EUROMED 2017

European Desalination Society

Desalination Branch of China Water Enterprises Confederation

Government of Italy

Desalination for Clean Water and Energy
Cooperation around the World
9–12 May 2017
David Intercontinental Hotel, Tel Aviv, Israel

ABSTRACTS

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Study on treatment of oil-field produced water by liming

Marco Tagliabue*, Alessandra De Folly D'Auris, Paolo Filtri, Roberto Bagatin

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Produced water is by far the largest volume waste stream from energy industry. It is water trapped in underground formations, brought to surface along with oil and gas. Main produced water pollutants are hydrocarbons and their derivatives (e.g., carboxylic acids, phenols), chemicals used as additives (e.g., surfactants, corrosion inhibitors) and natural occurring inorganic salts.

Produced water management is particularly critical in case of surface disposal within on-shore operations. In this case, quite complex treatment trains have to be considered in order to front wide spectra of pollutants and stringent environmental regulations.

Liming is frequently considered just after primary treatments (e.g., de-oiling, gas stripping). Its main purpose is influent sweetening before further processing (e.g., membrane treatments). In spite of the simple chemistry involved, quite unpredictable additional effects have been reported in literature, mainly due to sorption on precipitating carbonates and hydroxides (e.g., abatement of silica, boron and organics).

A lab-scale study on the effect of liming on produced water (Italy on-shore oil production site) is reported.

This is part of a wider company program on produced water, regarding both its effective disposal and its valorisation as alternative freshwater resource.

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Application of reverse osmosis to treat high ammonia concentrated reject water from sewage sludge digestion

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Treatment of municipal or industrial sewage using the sludge activated method is strictly connected with production of excess sewage sludge as a by-product. The largest plants utilize anaerobic sewage sludge digestion. The biggest advantage is the production of heat and electric energy from biogas. On the other side, during the final dewatering of digested sludge high concentrated reject water is produced. It is usually returned to the main line of wastewater treatment plant (WWTP) without any separate treatment. It causes problems with high efficiency treatment, especially due to the extremely high concentration of ammonia nitrogen. A novel approach is presented in the article that removes ammonia nitrogen from reject water using a membrane technique treatment with reverse osmosis (RO). RO is well known as an efficient tool to remove different kinds of contaminants and is successfully applied to treat water and sewage. The developed technique provides efficient treatment of reject and production of quality water for industrial purposes. RO concentrate that contains ammonia is added to the sludge and withdrawn together with dewatered sludge as the sludge moisture. A flow diagram

of the process is presented that describes principles of dewatered reject treatment by RO and ammonia balance. Looking for a new application of RO technology, laboratory scale research was performed to evaluate its efficiency for reject water treatment. Excess sewage sludge with whey and flotation sludge in a dairy WWTP was stabilized in a digestion chamber and then dewatered with a centrifuge. The quantity of reject water measured in the dairy WWTP during the research period was up to 10% of the total amount of raw dairy sewage. The average concentrations of pollutants in reject water used in laboratory experiments were: COD - 1830 mgO_2/L; TOC - 155.3 mg/L; ammonia nitrogen - 1537.6 mgN-NH4+/L, total phosphorus - 137.1 mgP/L. The study showed high efficiency of RO in removing of main pollutants from the reject water generated during anaerobic sewage sludge stabilization in a dairy WWTP. The research indicated that the use of RO in full scale in dairy WWTPs would result in a significant decrease of contamination load in reject water. It might assure stable and effective functioning of dairy WWTPs. Concentrate produced during RO treatment can be used for fertilizer production or blended with dewatered sludge before its final use.

Keywords: Ammonia nitrogen, Reverse osmosis, Reject water, Sewage sludge digestion, Wastewater treatment

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Hybrid MBR-PAC process for wastewater treatment

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The goal of this study is to test the combination of membrane bioreactor (MBR) with an adsorption-desorption-biodegradation processes using powdered activated carbon (PAC) suspended with the mixed liquor suspended solids (MLSS). Under certain conditions, the MBR-PAC hybrid process may provide a synergetic behaviour as a solution for membrane biofouling in the MBR: The adsorption-desorption-biodegradation characteristics of the MBR-PAC reactor can also improve the stability of acclimated microbial community for biodegradation of recalcitrant organic compounds that can also acquire strong membrane fouling capabilities. Therefore, the main hypothesis is that the MBR-PAC process will provide the MBR with higher microbial activity, stronger capacity to cope elevation of certain shock loads of organic pollutants, and an alternative media for adsorption of organic foulants, to the membrane surface, and as such, the presence of PAC may sequester organic fouling. The two experimental systems include MBR with PAC (0.1 g/L PAC) and MBR without PAC treating domestic wastewater, flat-sheet membrane module made from poly-ethersulfone membranes. In addition to the MBR operating conditions (including permeate flux, transmembrane pressure and MLSS concentration) we also performed QCM-D adhesion tests for the organic MBR fractions, extracellular polymeric substances (EPS) and soluble microbial products (SMP), in which the effects of the PAC on the fouling propensity of the MLSS were deduced. Initial permeate flux in both reactors was set to 5 L $\cdot m^{-2} \cdot h^{-1}$ and the initial pressure to 0.05 bar. Optimal concentration of PAC is currently being explored, as well as the conditions in which, membrane fouling is reduced.

Surprisingly, when PAC was added to the municipal wastewater feed solution (0.1 g/L), membrane fouling was enhanced (Fig. 1). While in the absence of PAC, membrane permeability maintained higher, in spite of the higher dissolved organic carbon in the MLSS. The reason for this observation was delineated using adsorption tests of the dissolved organic fraction from the MBR. Apparently, organic components with lower affinity to the membrane were adsorbed to the PAC, while organic components with higher affinity to the membrane material remained in the MLSS and likely, enhanced fouling rate (Fig. 2). Hence, a faster fouling rate was observed when PAC was added to the MLSS in real MBR operation and to batch experiments with the MBR supernatant (exposed to PAC) followed by QCM-D adsorption tests. Since MBR-PAC hybrid process was reported as a preferred selection for industrial wastewater, further study on MBR-PAC process treating olive oil mill wastewater is being carried out, in which the interactions between PAC, organic foulants and the membrane are being analyzed.

Keywords: PAC, MBR, biofouling

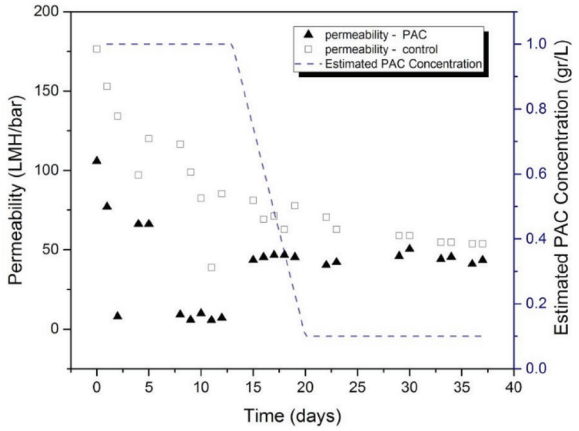

Fig. 1: Permeability of the membranes in the MBR-PAC and the control (MBR w/o PAC) during the start-up period of 25 days.

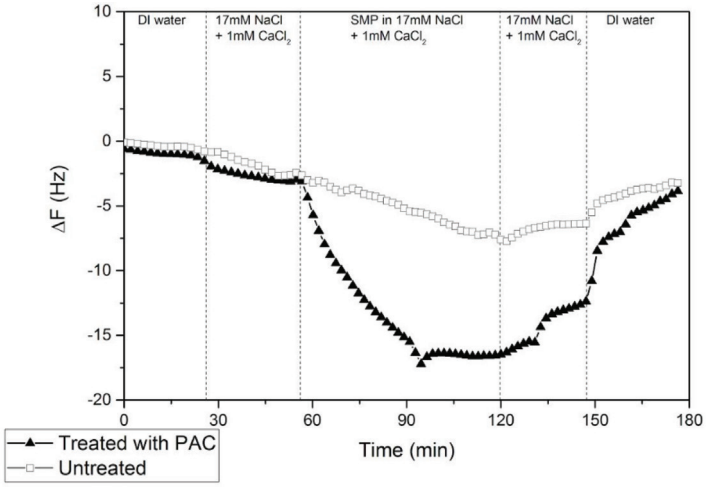

Fig. 2: Adherence properties of SMP, extracted from the MBR, after runs with and w/o PAC provided as frequency shifts during SMP adsorption to PES coated QCM-D sensors. A background solution with ionic strength 20 mM (17 mM NaCl + 1 mM $CaCl_2$) supplemented with SMP at 50 mg DOC/L was injected to an E4 QCM-D parallel flow cells (Q-Sense, SWEDEN) at a flow rate of 150 µL/min.

The influence of electric fields on the adsorption dynamics of bio-polyelectrolytes at solid–liquid interfaces

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The range of environments in which microorganisms thrive is wide and in most cases, the presence of biofilms formed by them is regarded as undesirable. In processes that involve membranes, electrodes and other surfaces, the formation of a biofilm on surfaces hampers their proper functioning. The adverse effect of biofilm is mainly due to changes in mass and heat transfer properties.

A previous study [1] confirmed that electric fields have an effect on bacterial attachment and biofilm formation, but a thorough investigation of the mechanism has yet to be done. In this study, a model system – alginate, which is common in *P. aeruginosa* biofilms – is studied using Quartz Crystal Microbalance with Dissipation (QCM-D) with an electrochemical flow cell. Alginate is allowed to adsorb on a resonating gold coated electrode/sensor before an external voltage is applied on the sensor. Fig. 1 depicts our results.

