efficacy comparison were to be conducted for the same energy input processes. The misconception of considering all derived energies as equivalent in desalination industry has severe economic and environmental consequences. In the realms of the energy and desalination system planners, serious judgmental errors in process selection of green installations are made unconsciously as the efficacy data are either flawed or inaccurate. The inferior efficacy technologies implementation decisions were observed in many water stressed countries that can burdened a country's economy immediately with higher unit water and energy costs, as well as causing greater undesirable environmental effects to the surroundings. In this article, a standard primary energy (SPE) based thermodynamic framework is presented that addresses the energy efficacy fairly and accurately. It clearly shows that thermally driven process consume less than 1% of SPE when combined with power plants. We also presented that standard universal performance ratio (SUPR) for all desalination processes varies from 13-20% of thermodynamic limit but with best technologies mix and proper economic analysis approach, up to 23% energy savings are possible. The proposed roadmap is important to achieve 2030 sustainability goals.

Keywords: Standard primary energy, Primary energy, Standard universal performance ratio, Desalination

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Evaluating desalination's sustainability under the ecosystems approach

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As freshwater supplies become more limited and economic development comes with increasing water demand, technologies such as desalination and water re-use offer a great potential in reducing the gap between availability and demand. However, most desalination technologies are energy intensive, and the establishment of desalination plants around the world has not always been at an opportune time. On the other hand, economic competitiveness of RO versus conventional ground and surface water supplies will also tend to be location-specific, making most financial sense where water is scarce or the supply is perceived as being unstable. Economic evaluation of desalination projects is therefore important because it aids in determining whether the public supports proposed projects and in estimating the degree to which they are willing to pay for the benefits. Evaluating the sustainability of desalination as part of an integrated water management strategy for water se-

curity under the ecosystem approach is therefore proposed here. Considering ecosystem services in the decision making process can lead to well informed decisions, strengthening the economic and environmental argument of actions that can deliver environmental quality.

Keywords: Ecosystem services, Desalination, Nexus, Water security

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Multi-stage filtration in Iraqi drinking water plants

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Producing drinking water within the suspended particles less than 0.5 micron by the combination of classic filtration (sand filters) with centrifugal separation (Vortex effect) has been studied in this research work in one of Iraqi drinking water plants in Baghdad. Horizontal and vertical sand filters with multi-layered media filter (vortex sand) were connected together and used to extend removing the suspended solids and significantly increases the effective filter surface within the tank. The turbulence produces a sustained cleaning action that forces the suspended solids to accumulate on top of the media surface. As a result, much finer sand can be used without clogging the media. The water, which is now largely free of impurities, is then filtered through the media and subsequently collected. Contaminants trapped above the sand are removed using an automatic backwash cycle which Vortex sand requires less water and a shorter operating time than traditional sand filters. This process contributes to longer run cycles and much finer filtration levels.

Keywords: Drinking water plants; Micron filtration; Vortex sand; Sand filters

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Development of standard protocol for MFI-UF method to assess particulate fouling in RO systems

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Particulate/colloidal and organic fouling in reverse osmosis (RO) systems results in flux decline, higher energy cost, increased salt passage, increased cleaning frequency, and use of chemicals. In practice, ASTM standard indices like SDI (D4189) and MFI-0.45 (D8002) are used to assess particulate fouling. Both are performed using 0.45 um filter which does not capture the smaller colloidal particles (<0.45 um), and they are operated at constant pressure unlike the case in real RO systems. To address these issues, MFI-UF based on constant flux has been developed. However, no standard protocol is designated yet for the method. Various factors such as membrane properties, equipment accuracy and artifacts can affect the accuracy and reproducibility of MFI-UF. For that, this research aims to propose calibration procedures within new standard protocol for MFI-UF method.

Calibration procedures of MFI-UF were investigated using two solutions prepared by; i) Poly-

styrene microspheres with nominal diameter of 25 nm (aqueous state) at concentration range of 5–20 mg/L, using ultrapure water (Milli-Q water) as a solvent. ii) dextran polymers with molecular weight of 150 kDa (powder state) at concentrations range of 0.1–400 mg/L, using 0.05 mol/L KH_2PO_4 as a solvent where the pH of buffer was adjusted to 7.0 ± 0.1 by adding NaOH. The prepared calibration solutions were validated by checking the linear relationship between the sample concentrations and corresponding MFI-UF values measured at constant flux of 100 L/m^2/h using 100 KDa PES membrane. Prior to the experiments, accuracy and reproducibility of instruments used in MFI-UF setup (i.e. pump and pressure sensor) were checked.