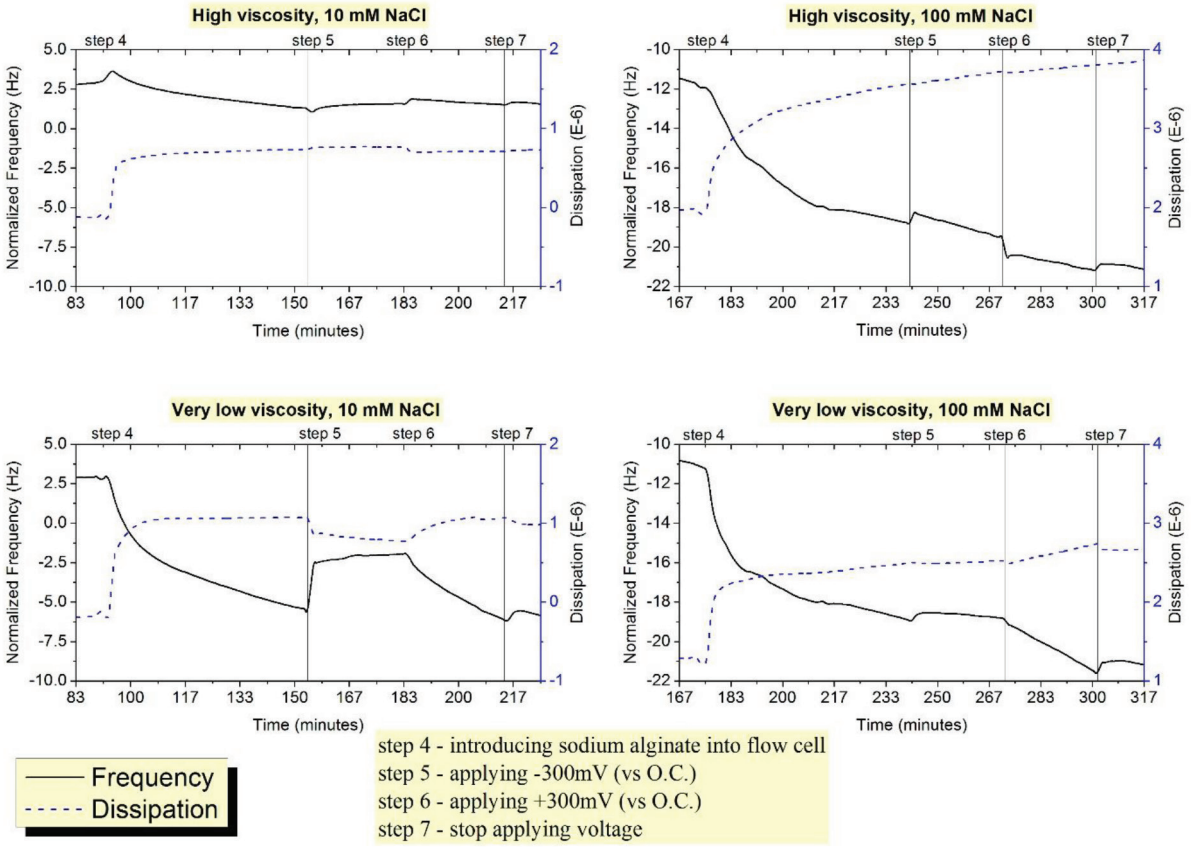

Fig. 1. Electrochemical QCM-D experiments of sodium alginate, at 2 ionic strengths (left - 10mM, right - 100 mM, of NaCl), and 2 molecular weights (top-high, bottom-very low, signified by their viscosities)

The adsorbed high viscosity alginate (HVA) exhibits small responses to the applied voltage, in contrast to the very low viscosity alginate (VLVA) that shows interesting behavior at the same conditions. Both solutions (10 mM and 100 mM) of VLVA show an increased adsorption when a positive voltage is applied, which is expected due to the negative charge of alginate. A result of important consequence is the reaction of the 10 mM VLVA to a negative voltage. Under these conditions there is an almost-immediate desorption of alginate. This is due to the decreased electrostatic shielding occurring in the weaker ionic atmosphere.

Our future work includes studies of a positively charged bio-polyelectrolyte and a study of the change in electric properties of the adsorbed alginate using electrochemical impedance spectroscopy, which allows a better understanding of the changes in electrostatic interactions and their importance with regards to the behavior of adsorbed bio-polyelectrolytes under the influence of electric fields. Furthermore, the adsorption behavior of alginate to a surface at which there is already an applied electric field will also be studied.

Our results show clear dependence of the behavior of adsorbed alginate on both the ionic atmosphere and molecular weight. We show that under conditions of that are accessible in water treatment systems it is possible to cause desorption if alginate.

Keywords: Electroadsorption, alginate, electric fields, fouling-removal

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Off-grid desalination for irrigation in the Jordan Valley: A student-led team project

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Transboundary groundwater resources in the Jordan Valley are seriously depleted and over-pumping has led to an increase in water salinity. Due to the inefficiency of the electricity grid in the Palestinian Jordan Valley, off-grid desalination technology, powered by solar energy, is a good solution to improve the quality of brackish water for irrigation by local farmers.

This poster proposes a student-led project in which university students will work in teams to develop a desalination prototype that is solar powered and provides high recovery of freshwater from brackish feedwater. The approach is based on a similar project that has been implemented with the participation of M.Eng* students at Aston University, UK. The Aston students used a novel double-acting batch reverse osmosis concept to maximise recovery of water and energy. The experience and outcomes of that project are evaluated through reflections by the instructor and through feedback gathered from the participating students, to extract lessons for future delivery.

The authors believe that this approach to student learning has potential in helping to build capacities in areas suffering from groundwater salinization and in encouraging international collabora-

tion to address shared challenges in the Jordan Valley. Successful developments from the proposed project can be taken up by technical civil society organisations, such as the Palestinian Wastewater Engineering Group, to scale up and implement solar-powered desalination plants and extend the capacity building through training workshops for farming communities.

*M.Eng: Masters of Engineering

Keywords: Transboundary groundwater resources, solar, batch RO, high recovery, capacity building, international cooperation

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Gaza sustainable water supply program. Associated works to Gaza desalination plant. Blending between desalinated water and other sources

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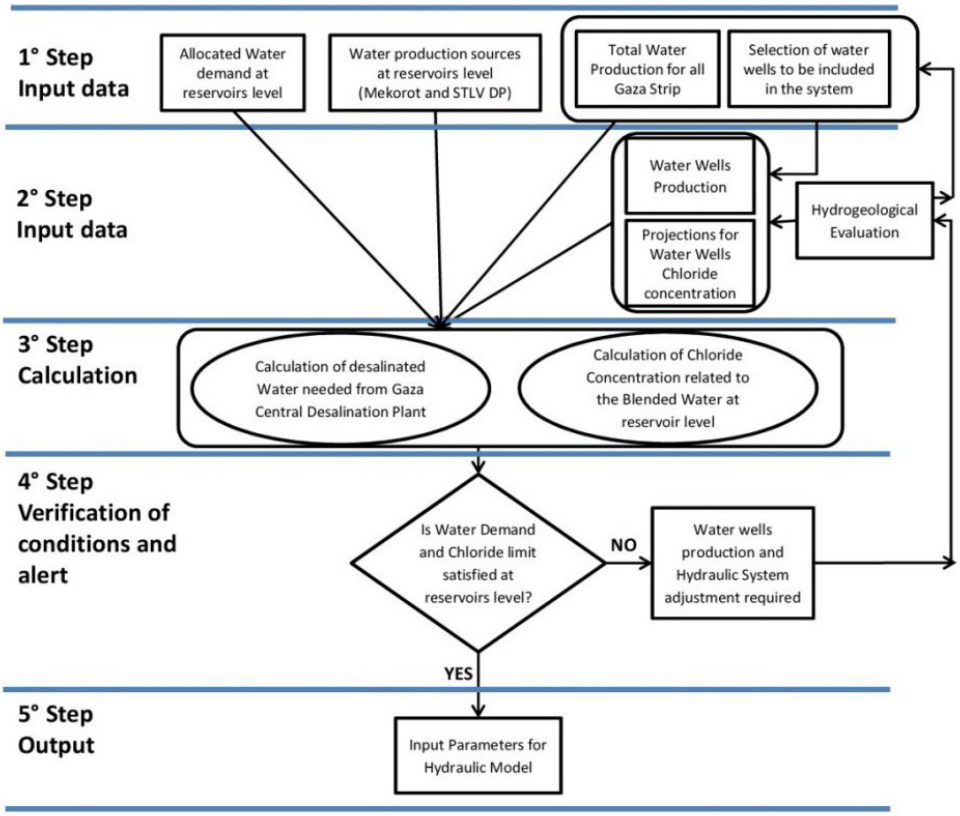
Desalinization may be a crucial component in water resource development of coastal areas. Water quality needs to be corrected and balanced as necessary for the intended users. Other sources may be locally available and can be retained as a complement to lower the production cost and to correct the quality parameters as required. In coastal areas were ground water of lower quality may be available, blending two or more sources is the winning solution. However, blending needs constant monitoring and continuous adjusting of proportions in the mixt. To do that the operators need a decisional tool that allows the blending to be adjusted as necessary. A simple but comprehensive tool was developed by Lotti Ingegneria in the framework of the study on the "Gaza Sustainable Water Supply Program: Project Implementation Consultant - Associated Works to Gaza Desalination Plant". The Blending Tool is an operational instrument aimed at calculating the chemical parameters concentration at blending reservoir level, on the base of input and control data, by signaling the occurrence of possible critical situations. Summarizing by steps the operating principles of the Tool, in the following figure is shown the flow chart related to the Blending tool.

The tool is based on a wells data base spreadsheet with over 180 wells described in terms of actual and target quality parameters and 68 blending points (storage and blending reservoirs) where the blending will be done with present and planned desalinization plants. It is (it will be) interfaced with SCADA and allows easy monitoring and prompt evaluation of corrective actions as necessary.

Keywords: Blending; Water management; Sustainability; Optimization



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$CaSO_4$ scaling on ion exchange membranes during Donnan exchange and electrodialysis

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Electrodialysis (ED), an electrochemically driven membrane separation process, is considered today an optional stage in the treatment chain of brackish water reverse osmosis (BWRO) brines to improve water recovery and to reach near-zero liquid discharge (ZLD)[1, 2].

However, using an integrated RO-ED process for ZLD requires managing mineral scaling by sparingly soluble salts such as $CaSO_4$. Scaling may result from the high concentrations evolving in the brine streams as well as concentration polarization at the membrane–solution interface in the brine compartments. Mineral scaling results in a significant, often irreversible, increase of stack electrical and hydraulic resistances and consequently resulting in larger energy consumption.

Calcium sulfate scaling is studied at Donnan exchange[3] and ED conditions[4]. *Scaling* and *Non-scaling* experiments have been conducted using both anion and cation exchange membranes with hetero-

geneous (MA-40 and MK-40) or homogeneous (AMV and CMV) structure. The effect of $CaSO_4$ scaling on membrane performance is expressed in terms of sulfate-flux decline due to membrane blocking by scale, membrane potential changes, stack total resistance changes and water splitting extent. Effects of current density, membrane type and hydrodynamic conditions on scaling extent are discussed. Fig. 1 shows SEM images of $CaSO_4$-scaled anion- exchange membranes.

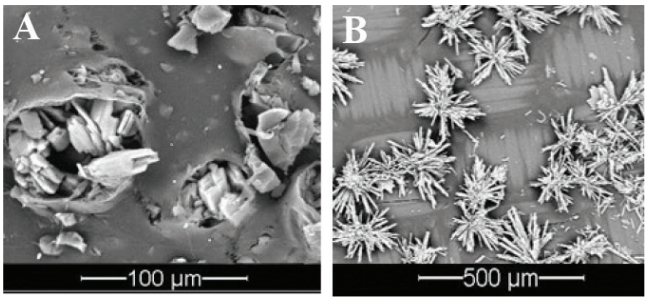

Fig. 1. SEM images of $CaSO_4$-scaled: A) MA-40 and B) AMV membranes

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Advancement in seawater and wastewater membrane foulant analysis using chromatic elemental imaging

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Chromatic Elemental Imaging (CEI) has been used to enhance the findings of membrane autopsies for the last few years. The technique offers benefits in determining the spatial distribution and relative concentration of elements with a high degree of accuracy.

This paper explains the differences between how CEI works and the previous most common membrane examination techniques of Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (known as EDX or EDS) and shows how adding CEI to the analysis is bringing greater clarity to autopsy findings.

Examples drawn from a variety of seawater and wastewater reverse osmosis membrane autopsies will demonstrate the limitation of SEM/EDX and highlight additional information provided by CEI that informs the practical actions that can be taken to avoid or mitigate the fouling. These examples include:

- Telling the difference between sand/algae and sand/clay
- Differentiating between in situ formed clay and sand/silt

- Understanding layered and mixed scales
- Differentiating between corrosion particles and iron foulant
- Identifying complex 'new' foulants occurring on wastewater reuse applications

Each case explains membrane autopsy findings derived by CEI and highlights efficient system improvements that were implemented as a result. The cases serve to illustrate some of the limitations of traditional analytical techniques for today's complex systems and set out commonly encountered difficulties in identification of foulants. It reinforces the value of modern analytical methods in enhancing the understanding of the detailed nature of fouling which leads to optimal system remediation and ongoing operation improvements.

Keywords: Chromatic elemental imaging; Reverse osmosis; Membrane autopsy

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Asymmetric capacitive deionization for water purification and recovery by using mesoporous carbon and silver nanoparticles

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In this study, an environmentally benign and mass productive strategy for the fabrication of 3-D ordered mesoporous carbons including (OMCs) was developed by using sugarcane bagasse as the scaffold. The OMCs were further physically and chemically activated nitric acid and carbon dioxide, respectively, for capacitive deionization (CDI) application. The SEM/TEM images showed that the OMCs retained large domains of highly ordered 1-D strip-like channels and the 2-D hexagonal mesostructures. All the cyclic voltammetric curves of OMCs showed ideal rectangular and symmetry voltammograms with Faradic reaction at scan rates of 1-10 mV/s, indicating the typical capacitive behaviors with good charge propagation and easy ion transport in the electrode materials. The specific capacitances of OMC is 84-93 F/g. When silver nanoparticles and OMCs were used as the anode and cathode electrodes, respectively, the CDI efficiency was enhanced. The electrochemical performances of OMCs and activated carbons (ACs) showed rectangular voltammograms at 5–100 mV/s, while two peaks with Faradic reaction occur for Ag electrode. The specific capacitance of OMC electrode is 104.2 F/g at 5 mV/s, which is 2.84 times higher than that of ACs. In addition, the asymmetric Ag||HOMC electrodes show excellent electrosorption capacity (SEC) and high stability toward sodium ion removal. The specific electrosorption capacity is 356.3 and 251.6 μmol/g at 1.2 V in batch and continuous flowing solutions, respectively, which is 1.4–2.7 and 2.2–2.7 times higher than those of symmetric carbon-based electrodes. In addition, the asymmetric electrodes were used to remove Ni^{2+} and salt in solution simultaneous and found that Ni^{2+} ions can be completely removed from asymmetric capacitve deionization processes. Results obtained in this study clearly indicate that the asymmetric Ag||HOMC electrode is a promising alternative nanomaterial which can open an innovative CDI technology to treat grey and brown waters that need high desalination efficiency.

Keywords: Asymmetric capacitive deionization; Ordered mesoporous carbon; Silver nanoparticles; Nickel ions; Desalination

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Uncertainty analysis as criteria for select the best coefficient of performance prediction by artificial neural network

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For this research, four artificial neural networks models presented in Martinez-Martinez et al.(2017) aimed to predict the coefficient of performance (COP) for water purification system coupled to an absorption heat transformer with duplex components were evaluated. About the models, the hyperbolic-tangential and linear functions were selected for the architecture of artificial neural network, the number of neurons in the hidden layer was fixed to 4 and the input layer the number of neurons were considered from 3 to 6. For these models, if certain level of error is fixed in the process of measuring the independent variables (temperature and pressure), the error propagation (or deviation standard) of the COP is unknown. For this reason, the present research introduces the error propagation criteria based on Monte Carlo method results to select the best artificial neural network model in according with the following criteria, the best model could be the one whose standard deviation is smaller and it mean agrees with the experimental value. Two errors levels are proposed in this research: i) as "typical" error, it represented a routine measurement of the heat transformer and ii) the use of high precision equipment to measure the operation variables. Monte Carlo method is a numerical method to estimate the error propagation in models with complex mathematical structure allowing us to evaluate the type of distribution in the dependent variables, in this case, the COP. The error propagation analysis provides confidence in the prediction and in the model selected.

Keywords: Standard deviation, Heat transformer, Monte Carlo method

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Antimicrobial and antifouling graphene containing spacer for fouling control in membrane and water treatment technology

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Fouling is a major challenge in water purification technology that utilizes polymer membranes. Microbial fouling is especially difficult as biofilm growth on surfaces exposed to environmental conditions is ubiquitous. For example, biofilm growth occurs in membrane modules in the spiral wound configuration not only on the membrane surfaces, but also on the accompanying spacer materials. Here we show a new concept in spacer design and present a graphene containing spacer with both antimicrobial and antifouling properties. Our design may lead to elimination of biofilm accumulation on the spacer and concomitant prevention of bacterial attachment on the membrane surface. The mechanism of antibiofilm action of the graphene spacer will be explained. This concept could be extended to many applications in water treatment technologies.

Keywords: Graphene, Spacer, Antifouling, Membranes

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The effects of SWRO desalination brine discharge on benthic heterotrophic microbial communities

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Seawater reverse osmosis (SWRO) desalination facilities continuously discharge hypersaline brine into the coastal environment. Without proper dilution measures, the brine form a salinity plume near the seabed of up to 10% above the ambient levels. Brine waste is denser than ambient seawater due to the higher concentration of salts and therefore tends to sink and flow along the seafloor. Saline flow over the bottom may result in accumulation of brine within the sediment grains, hence alter benthic microbial activity, diversity and functionality, thus alters coastal food webs. In this study, we examined the short-term (days) and long-term (weeks to years) effects of different elevated salinity scenarios on benthic bacterial abundance, diversity and activity in coastal sediments of the eastern Mediterranean Sea. Our results demonstrate that even a short exposure to 5% elevated salinities may trigger a decrease in bacterial abundance by ~40% during summer, increase bacterial cell specific activity (~60%) and increase bacterial carbon demand (~70%). Yet,

no change in microbial diversity was recorded under short exposure in any of the salinity treatments. In contrary, long-term exposure to high salinity may cause more profound effects on benthic microbial communities. Thus, a benthocosm setup simulating SWRO desalination brine discharge with elevated salinities of 2%-10% above ambient levels was tested for one-month. Additionally, a seasonal series of coastal in situ sediment samplings were conducted aboard the R/V Mediterranean Explorer during 2016-2017 to determine the spatial extent as well as the biological and ecological effects of brine in the field. This study enables new insights on the effects of brine upon coastal ecosystem and emphasizes the need for science-based regulation of SWRO brine discharge.

Keywords: SWRO desalination, Brine, Heterotrophic bacteria, Bacterial production, Eastern Mediterranean Sea

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Impacts of seawater desalination on coastal environments

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Today, and in the near future, extensive large-scale seawater-desalination facilities will serve as the main source of freshwater supply. However as part of the desalination process, seawater desalination facilities discharge brine-waste acute and chronic effects to marine coastal environments. Typical desalination brine-waste consists of hypersaline-seawater along with different chemicals such as antiscalants and coagulants. The spatial characteristics of the brine-plume, namely the perimeter, flow direction and buoyancy, vary according to the volume and rate of discharge and the technology used to dispose the brine-waste. In this study, we will present a comprehensive overview highlighting the environmental effects of brine discharge from desalination facilities on coastal key species, including bacteria, seagrass, fish-larvae, plankton and different coral species. Once subjected to elevated salinities (>50 ppt), sessile organisms such as sea-grass displayed severe physiological response, including leaf necrosis, reduction in growth rates and up to complete mortality. Benthonic heterotrophic bacterial activity remind unchanged when exposed to elevated salinities (>48 ppt), while their abundance decreased in microcosm-core experiments. Bacterioplankton and phytoplankton exhibit changes in productivity and community composition, however these effects were only captured once exposed to high salinity brine in mesocosms (>48 ppt), or in close proximity to the desalination outfall. Corals have displayed different physiological responses following long exposure to hyper-saline brine as well as antiscalants. Finally, higher trophic levels such as fish were reported to be unaffected by brine discharge, however fish eggs as well as juvenile displayed higher motility rates once exposed to >60 ppt. Following the above, we will discuss possible engineered solutions that were previously designed and applied by the desalination industry to minimize the impact of brine discharge on the coastline biota.

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Saline groundwater from coastal aquifers as a source for desalination

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Reverse osmosis (RO) seawater desalination is currently a widespread means of closing the gap between supply and demand for potable water in arid regions. Currently, one of the main setbacks of RO operation is fouling, which hinders membrane performance and induces pressure loss, thereby reducing system efficiency. An alternative water source is saline groundwater with salinity close to seawater, pumped from beach wells in coastal aquifers which penetrate beneath the freshwater-seawater interface. In this research, we studied the potential use of saline groundwater of the coastal aquifer as feed water for desalination in comparison to seawater using fieldwork and laboratory approaches. The chemistry, microbiology and physical properties of saline groundwater were characterized and compared with seawater. Additionally, reverse osmosis desalination experiments in a cross flow system were performed, evaluating the permeate flux, salt rejection and fouling propensities of the different water types. Our results indicated that saline groundwater was significantly favored over seawater as a feed source in terms of chemical composition, microorganism content, silt density and fouling potential, and exhibited better desalination performance with less flux decline. Saline groundwater may be a better water source for desalination by RO due to lower fouling potential, and reduced pretreatment costs.

Keywords: Desalination; Saline groundwater; Reverse osmosis; Coastal aquifer; Seawater

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Development of high recovery MSF desalination process

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The multi stage flash evaporation process (MSF) is a robust, simple to operate, thermal desalting process widely practiced in Gulf countries for generating drinking water from seawater. This process has also the advantage of being able to cope with poor quality feed waters [1] such as produced waters.

The MSF process has certain limitations that the present research aims to overcome. Typical seawater contains 400 mg/L Ca^{2+} and 2600 mg/L SO_4^{2-} [2]. Calcium sulfate solutions can precipitate this salt in three different polymorphs: gypsum ($CaSO_4 \cdot 2H_2O$), anhydrite ($CaSO_4$) and hemihydrate ($CaSO_4 \cdot ½H_2O$). Fig. 1 shows the solution process path of actual MSF plants on a concentration factor-temperature diagram [3]. It is seen that scale free operation is ensured by operating at an evaporation temperature of up to 120°C and at a seawater concentration factor of up to two. Under these conditions the solution is actually supersaturated with respect to the anhydrite polymorph. The absence of anhydrite precipitation is ascribed to the slow nucleation kinetics of the anhydrite.

Thus, under some poorly defined solution flow and heating conditions, the threshold precipitation limit is governed by the higher solubility limits of the hemihydrate polymorph.