The preliminary results showed good linearity between the polystyrene concentrations and corresponding MFI-UF values. The linear correlation was also between the dextran concentrations and corresponding MFI-UF values greater than 2,000 s/L^2, where irregular trend was found in the lower MFI-UF values produced by low dextran concentration. The reason of this could return to the adsorption of dextran during the process of preparation (onto beaker, pipette, etc.) and filtration (onto membrane surface, membrane holder, syringe, etc.), which had higher effect on the accuracy of MFI-UF value in the case of low dextran concentrations. Alternatively, MFI-UF value of dextran with low concentration might be close to the detection limit value relevant to the prepared dextran solution. These preliminary results could indicate the invalidity of used dextran to calibrate the MFI-UF values below 2,000 s/L^2, while this was not yet proved for polystyrene. Both dextran and polystyrene could be appropriate for the calibration of MFI-UF values higher than 2,000 s/L^2, but still further investigation is ongoing. The future work will include more investigation using different concentrations of dextran and polystyrene at several testing conditions such as different flux rates, membrane materials and membrane pore sizes.

Keywords: Particulate fouling, MFI-UF, Constant flux, Standard protocol, Calibration standards

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Operating experience and process optimization to maintain the low energy consumption for a 15 MiGD SWRO plant in UAE

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Aquatech was awarded the contract for the 68,130m^3/d seawater reverse osmosis (SWRO) plant in Ras-Al-Khaimah, UAE, one of the most fiercely contested tendering processes in the Gulf Municipal Desalination market.

In predetermined and widely published evaluation criteria of contract Aquatech had lowest life cycle cost of water. Apart from selection of technologically superior components in terms of its energy efficiency, some of the innovative design concepts were applied during construction of the plant.

After successful completion of the reliability test and the initial performance test, customer has taken over the plant operation since 1st April 2015. Plant is achieving the desired performance in terms of quality and quantity from the SWRO membrane units after almost 3 years of continuous operation.

Specific power consumption i.e. power consumed per cu meters of final product water transfer was 3.014 kWh/m^3 which is well below the guaranteed value of 3.1379 kWh/m^3. Consumption of

chemicals across various treatment stages of the desalination system is well within the limits of guaranteed values.

In this paper, we will share the operating experience and biofouling problems encountered and process optimization done to mitigate it, in order to maintain the energy consumption within range.

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Thermodynamic characterisation of novel solutions for closed-loop reverse electrodialysis

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Closed-loop reverse electrodialysis is a novel technology to convert low-grade heat directly into electricity. It consists of a reverse electrodialysis unit coupled with a regeneration unit in which the waste-heat is used to restore the initial conditions of the two solutions. One of the most important advantages of closed-loop system is the possibility to select an ad-hoc salt solution to obtain high efficiency. In this regard, it is important to assess how the salt solution properties affect the performance of the energy generation and solution regeneration processes.

The aim of this study is to analyse the effect of thermodynamic properties of non-conventional salt solutions within a RED closed-loop with evaporative regeneration unit. New data for caesium and potassium acetate, in terms of activity and osmotic coefficients, in aqueous solutions at temperature between 20 and 90°C are reported as a function of molality. The data are correlated using Pitzer's model which is then used to assess the performance in terms of Gibbs free energy of mixing, thermal power consumptions, thermal and exergy efficiency for different salt-water solutions (i.e. sodium chloride, lithium chloride, sodium acetate, caesium acetate and potassium acetate) are evaluated and compared considering single and multi-stage regeneration units. Results indicated that lithium chloride, potassium acetate and caesium acetate are the most promising salts among those screened.

Keywords: Closed loop reverse electrodialysis, Multi-stage evaporative regeneration unit, Potassium acetate, Caesium acetate, Osmotic coefficient, Pitzer's model

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Experimental assessment of reverse electrodialysis in closed loop configuration fed by NH_4HCO_3-water solutions

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Closed loop reverse electrodialysis is a novel technology for converting low-temperature waste heat into electric energy. This innovative heat engine consists of two units: (i) a reverse electrodialysis unit where power is produced exploiting the concentration difference between a diluted and a concentrated salt solution and (ii) a thermally driven regeneration unit where low-grade waste heat is used to re-establish the original salinity gradient between the two salt solutions.