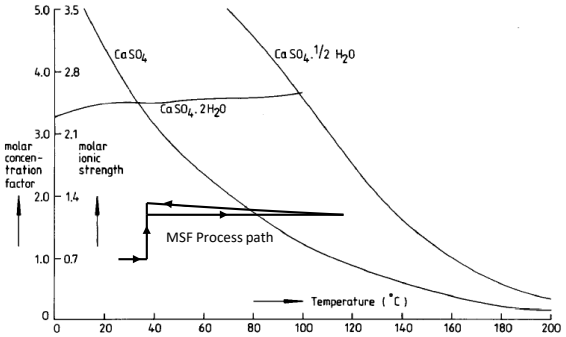

Fig. 1. Solubility diagram of calcium sulfate in seawater with typical MSF operating line

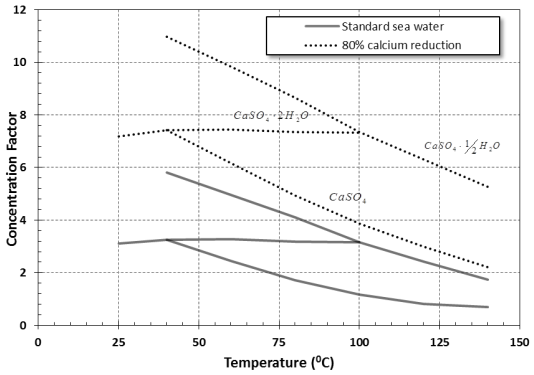

Fig. 2. Solubility diagrams of $CaSO_4$ for standard seawater and for seawater with 80% Ca reduction

Scale free operation at increased concentration factors and higher evaporation top temperatures than currently used, would result in considerable savings through the increased water recovery level and the decreased energy consumption. The basic approach of this project for extending the calcium sulfate solubility limits is partial removal of seawater calcium ions using an efficient electrochemical system. Calcium bicarbonate is precipitated by reacting with the alkali produced at the cathode:

$$Ca^{2+} + HCO_3^- + OH^- \rightarrow CaCO_3 + H_2O$$

The hybrid electrolysis- crystallization system developed in our laboratory [4] overcomes the limitations in the current electro-precipitation systems; in the hybrid system cathode area requirement is reduced by an order of magnitude and the cumbersome need for periodic cleaning of the cathode surface is eliminated.

Fig. 2 shows calculated solubilities of the $CaSO_4$ polymorphs for seawater in which 80% of the calcium has been removed [5, 6]. It is seen that at 120°C the precipitation limit of the anhydrite has been extended to a concentration factor of three and that of the hemihydrate has been extended to a concentration factor as high as six. To determine the actual threshold precipitation limits, a single stage experimental MSF system has been constructed enabling continuous operation. Measurements of permeate flow rates, pressures and solution temperatures at various locations enable detection of the inception of scaling.

Preliminary results of this ongoing research measured at an evaporation temperature of 120°C showed that removal of 80% of the calcium in seawater enabled scale free operation at a concentration factor exceeding four. These encouraging results are being extended by systematic mapping of threshold scaling limits at various temperatures and concentration factors. It is hoped that the results of this project would also advance the use of MSF systems for cost effective treatment of produced waters [7]

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Reverse electrodialysis – reverse osmosis hybrid for seawater desalination using secondary treated wastewater effluent: optimal pre-treatment strategy

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Water scarcity is driving research into alternative waters sources and energy efficient water treatment systems. Seawater is a seemingly endless source of water that can be used for drinking water purposes. However, its high salt content results in a higher energy demand for the desalination system. State-of-the-art reverse osmosis (RO) systems require around 2-3 kWh to produce 1 m³ of drinking water from seawater. Besides the energy cost, the investment for these systems is high, limiting their application in developing regions.

Within the REvivED water project, co-funded by the European Union, Horizon 2020 project, which started in May of 2016, energy efficient and economically viable desalination systems are developed. One of the investigated technologies is Reverse ElectroDialysis (RED) that can harvest the energy from a salinity gradient. If RED is used as a pre-desalination step for seawater RO, energy can be saved in two ways: energy is produced in the RED step and the seawater is already partially desalinated, decreasing the energy demand in the RO step. This is schematically shown in Fig. 1.

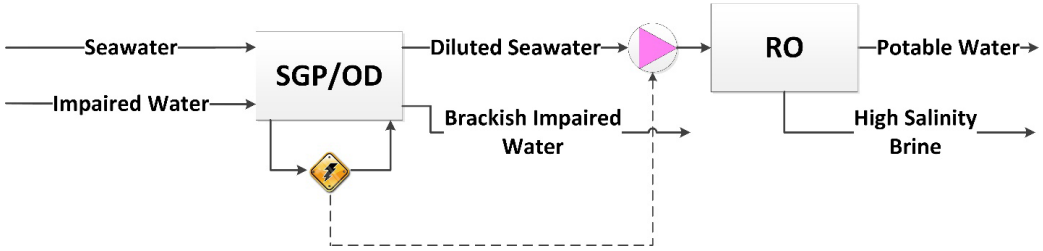

Fig. 1. By coupling RED with RO, energy can be saved by the energy production in the RED step and the lower energy demand in the RO step. SGP = salinity gradient power, OD = osmotic dilution, RO = reverse osmosis.

However, the RED step requires a fresh water source as a sink for the ions coming from the seawater. Impaired water, such as secondary treated wastewater, is usually discharged in the ocean in coastal regions and as such seems a viable source. It comes with its challenges, as the impaired water contains many components that can cause fouling of the membranes. Fouling in RED has received little attention in literature so far[1] and has only focused on fouling using river water, which is a classic fresh water source in RED.

This research focuses on different pre-treatment options for RED using secondary treated domestic wastewater. Two testing periods were executed, with three RED stacks running in parallel for 6 weeks continuously during each period. The stacks contained 5 cell-pairs and were fed with seawater from the North Sea and secondary treated wastewater from Aquafin, Ghent, Belgium. The wastewater was pre-treated using a rapid sand filter, a 100 µm filter, a 25 µm filter or an MF filter. A reference experiment without pre-treatment was run simultaneously. By monitoring the voltage, open circuit voltage (OCV) and pressure drop over the different compartments, the efficiency of the pre-treatment could be determined. At the end of the testing period, the membranes were removed from the stack and analyzed by scanning electron microscopy, X-ray diffraction and biological characterization tests.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement no. 685579.

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Selective desalination of brackish water by electrodialysis for irrigation use

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Given that the ionic composition of desalinated seawater is inappropriate for irrigation because of the lack of essential minerals (calcium, magnesium, and sulfate), brackish water is added back into the desalinated seawater to provide these minerals. However the chloride added back with the minerals increases plant irrigation water consumption, and sodium that is also present sometimes significantly increases the sodium adsorption ratio (SAR). Electrodialysis (ED) was successfully implemented in an automated batch system (0.2 m^2 cell pairs) equipped with monovalent selective membranes to partially desalinate the brackish water from the Mashabe Sade well field, reducing sodium chloride levels while retaining almost all of the sulfate and significant amounts of magnesium and calcium. Choosing appropriate ion exchange materials and conditions resulted in reducing the SAR of treated well water from 12.3 to 2.4.

In order to upgrade marginal waters (e.g. saline ground water) for irrigation, it was necessary to gain a better understanding on the ED separation process between beneficial ions (i.e., Calcium and Magnesium) and other ions such as chloride and sodium. The ions separation study was carried out progressively by examine three types of commercial monovalent selective ion exchange membranes (MIEM); Neosepta CMS/ACS by Astom Co., Selemion CSO/ASA by Asahi Glass, and MVK/MVA by PCCell using two ED cell units (PCCell ED200 and PCCell ED 64). Primarily, these experiments focused on ED performance under various operating conditions of current density and feed ionic strength. The influence of current density was studied on CSO/ASA membranes by operating the ED stack at currents level on the scale between 0.3-1.4 of I/I_{lim}, based on earlier findings of the limiting current. The effect of feed water initial ionic strength was studied on the Neosepta CMS/ACS by assessing separation and membrane selectivity using an artificial solution with significantly higher ionic strength. Furthermore, membrane permselectivity was compared by means of separation efficiency of different pairs of ions namely Cl versus SO_4, and Na vs. Ca and Mg.

It was found that monovalent cation selectivity was significantly more challenging to maintain at lower ionic strengths. Furthermore lowering the current density relative to the limiting current based on sodium concentration, improved monovalent cation selectivity. Highest monovalent cation selectivity was obtained using the CSO/ASA membranes.

Keywords: Monovalent selective, Ion exchange membrane, Electrodialysis, Brackish water, Irrigation

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A study on the design of SWRO-PRO hybrid desalination system

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Introduction

Seawater reverse osmosis (SWRO) desalination technology covers 78% of annual new contracted desalination capacity from 2006 to 2012 owing to its lower electrical power consumption (3-5 kWh/m^3) compared to thermal desalination technologies(up to 18 kWh/m^3) such as MSF, MED, etc. However, existing SWRO desalination systems are still required to be further improved to lower their energy consumption required. Recently, a novel hybrid SWRO desalination system utilizing pressure retarded osmosis (PRO) technology has been studied, which can recover a large amount of osmotic power from concentrated brine with 60,000 to 80,000 ppm of TDS. In this study, GS E&C evaluated and created an advanced engineering approach to the economically feasible SWRO process with PRO implementation. The ultimate goal of this research project is to create an engineering scheme where the SWRO-PRO technology is applied to a seawater desalination process in a gradual scale-up plan from pilot plant to full scale plant. In this paper, more details of the technology implementation feasibility and the pilot study results are discussed.

Keywords: Seawater reverse osmosis (SWRO); Pressure retarded osmosis (PRO); Energy recovery; Power density

Materials and methods

To investigate optimal operational conditions in a PRO system, we have performed PRO evaluation test using a 20 m^3/d PRO pilot plant with 4, 8 inch TFC spiral wound membrane module under a wide range of operational conditions. The schematic of the pilot plant is shown in Fig. 1.

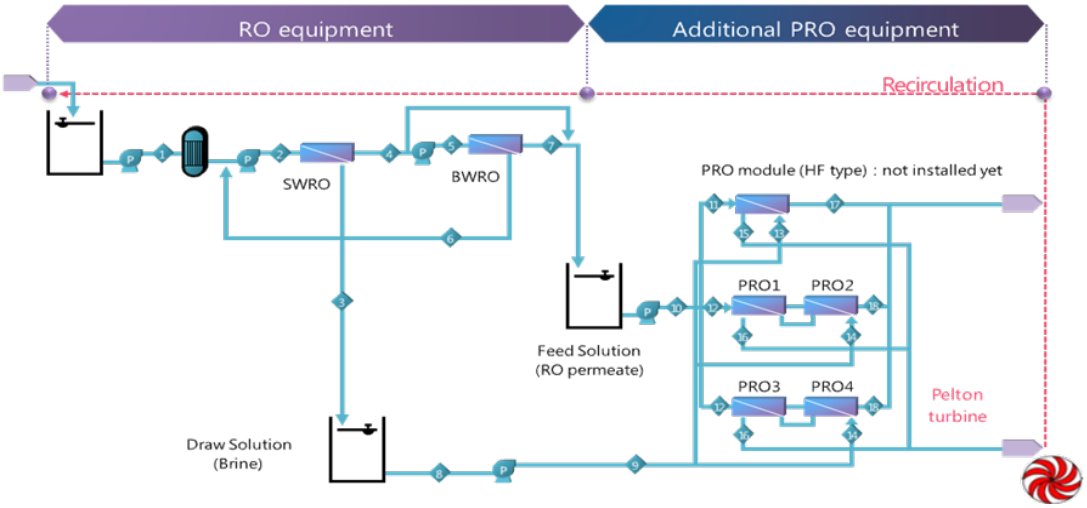

Fig. 1. Schematic of SWRO-PRO pilot plant (20 m^3/d)

Results and discussion

Many test parameters such as pressure, concentration and flow rate of draw solution (DS) and feed solution (FS) have important been regarded to optimize a longterm operating condition during SWRO-PRO pilot test. In order to realize further high power density than that of present TFC SW membranes, the research of new spiral wound membrane or hollow fiber membrane should be conducted.

Conclusions

Those results on this project research indicate that a commercial PRO plant for energy recovery from SWRO brine will be available in the near future.

Acknowledgements

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Membrane production quality control for improved performance of desalination

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A new plant MEMBRANIUM (RM Nanotech) producing reverse osmosis, nanofiltartion and ultrafiltration membrane flatsheet and spiral wound filter elements was commissioned in September of 2013 based on the increasing demand in membrane materials for different types of sea water desalination and drinking water production as well as on modern requirements of industrial water treatment.

The reverse osmosis spiral wound membrane elements made by RM Nanotech meet all general requirements on type, dimensions and areas of application.

The whole manufacturing process is carried out inside the facilities with strict control and maintaining of climate conditions (temperature, humidity) based on the importance to stabilize conditions of membrane flatsheet production at all stages.

Today RM Nanotech manufactures two type of spiral wound membrane elements for sea water desalination, which differ in flow rate (10,500 GPD and 8,000 GPD), salt rejection (min 99.55% and 99.6%4 nominal 99.7% and 99.8%) and Boron rejection (88% and 92%) respectively. Increasing rejection and thermal stability of the membrane has been achieved due to the additional cross-linking of selectibe polyamide layer of a composite membrane.

Control of composite membranes (including those for sea water desalination) production is carried out mostly on-line by IR- spectroscopy for monitoring of concentrations of crosslinking agent or its mixtures. This has been made possible as a result of identification of proton's absorption band of aromatic ring of bi- and-trifunctional acid chlorides.

Due to the fact that the performance of sea water desalination composite reverse osmosis membranes is determined significantly by the quality of ultrafiltration support we paid a lot of attention to its manufacturing without possible micro defects which control is performed using multipoint diffusion test (used while microfiltration membranes production) with device Sartochek-3, cell diameter 142 mm. Unfortunately, standard performance characteristics of ultrafiltration support such as flow on deionized water and rejection on globular proteins are not tools of the objective control of the above mentioned micro defects.

Particular attention is paid to the application uniformity and stability of the water solution amine component retention on the surface of ultrafiltration support which is largely driven by its hydrophilic-hydrophobic balance during composite membrane production. That is why the researches of the dependences between hydrophilic property of ultrafiltration support and performance characteristics of final composite membrane drive us to the understanding of wetting angle constant control which is accomplished by utilizing special device and software.

Distinctive feature of our spiral wound elements production is their 100% testing on model solutions and the inclusion of this data in technical specification of each module. This approach provides additional advantages for the end users. When loading the membrane elements in pressure vessels they can do it in a certain order to optimize the operation of each element and to extend its running time before replacement.

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Deposition of calcium and magnesium from RO concentrate by means of seed crystallization and production of softened water for technical purposes

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Existence of reverse osmosis concentrate effluents often constitutes a problem that limits industrial applications of this technique for drinking and industrial water supply. The article presents results of development and field testing of new proposed technique that removes calcium carbonate and magnesium hydroxide from RO retentate streams using seeding techniques. This new concentrate utilization technique uses RO membrane unit operated in circulation mode. Seed crystals of calcium carbonate and magnesium hydroxide are added to the circulating concentrate flow. Calcium and magnesium deposit on the seed crystals due to their concentrations increase in membrane channel. The test unit is tailored with membrane modules having an "open channel" that are not fouled with seed crystals suspended in circulating concentrate stream. The seed crystallization procedure provides up to 90% removal of hardness and alkalinity from RO concentrate and decrease concentrate TDS due to withdrawal of alkalinity as calcium carbonate precipitation. Concentrate thus becomes softened water with decreased TDS that can be blended with product water to produce technical water used for cooling or heating, as well as drinking purposes. The developed process does not require softening reagents that are used in stoichiometric amounts to deposit calcium carbonate and magnesium hydroxide during chemical softening. Sodium hydroxide is used only to produce seed crystals and to maintain pH of feed water at value 8.8-9.0. Consumption of caustic by new seed crystallization process constitutes 2-4% of stoichiometric amount.

Results of experiments are presented that show dependencies of calcium and magnesium ion removal efficiencies on various process conditions: recovery, feed water pH, presence of antiscalants, and amount of added seed crystals. The developed technique can be efficiently used to "hide" RO concentrate streams at the existing power industries and RO/NF facilities that produce drinking water.

Keywords: Concentrate treatment, Reverse osmosis, Seed crystallization, Water softening, ZLD

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Organic-inorganic ion-exchangers based on weakly acidic resin for removal of toxic components from water

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Organic-inorganic ion-exchange materials are more attractive comparing with polymer ones due to their considerable protonic conductivity under low humidity conditions, stability against fouling with organic substances and bacteria, selectivity towards d-metal ions etc. They are used for low-temperature fuel cells, electromembrane separation, ion exchange. However, some processes which require organic-inorganic materials involve organic solvents. They are able to change structure of the polymer constituent (matrix). Inorganic particles can be located in different pores of the matrix: in clusters, empties between gel fields, structure defects. Thus, particles location results in transformation of porous structure of the swollen polymer. The aim of the investigation was to evaluate the influence of the modifier particles on functional properties of the ion-exchanger.

Organic-inorganic ion-exchangers have been synthesized by modification of weakly-acidic macroporous commercial ion-exchange resin, such as *Dowex MAC-3* (Dow Chemical). Multiple modification of amorphous resins with nanoparticles of zirconium phosphate (ZrPh) in aqueous media provides deposition of nanoparticles from $ZrOCl_2$ solution. The materials were investigated by scanning and transmission electronic microscopy, standard contact porosimetry using water as a working liquid and NMR ^{35}P spectroscopy.

Non-aggregated ZrPh nanoparticles, which are stabilized by walls of mesopores of the polymer matrix (clusters) were found. Aggregates are located in voids between gel regions, agglomerates are placed in structure defects. Polymerized phosphates are probably formed in clusters and channels. The isotherms of water adsorption were analyzed, a change of swelling pressure caused by modifier was found. The amount of water molecules at counter-ions of functional groups was calculated.

The samples were used for removal of Cd^{2+}, Ni^{2+} and Cu^{2+} ions as well as toxic dyes from water, which contains also hardness ions and organics. Sorption isotherms were modelled using Langmuir, Freundlich and Dubinin-Radushkevich approaches. As shown, modification provides increase of a volume of micropores, a size of which is comparable with a sizes of sorbed species. The composites show higher exchange capacity under batch conditions as well as higher break-through capacity towards toxic components than the pristine resin. Better selectivity was also found. Moreover, the organic-inorganic ion-exchangers are stable against fouling with organics. The modified samples require lower amount of reagents for regeneration, they can be regenerated practically completely. This allows us to increase a period for water purification, to decrease consumptions of the reagents for regeneration and water for washing of the ion exchange column. Moreover, the complete regeneration provides multiple usage of the organic-inorganic resins, especially for daily living needs.

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Six-stage solar multi-effect humidification dehumidification desalination process plotted from pinch analysis

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This paper presents a six-stage solar multi-effect humidification dehumidification desalination process plotted from pinch analysis. The sketch of six-stage solar multi-effect humidification dehumidification desalination process is given. The solar vacuated tube collector is employed in the desalination system, multi-effect humidification dehumidification desalination (HDD) processes are plotted six different temperature range according to pinch technology. The temperature ranges are 90-82°C, 82-74°C, 74-65°C,65-55°C, 55-45°C, and 45-30°C. The mass flow rates of dry air in the six stage desalination units are different. The pinch analysis charts are given. According to the pinch chart, the energy recover rate could reach 0.89 when working temperature range is from 30 to 90°C and the temperature difference between the spraying seawater and the outlet of the cooling water is about 6°C. The energy recover rate could overreach 0.9358 if that temperature difference reach 4°C with working temperature range from 30 to 100°C. The research proves that the multi-effect HDD has much room to be improved.

Keywords: Solar desalination, HDD, MEH, Pinch technology

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Experimental research of a multi-basin type desalination installation

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This paper presents an experimental research of a multi-basin type desalination installation. The purpose of the multi-basin type desalination installation experiment is to ascertain the ability of production water using hot seawater in the long nightmare. The sketch of a multi-basin type desalination installation is given. The mount of water obtained from one stage, two stages, three stages, and four stages is given, respectively. Leakage of wet air inflect the results heavily.

Keywords: Solar desalination, Basin type

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Comparing the impact of spacer-biofouling in forward osmosis and membrane distillation by lumped parameter modeling

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Reclamation of highly contaminated water has prompted the need for novel membrane-based technologies with low biofouling propensity such as forward osmosis (FO) and membrane distillation (MD). Permeate flux in FO is driven by an osmotic pressure gradient across semi-permeable membranes, whereas in MD water vapor permeates across hydrophobic membranes due to a thermally induced vapor pressure gradient. The role of spacers in membrane modules consists in maintaining a flow path between adjacent membranes as well as inducing turbulence. Turbulent flow enhances flux in FO by promoting mass transfer, while in MD flux is increased by augmenting mass and heat transfer. Spacers also impact biofouling development, a critical hurdle in membrane-based reclamation of wastewater with high fouling potential. The goal of this study is to develop a spatially lumped parameter model describing the combined effects of spacer-biofouling on heat and mass transfer and consequently on permeate flux in FO and MD systems. Biofilm properties such as porosity, tortuosity and thickness are applied to compute transfer coefficients for heat and mass transfer equations, influencing concentration and temperature polarization. Comparison of spacer-biofouling impact in FO and MD systems was done by modeling different scenarios in which biofilm and spacers were absent or present. The simulations indicate that the distinct driving forces cause a variety of spacer-biofouling effects that lead to differing impacts on permeate flux of the two systems. Our results shed new light on the application of spacers to enhance the suitability of FO and MD systems for reclamation of highly impaired water streams.