Among all the possible salt solutions suitable as working fluid in such application, thermolytic salts solutions, in particular ammonium bicarbonate solutions, may be promising thanks to their characteristic thermally degradation properties. The thermolytic salt ions dissolved in water are converted into ammonia and carbon dioxide when heated up above a certain temperature (around 60°C). Then, dissolved thermolytic salt can be removed nearly completely from the dilute solution by means of a thermal desorption process and absorbed again in the concentrate solution, thus restoring the salinity gradient exploited by the reverse electrodialysis unit.

In this work, for the first time a lab scale prototype of a closed-loop reverse electrodialysis fed by ammonium bicarbonate aqueous solutions was built and tested. The proposed prototype consists of a conventional reverse electrodialysis unit and a regeneration unit constituted by (i) a vapour stripping column and (ii) a barometric column. The process performances in terms of power output, thermal power consumption, thermal and exergy efficiency were experimentally assessed. Also the influence of operating conditions, e.g. solutions concentrations was investigated. First experimental results demonstrated the feasibility of the process.

Keywords: Thermolytic salts, Ammonium bicarbonate solutions, Reverse electrodialysis heat engine.

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Techno-economic evaluation of reverse electrodialysis process in different real environments

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Salinity gradient power is a promising renewable energy source based on the recovery of the chemical potential released from the mixing of solutions at different concentrations. Natural salinity gradients are extensively available worldwide in natural reservoirs. Reverse electrodialysis is an innovative technology able to perform a direct conversion of the energy of mixing into electricity.

Salinity gradients coming from natural resources or from human activities are worldwide available. In the present work a number of different scenarios, including natural resources (e.g. rivers, seas, lakes and salt ponds), industrial/urban wastes (e.g. brine and treated wastewaters) are analysed.

The aim of the present work is to present a techno-economic model able to evaluate the potential and the economic feasibility of the RED process for the selected different existing scenarios. A RED model already developed by our group and widely validated is used to estimate the actual amount of power that can be harvested from real salinity gradients. For each scenario, also the theoretical mixing free energy and the yield are calculated.

The results from the process model are used to carry out an economic analysis providing the LCOE for three different stack sizes (0.1 x 0.1, 0.5 x 0.5 and 1.0 x 1.0 m^2) in each scenario. Furthermore, a perspective analysis was performed considering future membranes with lower specific costs and higher performance. Results suggest that the adoption of high performing membranes in scenarios with large difference in the streams salinity may lead to LCOE values competitive of even 0.10 €/kWh, highly competitive to other energy technologies.

Keywords: Reverse electrodialysis, Salinity gradient power, Open-loop RED, Gibbs free energy of mixing

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Performance analysis of RED-MED heat engine with non-conventional solutions

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In this work, a thermodynamic analysis of a salinity gradient heat engine (SGP-HE) for the conversion of low-grade heat into electricity is carried out. In particular, the performances in terms of thermal and exergy efficiencies of a closed-loop reverse electrodialysis (RED) coupled with multi-effect distillation (MED) regeneration unit is evaluated. The working fluids adopted for the present study are sodium chloride and potassium acetate aqueous solutions. Detailed mathematical models

for the RED and MED systems have been developed in order to investigate the efficiency of the integrated system. The RED process is described by a hierarchical model, where the low level is a distributed parameter model discretized along the length of the membranes, and the high level consists of the electrical equivalent circuit of the entire stack. The MED model is mainly based on mass and energy balances applied over the different components of the unit, together with the heat transfer equations associated with the heat exchangers. The overall model implemented in the engineering equation solver (EES) software, takes into account all the main phenomena involved in process and after validation proves to be reliable. Also, both working fluids have been characterized by their thermophysical and transport properties.

The influence of the main operating conditions (i.e. solutions concentration and velocity) and design features (stack aspect ratio) has been assessed, identifying the most advantageous scenarios. The effect of new generations of high performing membranes has been considered. Results show the great potential of this novel and promising power conversion technology, which has a large room for improvement if high-performing membranes and suitable artificial salt solutions are employed.