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Pressure membrane separation of peat components

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Peat used in natural medicine is called balneo peat or therapeutic mud. It belongs to the peloids, the geological formations with a high content of organic matter and mineral salts. It contains a minimum of 75% organic compounds in the dry matter. Poor thermal conductivity and simultaneous high heat capacity provides a deep and prolonged body heating which in turn leads to the effective metabolism products removal from the body. Moreover, increased temperature extends blood vessels allowing therapeutic compounds of mud to penetrate body more efficiently.

Biologically active components present in the balneo peat mainly include humic acids, fulvic acids, sugars, proteins, bitumens and humines. They act in a synergistic manner. The unique physical

parameters and the ingredients contained in the balneo peat influence its properties such as anti-inflammatory, astringent, bacteriostatic and bactericidal ones.

The aim of the study was the concentration of the active ingredients of the balneo peat with the use of ultrafiltration, ceramic and polymer membranes. Research was preceded by a sedimentation in a centrifuge (5000 rpm, 10 min) that allowed to keep a relatively stable permeate stream during filtration. Optimal conditions of the process were chosen on the base of experimental data.

The membrane having a coefficient of cut-off 45 kDa provides retention at the level of 0.96 without any loss of the mud reducing compounds and the compounds with the α-amino group. Their presence in a retentate stream and absence in a permeate stream was confirmed by specific colorimetric assays.

Keywords: Membrane separation; Membrane selection; Permeate flux

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Does the membrane zeta potential approach zero at high salinity?

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In the past decade the zeta potential has gained importance for the surface analysis of solid samples such as membranes of various kinds. Most of the membrane zeta potential data presented in the literature refers to the analysis of flat sheet ultrafiltration and thin-film composite nanofiltration and reverse osmosis membranes. These membranes play a major role in the process of seawater and brackish water desalination. While membranes get exposed to high salinity conditions when in use, the membrane's zeta potential is primarily determined in the presence of dilute aqueous solutions with an ionic strength in the range of 0.001-0.01 mol/l. Although a correlation of the zeta potential obtained at low ionic strength with membrane performance at high salinity is feasible, it is still desirable to obtain the information about zeta potential and thus the membrane surface charge under environmental conditions.

For solid material surfaces the zeta potential is obtained from the measurement of the streaming potential. With increasing ionic strength the streaming potential decays almost in a double-exponential manner. This dependence limits the applicability of a streaming potential analyzer for the determination of the zeta potential at high salinity conditions. The upper limit for the ionic strength is typically in the range of 0.1 mol/l and thus almost one order of magnitude below the salinity of seawater. On the other hand the zeta potential may be determined in a range of ionic strength covering 4-5 orders of magnitude starting with ultrapure water and proceeding towards 0.1 mol/l. It thus seems straightforward to extrapolate the zeta potential to the ionic strength corresponding to seawater and even brackish water salinity from experimental data obtained at lower concentration.

We demonstrate a new approach for the estimation of the zeta potential at high ionic strength. With this approach we obtain negative zeta potential data for a series of TFC membranes for forward osmosis at I > 0.1 mol/l, which seem to level off. The extrapolated data contradicts the model of the electrochemical double layer (EDL), which predicts that the zeta potential approaches

0 mV at high ionic strength. We conclude that the EDL does not suitably describe the membrane-water interface at high ionic strength and explain the equilibrium zeta potential by a saturation of (hydrated) counter-ions in the stagnant layer of the EDL due to steric hindrance.

Keywords: Surface charge, Membrane characterization, High salinity, Nanofiltration, Reverse osmosis

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Industrial effluents reuse via advanced membrane technology – unique projects in Israel

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The reuse of wastewater gradually become a common practice in many countries since it offers benefits in water saving and compliance with environmental regulations.

Domestic wastewater is mainly reused for agricultural irrigation and in fewer cases for industrial, domestic and potable uses. While domestic wastewater treatment process is quite standardized around the world and differ mainly in capacity and engineering design, this is not the case for industrial effluents.

Industrial wastewater is usually treated prior to discharge to meet local environmental regulation, but in growing number of cases it is further treated for reuse, mostly for applications within the plant. After proper treatment, reused wastewater can be utilized by the factory for cooling or boilers makeup, manufacturing processes, landscaping and more, thus saving significant portion of the plant's fresh water consumption. At the same time, effluents reuse reduces the effluents volumes for discharge thus assists in meeting regulatory demands and saves discharge costs. However, wastewater quality changes from one industry to the other, and often between factories in the same industry, so the treatment process must also be adapted for each case individually. Industrial wastewater sometimes contains high organic, salts, metals and other contaminant which often require complex multi-stage treatment. Also, since water used for industrial applications must be at specific quality, advanced treatment technologies must be used for industrial effluents reuse. This often includes membranes and other desalination technologies.

This paper presents two distinctive projects, both designed and supplied by RWL Water in Israel, where industrial wastewater from agro-chemical and power plant, are being treated for reuse, using membrane technologies. These two examples demonstrate the need for specific process and engineering design to meet the requirements and limitations of each industrial reuse project.

Adama chemical factory (formerly Machteshim-Agan) is located at Neot Hovav industrial compound, ~10 km south of Beer Sheva, Israel. It is a major manufacturer of agro-chemicals, mainly herbicides and pesticides. The Adama factory includes several production facilities that manufactures various streams of wastewater which includes high salinity and complex organic materials. For decades, the entire wastewater form the factory, and others in the Neot Hovav complex, were treated at a central biological plant and sent for evaporation ponds, which created major environmental problems. In the last ~10 years, each factory is required to treat its own wastewater, prior to discharge to the ponds, with strict quality and quantity monitoring by the authorities. To comply with this requirement, Adama installed in 2008 an MBR plant for its entire wastewater capacity, followed by filtration and 2 x 50% RO systems which have been designed after extensive pilot trials.

The RO systems receive MBR treated effluents and desalinates it for reuse and for reduction of bribe discharge to the evaporation ponds.

Table 1:
Operating cases for the RO at various feed conditions in Adama reuse plant

Case 1:	Description	Feed	Total permeate	Total brine
12.6 lmh	Flow rate [m^3/h]	75	48.75	26.25
	Pressure [bar]	37.68	2	2
	TDS [ppm]	20000	232.32	60300
	Conductivity [µS/cm]	31300	363	94200
Case 2:				
9 lmh	Description	Feed	Total permeate	Total brine
	Flow rate [m^3/h]	75	41.25	33.75
	Pressure [bar]	36.21	2	2
	TDS [ppm]	27,000	324.43	61,251
	Conductivity [µS/cm]	42,200	506	95,700
Case 3:				
9.6 lmh	Description	Feed	Total permeate	Total brine
	Flow rate [m^3/h]	75	30	45
	Pressure [bar]	40.51	2	2
	TDS [ppm]	35,000	318.34	60,797
	Conductivity [µS/cm]	54,700	497	95,000
Case 4:				
6.6 lmh	Description	Feed	Total permeate	Total brine
	Flow rate [m^3/h]	75	30	45
	Pressure [bar]	36.05	2	2
	TDS [ppm]	35,000	448	60,711
	Conductivity [µS/cm]	54,700	700	94,900

Wastewater fed into the reuse system is saline and organic loads are still high even after the MBR, with large variability. Such feed water poses major challenges for RO desalination design and required a robust high-pressure system which can maximize recovery (i.e brine concentration). The RO operates on site continuously since 2010 despite relatively high frequency of cleaning and cartridges replacement. It produces approx. 2,100 m^3/d of desalinated water at ~60% recovery. System uses Dow seawater RO membranes and Fedco turbo-charged inter-stage boosting to maintain high permeate quality and minimize energy use. Given the high maintenance requirement and the need to allow operational flexibility, client decided in 2014 to double the RO capacity by adding two extra skids. The new RO trains are designed based on experience from operation of the initial RO units. To cope with the large salinity range (20-35 g/L TDS) it includes Dow low-fouling seawater membranes, can operate at variable fluxes (6-13 lmh) and two parallel turbo-charge boosters. They also include dedicated automatic flush and CIP systems. Client is also considering options for improving pre-treatment to further improve RO feed quality and further lowering maintenance frequency and OPEX.

Fig. 1. Adama RO units (new trains)

The Ashalim thermo-solar power plant in the Negev desert of Israel, is built as a BOT by Alstom/GE & Brightsource (Megalim JV), and planned to be operated in 2017. It is the 1st thermo-solar field in Israel and the largest solar power plant ever built in the country. It will use Concentrated Solar Power technology (CSP, with mirrors and 'sun tower') to produce high pressure steam which will be used in power turbines. Overall the plant has a capacity of 212 MW.

Fig. 2. The Ashalim CPS power station (right) and water treatment system (left) during construction

In order to save fresh water while supplying the required demineralized makeup water for cooling and steam boilers, RWL Water designed and supplied to Alstom/GE a containerized system for reuse of cooling-towers blow-down and production of ultra-pure water (UPW). Brackish blowdown wastewater is continuously discharged on-site and if not reused must be disposed via evaporation ponds. Therefore reusing it in the power plant can both save valuable fresh water and reduce discharge volumes.

The Ashalim reuse system is designed to take 40 m^3/hr (960 m^3/d) of blow-down effluents and treat it via multi-stage membrane process producing 20 m^3/h of cooling makeup (after UF and pass-1 RO), and additional 10 m^3/h of ultra-pure water (UPW) for steam boiler makeup, after 2nd pass RO, GTM degassing and CEDI polishing. The entire 2 x 100% process is installed in several shipping containers for redundancy and minimal site works.

The two projects demonstrate the possibility to treat various effluents in different industrial operations while creating value in reducing water use and environmental impact. They also show how specific process and engineering design are required in different effluents reuse systems to deal with site-specific challenges and requirements. This approach will be necessary for successful reuse schemes as the demand for beneficial reuse of industrial wastewater increases globally.

Keywords: Industrial wastewater, Reuse

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Proof of design and system balancing through use of transient pressure monitoring

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"Water hammer" is a serious concern for the municipalities today in order to insure water quality and to keep fluid distribution pipelines efficiently operating consistently without expensive downtime. Whether the application is pump station control, pressure/flow balancing or age of water; a systematic approach is needed to prevent potentially catastrophic events from occurring. By utilizing computer surge modeling software and transient monitoring equipment, the causes and effects of water hammer can be identified, analyzed, and resolved through a system design solution that may involve pump control valves, surge vessels, air/vacuum valves, surge anticipatory valves, control valves and check valves.

Site operators and managers have not traditionally had the tools necessary to assess what specifically happens when the pump(s) start/stop or when a valve is suddenly closed with the pump(s) running. The mathematical calculations for pressure surge effects are quite extensive and only through computer surge modeling can this process be conducted quickly and accurately. In conjunction with transient pressure monitoring equipment that can record data at over 100 times per second, municipal personnel now will know exactly what is happening with their pumping system and how to resolve it safely and comprehensively.

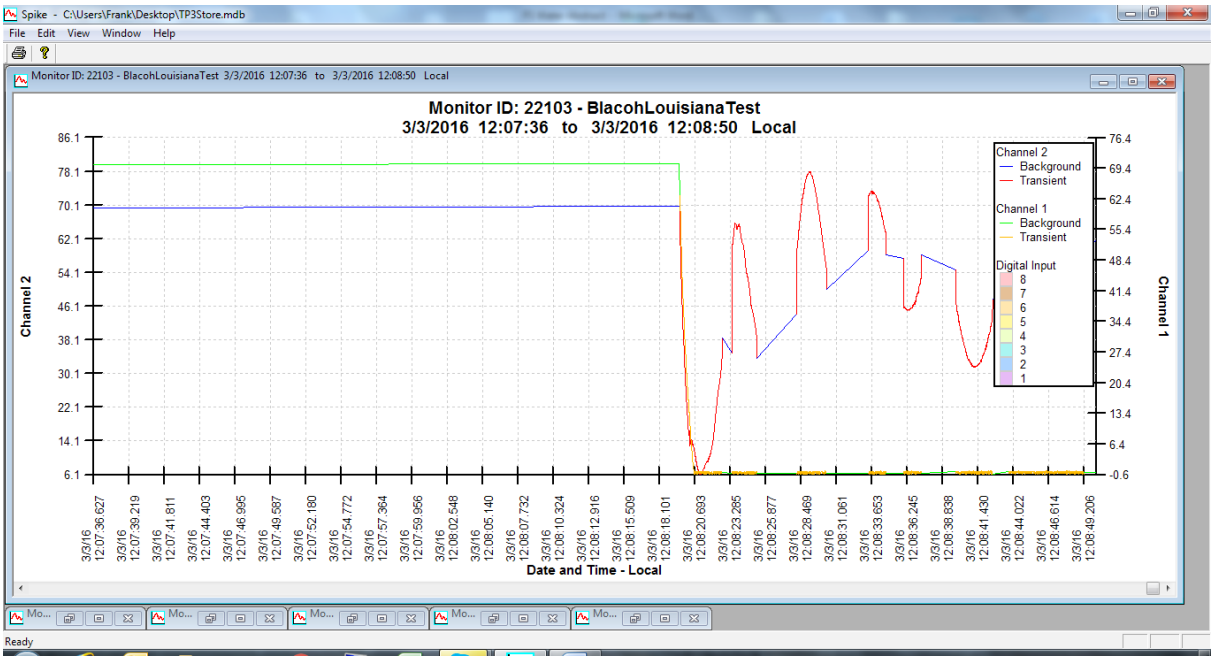
By incorporating both computer surge modeling and transient pressure monitoring at the time of identifying that a problem exists and finally at the start-up/commissioning of mitigation equipment, the selected solution can be confirmed as performing to expectations via this "*proof of design*" methodology. The mitigation equipment chosen (vessels, valves, etc.) can be tested and quantifiably measured with reporting results available the same day via email in text or graphical format.

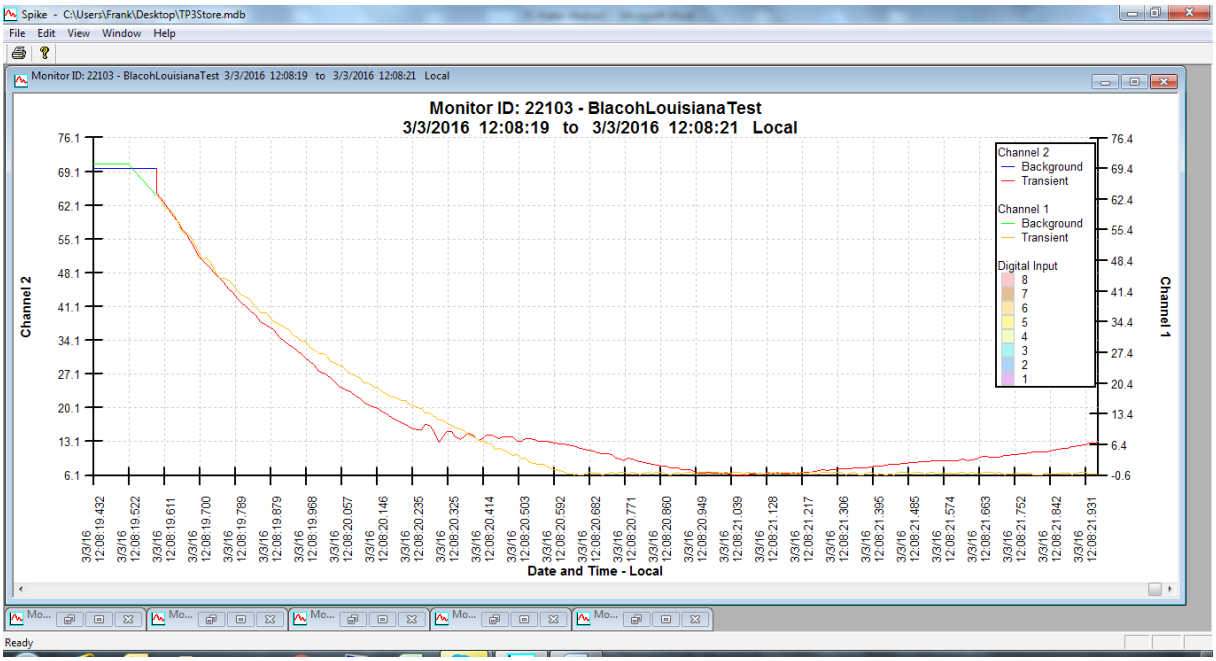
A detailed computer surge analyses study of your pump stations and distribution system followed by "*proof of design*" of equipment during startup and commissioning shall avoid hazardous and costly problems. Each step in this process will provide clarity on what can and likely will happen when surge events are not properly identified and inaccurate data leads to incorrect equipment being selected and installed. This study provides a cautionary example of the dangers, cost and bad publicity that can follow when pressure surge events are not treated seriously enough with the modeling and monitoring solutions that are available today.

The pump trip can cause a negative transient vacuum wave below atmospheric pressure affecting the entire system. The transient monitoring system shall alert the operator of any transient pressure wave which drops below the minimum operating pressure of the municipality. The SurgeWave employs a patented system of dynamic pressure transducers and digital technology to monitor pipelines for indefinite periods of time. When a transient such as a pressure surge, pressure spike or water hammer event is detected, the system records the high speed data at 100 times per second. When the pressure drops back to steady state, the system records the running average which is defined upon startup. The SurgeWave can record multiple devices to record transient pressure, flow, pressure, level, air/vacuum breaker movement and pump speed.

Below is an example of a vertical turbine pump trip. The liquid filled pressure gauge showed the steady state pressure at 70 psi and the low pressure wave pressure dropping to 50 psi. The SurgeWave transient monitoring computer system recorded the steady state pressure at 60.9 psi

and the low pressure wave pressure dropping to 6.1 psi which is below the minimum allowable pressure for a potable water system. The differential pressure across the check valve was 0.2 psi. Channel 1 is upstream of check valve and Channel 2 is downstream. When the pump tripped, the upstream pressure of the check valve dropped to -0.6 psi. I properly sized pump control valve can be modeled to keep the change in velocity from dropping below the minimum operation pressure. A Surge Vessel would have to be added to give energy to maintain minimum operating pressures during a power failure. Once the computer surge model confirmed the surge control devices, the SurgeWave would be used to calibrate and verify the system design.





Keywords: Comprehensive Fluid Integrity Solutions through computer modeling and field monitoring

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The effect of performance parameters and optimization of operating conditions for spiral wound PRO modules

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Developments in desalination technologies have focused and will continue to focus on reducing the overall energy consumption for fresh water production. Among the available options, the reverse osmosis (RO) membrane process has proven to be the most energy efficient commercial technology compared to traditional thermal desalination. And as such, the RO process has dominated the desalination market for the past decade. As alternative technologies to further reduce energy consumption continue to mature, the RO/PRO hybrid process is considered as the most logical next step for future desalination. The PRO process aims to harness the osmotic energy difference of two aqueous solutions separated by a semipermeable membrane. By using the concentrated water (RO brine) discharged from existing RO plants, the PRO process can effectively exploit a greater salinity gradient to reduce the energy cost of processing concentrated water. However, in order to use RO brine as the draw solution, PRO membrane must have high water flux and enough mechanical strength to withstand the high operational pressure (about 7.0 wt% and 20 bar).

This study investigates the development of a thin film composite PRO membrane and spiral wound module for high power density. Also, the influence of membrane backing layer on the overall power density was studied using the characteristic factors of PRO membranes. The design of the PRO membrane was optimized based on membrane characterization analysis. Among the various membrane characteristics, water permeability (A, $L/m^2/h/bar$), salt permeability (B, $L/m^2/h$) and membrane structural parameter (S, mm) were the main focal points of this study, with the reduction of S value being the key factor. The TFC PRO membrane was fabricated by interfacial polymerization of polyamide on a polysulfone support layer. The support layer was prepared by casting polysulfone with an additive onto either nonwoven fabric or porous fabric. Compared to the non-woven fabric backing layer, porous fabric backing layer was found to be more effective in improving power density. The PRO membrane made with the nonwoven fabric layer showed a power density of 8.6 W/m^2 while the one made with the porous fabric layer showed 17.1 W/m^3 using 7.0 wt% NaCl as the draw solution with the operating pressure at 20 bar. In addition, the S value was reduced from 2.1 mm to 0.9 mm when porous backing layer was applied to the PRO membrane.

Finally, the performance test of an 8-inch spiral wound module made with the porous fabric PRO membrane was carried out under various operating conditions (i.e. hydraulic pressure, flow rate, temperature). As the flow rate and temperature increased under the same hydraulic pressure, the PRO performance increased due to the minimization of ICP/ECP on the membrane surface. On the other hand, it was confirmed that the PRO performance decreased along with increasing hydraulic pressure due to the flow pressure on the spiral wound module. For a high performance PRO system, in order to optimize the operating conditions, it is highly recommended that the flow pressure be minimized while the flow rate is maintained at a high level.

Keywords: Pressure retarded osmosis, Thin-film composite membrane, Power density

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Innovative evaporator geometry for desalination applications and its promising thermal performance

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Multiple-effect distillation (MED) without and with thermal vapour compression (MED- TVC) and evaporation with mechanical vapour compression (MVC) are widely used for the production of drinking water and process water from seawater. In today's land-based MED, MED-TVC and MVC plants, horizontal tube falling film evaporators are commonly employed. Falling film evaporators are known to exhibit high overall heat transfer coefficients under clean surface conditions, i.e. without scale being formed on the heat transfer surface.

In view of growing cost of energy and material as well as steadily increasing demands for efficiency and resource conservation, there has been an increased emphasis on the optimal use of energy and efficient heat transfer equipment has become of vital importance. Enhanced heat transfer and thermal performance, minimization of crystallization fouling and cleaning and maintenance simplicity are main future goals. Therefore, alternative geometries of the heat transfer surface are in the focus of development.