Keywords: Salinity gradient power (SGP), Reverse electrodialysis (RED), Multi-effect distillation (MED), Reverse electrodialysis heat engine (RED-HE), Exergy efficiency

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Modeling and design of membrane process recovery of HCl and metals from pickling solutions

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Hydrochloric acid pickling is one of the key steps in the hot-dip galvanizing process. It is a process widely used as a chemical pre-treatment method for cleaning, where metal surfaces with oxides are immersed into an acid solution. During the pickling process, the acid concentration decreases with time while the metal is accumulated. Thus, the efficiency of the pickling solution decreases and fresh solution must be used. Continuous regeneration of pickling solutions enhances pickling rate and process performance, but also minimises industrial wastewater disposal and chemicals consumption. The recovery and recycling process of valuable substances (e.g. acid and metals) can be accomplished by coupling diffusion dialysis (DD) and membrane distillation (MD) technologies [1,2].

The integrated process is based on a recovery of more than 80% of the free acid exiting from the pickling bath by passing through a selective anionic exchange membrane (in the DD), and then, its concentration by water evaporation through a hydrophobic membrane (in the MD) in order to be recycled in the pickling tank. The outlet stream from the diffusion dialysis, concentrated of metal salts, is fed to a reactive precipitation unit to recover iron as valuable product (iron hydroxide) by adding an alkaline reactant, whereas zinc salt is kept in the solution to be reused.

In the present work, a steady state process simulator for the integrated process has been developed, in order to analyze and predict performances of a small pilot-scale unit to be installed and operated within a hot-dip galvanizing plant. A parametric analysis of the model is performed varying hydrochloric acid and iron concentration in the pickling tank. In this way, usual operations of withdrawing of partially exhausted solutions and refilling with fresh acid is avoided allowing to continuously operating under the optimal pickling conditions.

Keywords: Process simulator; Hydrochloric acid recovery; Diffusion dialysis; Membrane distillation

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Experimental investigation and modelling for sulphuric acid recovery by diffusion dialysis

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Sulphuric acid is known to be one of the key inorganic acid and has been widely used in chemical reaction and metal industries for surface treatments as in the copper electroplating process. During these processes, large amounts of waste sulphuric acid solution are generally generated, containing high concentrations of metals and acid. The possibility of recover and reuse the sulphuric acid in the process could avoid environmental contamination and reduce costs of the disposal. Among several separation methods, diffusion dialysis (DD) is becoming more and more attractive thanks to the recent important advances in ion exchange membranes (IEMs) field and because of its clean nature and operational simplicity, low installation and operating costs and low energy consumption [1,2].

In the present work, two single-cell diffusion dialysis modules, equipped with commercial anion exchange membranes, with different dimensions, were employed. The first consisted in a laboratory-scale DD unit (10 x 10 cm^2) operated in a batch configuration to study the effect of process parameters on the efficiency of H_2SO_4 recovery. The latter consisted in a large-scale DD unit (80cm long) operated in a continuous configuration to simulate the process operation at the industrial scale. Acid recovery has been evaluated at different operative conditions. In both the cases, the effect of the presence of copper salt on the acid recovery was also evaluated.

In addition, the mathematical model for the DD process, developed and validated with experimental data previously obtained for HCl case [3], has been adapted and validated with experimental data obtained in this work.

Membrane behaviors to H_2SO_4 diffusion were compared with results obtained for HCl [3]. Opposite to the HCl case, H_2SO_4 diffusion permeability tends to decrease when increasing the solution concentration and the presence of copper reduces sulphuric acid recovery.

Keywords: Sulphuric acid recovery; Copper electroplating solutions, Diffusion dialysis

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Modelling hybrid systems for seawater desalination: electromembrane processes (RED, ARED and ED) coupled with RO

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The need to reduce energy consumption in seawater reverse osmosis processes has pushed research towards the development of new hybrid systems in which, for example, other membrane processes can be used to pre-treat seawater. Electrodialysis and reverse electrodialysis can act as a dilution step before seawater enters the RO unit, thus leading to an important energy saving in RO. In this work, two coupled models are proposed for the RED-RO and ED-RO system. Each process model was validated before being used for a sensitivity analysis in which the effect of the integration on the cost saving in the overall process was assessed. The analysis was performed by changing (R)ED voltage and RO pressure and considering three different scenarios: a standard scenario, an optimist scenario with a lower membrane cost and a pessimistic scenario with a lower electricity cost and comparing the result with the a standalone RO process. Negative values of "*Cost Saving*" were found when an excessive dilution step was performed before the RO, while competitive scenarios were found by optimizing the dilution extent, especially for the RED-RO case.

Keywords: Reverse osmosis, Hybrid systems, Electromembrane processes, Coupled model, Cost saving

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Problems associated with fluctuations in potable water quality — The Cyprus experience during the last 3 decades and the role of reverse osmosis desalination

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The scarcity of potable water in Cyprus has become a matter of national emergency during the past few decades. This has been the result of prolonged draught periods and the absence of a sustainable national policy regarding integrated management of water resources on the island. Traditionally, potable water reserves have been solely dependent on rainwater collected in reservoirs. However, dry climatic conditions, increased demand from the tourism industry, additional requirements imposed by a diverse range of agricultural and industrial activities as well as the ever increasing domestic sector demand, have rendered the available water reserves insufficient, both quantity and quality-wise. The combined pressure to improve on water quality and quantity has led to the adoption of desalination as the only sustainable means of safeguarding adequate water reserves on the island. Nowadays, the island enjoys the benefits of 4 fully operational seawater desalination plants with a total daily production capacity of approximately 220 Km^3.

Seawater desalination has been operational since 1997; however, total production is still not adequate to cover increasing demand and the Water Development Department (WDD) of the Ministry of Agriculture, Rural Development and the Environment, is striving to meet demand by combining desalinated water with other surface waters. In this context, the government has already announced restrictions to the allocation of water for irrigation purposes during 2018, in favour of avoiding cuts in potable water supplies.

This mixing of good quality desalinated waster with water from other sources, of seldom questionable quality, has been creating a series of problems associated with potable water quality and other numerous anomalies being observed in the distribution network, the most important of which are the following:

1. Organoleptic problems observed at consumers outlets (e.g. bad odour and unpleasant smells, colouration)
2. Elevated pollutant/micro-pollutant concentrations (e.g. nitrates, heavy metals, pesticides)
3. Excessive scale deposition interchangeable with corrosive tendency
4. Elevated THM's concentrations in potable water supplies.
5. Biofilm formation.

This study examines these problems with documented evidence from water testing records during the past 25 years. At the same time, in the light of the above evidence and based on the authors' experience in the water sector, constructive comments are made and suggestions are put forward.

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Renewable energy powered nanofiltration and reverse osmosis: experience with fluctuating energy

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Membrane processes such as nanofiltration and reverse osmosis provide some advantages where water is contaminated with predominantly dissolved contaminants such as TDS, fluoride, arsenic, uranium, nitrate and many other inorganic as well as organic contaminants. Such water quality may vary significantly with season and affect treatability [1-3]. In the case where dissolved contaminants are problematic, rather than turbidity or pathogens, simple filtration technologies cannot adequately treat water and hence cannot make many available sources potable.

Fig. 1. Typical 'unprotected' water source used as potable water in Tanzania.

Decentralized, small-scale and autonomous membrane systems provide a unique opportunity to supply safe water in remote regions, in particular in developing countries. Given the availability of an entire range of membrane pore sizes, the process can be adapted to the water quality. The challenges of lacking or dysfunctional infrastructure – water supply, sewage and electricity – remain in many rural areas worldwide [4]. Using such 'advanced' technologies in rural areas requires electricity to power the pumps that produce the driving force, which is typically either not available or unreliable. Coupling membrane processes to renewable energies (wind or photovoltaics) can alleviate this problem. To realise robust and decentralised systems for remote areas, direct coupling (no batteries for energy storage) is recommended. This lack of energy storage results in fluctuating power availability for system operation. This poses challenges in terms of water quality, system operation, and maintenance.

During a long term project that is summarised in this paper, the implications of such discontinuous operation was investigated in a systematic manner. The study has to date focused on short-term operation (typically one solar day) with a hybrid ultrafiltration (UF) – nanofiltration (NF)/reverse osmosis (RO) system [5, 6]. This required an investigation of the nature of fluctuations for both

wind and solar resources in terms of frequency and amplitude [7]. The impact of such fluctuations on water quality was investigated both in a laboratory environment [8, 9], as well as in real waters, in both Australia [3] and Tanzania [10]. This information was then applied to establish the resulting performance as a function of minimum power requirements and the safe operating window [11]. Short-term energy buffering was investigated via super-capacitor banks [11, 12].

Fig. 2 Directly-coupled wind/solar submerged UF-NF/RO system for research on brackish water treatment

Fig. 2 Ngurdoto Defluoridation Research Station (NDRS) Tanzania (Photos © Schäfer 2013)

In summary, the water quality results with both synthetic as well as real waters indicate for a variety of dissolved species that the contaminants that are retained by size exclusion are unaffected by the fluctuation [3]. Contaminants that are retained by other mechanisms respond to the altered conditions in the boundary layer due to the fluctuation which affects transmembrane pressure and feed flow depending on power availability. This variability can result in increased permeate concentration, hence producing a lower quality water. This variation is however typically negligible in the cumulative water quality even during the treatment of highly saline or fluoride contaminated waters. This can be attributed to the fat that in periods of low power availability very little water is produced and hence this quality is very quickly diluted as soon as power increases and the water productivity is high.

Future work will investigate the effect of such 'natural' fluctuations on membrane scaling and fouling, while membrane damage resulting from often abrupt variations in transmembrane pressure and permeate flow direction may affect membrane lifetime. Beyond engineering studies, adapting such 'advanced' technologies that are technically well proven, to harsh and remote environments will provide transdisciplinary challenges to overcome before dissemination is possible with the certainty of sustainable long term performance. At the same time such technologies promise to solve a major global societal challenge: provision of safe water in rural and remote areas.

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How to select the correct cartridge element to achieve the best membrane performance and lowest operating costs

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Reverse osmosis is a pressure driven process where the feed water is opposed by a semi permeable film that is able to retain the concentrate (high salinity) and extract the permeate water (fresh water). Almost all the conventional pre-treatment systems used in reverse osmosis plants utilize as final pre-treatment stage cartridge filtration units.

The correct selection of the cartridge elements in a desalination plant is of utmost importance as they constitute the last barrier to unwanted particles. Cartridge elements can represent a very large portion of the operational costs of a plant.

This paper outlines the difference in performance of various types of cartridge elements. Comparison is based on the use of different elements on a water treatment plant operating under the same conditions and at the same time. Data on the comparison of seven different high flow polypropylene depth cartridge elements is given.

Comparative results on SDI, iron content and differential pressure will be presented in this paper along with elements capacity and duration (life). This paper will also present the operating cost for the seven tested elements along with comparisons on energy consumption.

Keywords: RO System, cartridge elements, depth filtration, micron

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Biological membrane for treatment of wastewater

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Anaerobic biological membrane is widely used in the treatment of wastewater. Recently, anaerobic biological membrane technology is used in the bioreactor. This bioreactor operates at the psychrophilic condition and is filtering the water as it passes through. It does not require adding of external energy and is very low maintenance.

Biological membrane reactors contain filter layers consisting of gravel or plastic gravel beds. It is used to treat sewage efficiently, which has low-density organic contamination. This process contains 3 steps: primary sediments, anaerobic filters and sludge tanks. The sludge can then be used to produce organic fertilizers.

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Water treatment (filtration) by bedrock

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Water treatment methods such as the reverse osmosis and ion exchange are being used in order to get clean water from seawater or from contaminated water, but it is costly since this method needs continuous upkeep and replacements.

The researchers in this field are using a new water treatment method by bedrock, such as sandstone in order to being able to utilize seawater and previously contaminated water for urban areas as well as seaside settlements of the DPR of Korea. This method has proven very cost effective as it is based on naturally occurring resources. The newly established trial sites from five years ago have been very successful and are now being adopted widely.

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Journey to brine solution

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There is a Korean research group, Global MVP (GMVP) working to find the brine solution in order to make the seawater desalination plant more environment friendly. Since the brine's problem is its high salinity, the GMVP proposed to dilute the brine salinity through mixing with impaired freshwater. They proposed to apply the technology of pressure retarded osmosis (PRO) during the mixing to recover the salinity gradient energy between the brine and the impaired freshwater. This approach allows to eliminate the environmental concern and simultaneously to reduce the energy consumption of seawater desalination. They also proposed another approach which is two-step process. The brine volume is first reduced by using the technology of membrane distillation (MD), and then valuable resources are recovered. This approach allows to reduce the brine discharge and to add values to seawater desalination through resource recovery. The GMVP demonstrated the technical feasibilities of PRO and MD at pilot-scale. They have built the pilot plant of SWRO-PRO (Q=240 m^3/d) using the 8" spiral wound PRO membrane modules. They used secondary effluent from wastewater treatment plant as impaired freshwater source for the mixing. The SWRO-PRO has been successfully operated for more than 2 years, demonstrating the 25% energy reduction. They have also built the pilot plant of SWRO-MD based on the hollow fiber MD membrane modules. The SWRO brines were fed to the MD pilot (Q=400 m^3/d), and Li and Sr were recovered from the MD brine. The remaining MD brine was then used to produce pavement blocks. The 5-year efforts of GMVP will be explained in this presentation together with the next phase research.

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Keywords: Membrane distillation (MD), Pressure retarded osmosis (PRO), resource recovery, pilot-scale

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Optimization of commercial scale hollow fiber membrane distillation module

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Membrane distillation (MD) is a thermally driven separation process using hydrophobic microporous membranes. Accordingly, its performances are largely dependent on the characteristics of MD modules. Currently, flat sheet membranes are used for most MD modules that are commercially available, leading to problems associated with low packing density and high manufacturing cost. Hollow fiber MD modules have potential to overcome such limitations but have been rarely investigated in pilot- or full-scale systems.

In this context, this study focuses on the design optimization of hollow fiber MD modules that are used in commercial scales. Porous PVDF membrane fibers were developed with a combination of TIPS (Thermally Induced Phase Separation) and stretching processes and HDPE membrane fibers manufactured through a stretching process. A series of experiments were carried out in both a bench scale equipment and a pilot plant. A mathematical model was developed and applied to analyze the mass balance and heat balance in MD modules. Results showed that the performance of MD modules is sensitive to the operating conditions as well as the module dimensions. Since the flux and thermal efficiency have a trade-off relationship, theoretical optimization of the MD modules was carried out to explore the way to minimize the total cost of the operation.

Keywords: Membrane distillation(MD), hollow fiber membrane, module, design, optimization

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Design and operation of a 400 m³/d membrane distillation plant for management of seawater reverse osmosis brine

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Membrane distillation (MD) represents a potential alternative to the management of seawater reverse osmosis (SWRO) brine because of its ability to treat feed waters with high salinity and to use low-grade thermal energy. Nevertheless, few works have been attempted to scale-up of MD technology for desalination and brine management. In this work, a MD pilot plant with the capacity of 400 m³/d (~ 0.105 MGD) was designed and constructed to demonstrate the technical feasibility of large-scale MD systems. Hollow fiber MD modules with the effective surface area of 10 m² were used in a vacuum MD process configuration. The MD process was integrated with a SWRO desalination plant having a capacity of 1,000 m³/d. The thermal energy remaining water vapor was recovered using two thermal vapor compressors (TVCs), allowing a high thermal efficiency in each stage. A systematic approach was carried out to design the MD process. Results showed that the MD process was successfully operated to fulfill the design requirements. The feasibility of the MD technology for SWRO brine management was confirmed by the techno-economic analysis based on the data from the pilot plant.

Keywords: Membrane distillation(MD), hollow fiber membrane, module, design, optimization

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Performance evaluation of a vacuum membrane distillation pilot plant with solar heat

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A solar desalination pilot plant has been designed, built, and demonstrated in Korea, which consisted of a vacuum membrane distillation (VMD) system and a solar thermal collecting (STC) system. For the VMD system, two membrane distillation (MD) modules having polyvinylidene fluoride (PVDF) hollow fiber hydrophobic membranes were installed in a parallel. The MD modules have a membrane surface area of 10 m^2 respectively, which allows the VMD system to generate a 4 m^3 of fresh water a day. The STC system used aqueous propylene glycol solution as a heat transfer fluid and collected heat from the solar thermal collectors having a total collection area of about 462 m^2, which consisted of 18 flat-plate (FP) solar collectors with about 175 m^2 collection area and 65 evacuated-tube (ET) solar collectors with about 287 m^2 collection area. The collected heat was stored in the thermal energy storage tanks to provide hot water to the VMD system for the desalination. The demonstration results showed that the efficiencies of both FP and ET solar thermal collectors are around 39% and 47%, respectively. In addition, a solar fraction in the VMD system was approximately 25.8%. The performance ratio (PR) of the VMD system, defined as the ratio of the vaporization heat associated with the generated fresh water to the heat transferred through PVDF hollow fiber membranes, was ranged from 1.0 to 1.2, which was in a good agreement with the performance of VMD modules obtained in the lab-scale tests. Furthermore, unmanned system operation technologies were additionally acquired from the long-term demonstration.

Keywords: Vacuum membrane distillation, solar thermal collector, unmanned operation

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