An innovative evaporator geometry based on folded corrugated titanium plates is being developed by PLEAT Evaporator AS in Norway. The thin plates are folded in such a way that pockets with a small height and a small slit width are formed whereby vapour is condensing in the pockets on the lower side of the plate, while saline water is evaporating in the pockets on the upper side of the plate. Novel liquid-liquid heat exchangers based on similar folded corrugated plates are already used for cooling purposes with seawater in marine applications. They are easy to clean and maintenance-friendly.

A small test rig was installed to study the heat transfer and the thermal performance of the new evaporator geometry. Various test runs were conducted in order to determine the overall heat transfer coefficient and the heat flux at various driving temperature differences.

In order to compare the thermal performance metrics of the new evaporator geometry with a conventional evaporator, a simulation model of a horizontal tube falling film evaporator was compiled. The model is based on energy and mass balances and heat transfer correlations for the condensation inside the tubes as well as for the evaporation on the outside of the tubes. It enables the calculation of the overall heat transfer coefficient and the heat flux at various process conditions. Firstly, a sensitivity analysis within the operating range of horizontal tube falling film evaporators were performed in order to gain a better understanding of the relationships between input and output variables in the model and to evaluate the modelling results in presence of uncertainty. In a second step, the overall heat transfer coefficients and the heat fluxes were calculated for a horizontal tube falling film evaporator at the same process conditions at which the measurements were performed in order to create comparable conditions with the measurement results.

The stage of development of the innovative evaporator with folded corrugated plates is shown and the heat transfer processes occurring on the condensation and on the evaporation side are

examined. Promising experimental results of the new evaporator geometry are presented and compared to simulation results obtained for horizontal tube falling film evaporators.

Keywords: New evaporator geometry; Heat transfer; Multiple-effect distillation

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Analysis of farmers' attitude toward irrigation with desalinated brackish water in Israel and Jordan

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Desalination has been proposed as a more sustainable alternative to brackish water irrigation in arid areas such as the Arava Valley in Israel. We explore the perception of 128 farmers in the Central and Northern Arava Valley regarding limiting factors in desalination, policies to address them, and willingness to irrigate with desalinated water. Most respondents are aware of the electro-conductivity of their irrigation water (95%) and are concerned about its increase over time (89%). About half is either planning to switch to desalinated water (18%) or intends to do so over the next few years (32%). Economic reasons are identified by 87% of respondents as the main limiting factor in the transition. The results of an ordered logistic regression show that water electro-conductivity, cultivation of at least one salt-sensitive crop, and attribution of high importance to water saving in agriculture are the main factors affecting the willingness to switch to desalinated water. When asked about their preferred type of financial assistance in transitioning to desalinated water, partial coverage of construction costs is preferred over assistance in switching to new (salt-sensitive) cultivations. Overall, the results support the notion that the agricultural sector in the region is mature for transitioning to irrigation with desalinated water.

Keywords: Agriculture, Brackish water, Innovation, Israel, Membrane desalination

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Numerical simulation for designing horizontal falling film evaporator for desalination process

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This paper presents a methodology to analyse a horizontal falling film evaporator in a pilot scale desalination unit combined with solar energy for a production capacity of 1.5 L/d of fresh water.

Horizontal falling-film evaporation is an effective design for evaporators with small temperature differences, low evaporation temperature and high heat transfer coefficient at lower flow rates [1, 2]. The evaporator consists of three columns and four rows per column of horizontal tubes,

where the heating oil flows inside the tube bank and the seawater flows as a falling film on the tube outside and it is heated and water vapour is generated. A numerical model of the horizontal falling film evaporator was developed that divided the evaporator into three different thermal elements: the flow inside the tube, the heat conduction in the tube wall and the falling film seawater flow. The modelling equations are given at steady-state conditions and based on mass and heat balances, heat transfer equations, thermodynamic and physical properties of each stream. The methodology is programmed in C and is used for resolution of the algorithm, in order to optimize the efficiency of the evaporator and consequently the energy consumption to predict the thermal and fluid dynamic behaviour of the system.

The impact of important factors such as the diameter of tubes, the heating medium temperature and inlet brine temperature on the performance ratio and production capacity has been studied to design more efficient heat exchangers, which simultaneously would help to improve the efficiency in the desalination unit. From this analysis, several suggestions and criteria for horizontal falling film evaporators design and optimization could be done.

Keywords: Desalination of seawater, Evaporation, Thermal behaviour, Falling film distribution

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Effect of cross-flow velocity, oil concentration and salinity on the critical flux of an oil-in-water emulsion in microfiltration

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Microfiltration is an attractive means for treating oily wastewater, especially when the size of the oil droplets are micrometer-sized since the conventional techniques become deficient. A systematic study on the critical flux of oil-in-water emulsion, which behaves differently from other colloidal foulants with regards to deformation, coalescence and splitting, has not been carried out to date. This was the goal of the current study, which employed the direct observation through the membrane (DOTM) technique to characterize the critical flux of oil-in-water emulsions of various concentrations, at various cross-flow velocities (CFV) and salt concentrations. Five observations can be highlighted here. Firstly, the oil droplets with a mean droplet diameter of approximately 5 µm exbited critical fluxes equal to or greater than latex particles of 10 µm. This is likely due to the twin effects of membrane oleophobicity effecting drop capture and the presence of a droplet size distribution with larger drops that can enhance the shear-induced diffusion of the average drops. Secondly, the critical flux values did not agree with the model that is valid for the size range the

mean droplet diameter falls in, but instead agreed with the model adapted for smaller particulate foulants. Thirdly, the increase in the critical flux with CFV was more significant for the lower oil concentration. Fourthly, a striping phenomenon was observed at higher oil concentrations and lower CFV values. Striping was not observed for latex particles. Fifthly, the critical flux decreased with salt concentration. These findings highlight the unique fouling behavior of oil-in-water emulsions in microfiltration.

Keywords: Microfiltration; Direct observation through the membrane (DOTM); Critical flux; Oil-in-water emulsion; Fouling

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Halophyte remediation of dairy farm wastewater

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New regulation in Israel requires that "hard" sewage producers treat wastewater onsite before release to the municipal sewage line. The main parameters under regulation are organic matter, solids, nitrogen and phosphorous. Certain heavy water footprint industries such as olive mills, wineries and dairy farms stand out because their onsite treatment options are limited. Previous technological developments at MIGAL include nano-composite modified clays for benign and rapid solids removal, and aerated solid state bioreactors for organic matter decomposition. The combination of these innovations resulted in a compact onsite treatment system for "hard" wastewater of wineries, to the point that onsite reuse for irrigation can be considered, thus allowing further progress towards sustainability. A crucial, as yet unaddressed aspect is the sodium content, conventionally removed by energy-intensive reverse osmosis or distillation. Sodium concentration above 150 mg/L renders treated wastewater unfit for irrigation, while in dairy farms the sodium content can range between 290-1000 mg/L. We present a combination halophyte and ion exchange wetland for removal of sodium from the treated wastewater. The sodium accumulating plants, collected from waterlogged saltmarsh in Israel, are currently under propagation at a specialized nursery constructed for this purpose at the Neot Mordechai Experimental Research Station. In parallel, natural zeolites are undergoing a battery of sodium exchange tests in a bench-top setup, using treated wastewater spiked with sodium. Preliminary results indicate that the plants can contain up to 5% sodium in their leaves and that the zeolite can remove 40% of sodium in a single pass, independent of flow rate. The salt-remediation wetlands will begin operation at a pilot scale in the Spring, at a dairy farm located in Kfar Blum. If successful, the model will be scaled up to include the treatment of the entire dairy farm waste stream. Options for onsite reuse for agriculture will be considered as well.

Keywords: Halophytes, Biodesalination, Onsite treatment and reuse

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Algae based wastewater treatment for energy saving and resource recovery

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Aquanos Energy Ltd. has developed a unique wastewater treatment technology and system, which produces a high-quality effluent while utilizing a fraction of the energy required by conventional wastewater treatment plants (WWTPs). The technology can reduce the energy required for wastewater treatment aeration by up to 90%. In addition, the system utilizes the algae produced in the treatment process as an instrument to harvest resources that are present in the wastewater. These resources include organic material that can be used to produce renewable energy in the form of biogas, and nutrients that are harvested through the algal biomass, which is used to produce high value algal products such as fertilizers, animal feed and bio plastics. Selling the energy and products will generate a new revenue stream to the wastewater treatment plants.

The system was tested on a small scale (3-5 m^3/d) within the Ra'anana (Israel) wastewater treatment plant (WWTP) for 18 months. Following the successful results in the pilot plant, the company has built a Beta site treating 30 m^3/d within the Dan Region (Israel) WWTP. The Beta site is operating for 24 months and producing excellent results.

The implementation of the technology can reduce capital and operational costs in wastewater treatment plants and increase its sustainability.

Keywords: Wastewater treatment, Algae, Energy savings, Resource recovery.

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The water and energy nexus as a catalyst for Middle East peace

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The Middle East is among the most water scarce regions in the world. Rapid population growth and mass migration due to political instability and conflict, combined with the impact of climate change is further increasing the pressures facing the already scarce natural water resources of the region. EcoPeace's Water-Energy Nexus Project is examining how these challenges can be addressed through greater integration of regional water and energy economies that will improve access for communities experiencing scarcity whilst laying a foundation for mutually beneficial regional co-operation and a more peaceful future.

Israel, Jordan and Palestine all share common surface and ground water resources. New technologies for treating waste water for reuse in agriculture and in water desalination for domestic purposes have revolutionized the water sector in Israel. From a water economy a decade ago of 2 billion m^3 per annum, the development and adoption of these technologies has increased Israel's water economy to over 3 billion m^3 per annum today. By contrast, per capita water consumption in Jordan and Palestine remains amongst the lowest in the world, leading to appeals by Jordan and

Palestine for greater access to shared regional water resources.

All three countries are also highly dependent on imported fossil fuels for energy production (despite the recent discovery of large offshore gas reserves in Israel) and all three have declared policy goals of achieving specific levels of energy production from renewable sources. However, none are currently on track to meet their targets, at least not the early stage targets set for 2020. Meeting ambitious renewable energy targets will require large-scale investment in solar, wind and/or other renewable technologies and not just improved energy efficiency.

The transformation of Israel's water economy and the need for increased reliance across the region on renewable energy sources has presented an opportunity to advance new forms of regional cooperation which are of critical importance to the people of the region and the stalled Middle East peace process. Like the agreements reached in Europe over steel and coal, which were the backbone to the development of a more peaceful Europe and led to the creation of the European Union, a water and energy nexus could provide a model for regional cooperation and a foundation for a more peaceful and sustainable Middle East.

Jordan's short coast-line limits its capacity for large-scale desalination. However, Jordan's high altitude and sparsely populated desert extending across a large portion of the country experiences high levels of solar radiation making it an optimal location for large-scale solar energy generation. By contrast, Israel and Palestine, have relatively limited open spaces, but have access to the Mediterranean. Given this reality, there is potential for mutually-beneficial exchanges of water and energy which would not only increase water supply to regions experiencing scarcity and create a more reliable and integrated energy grid, but also has the potential to strengthen ties between countries and create mutual-dependencies which will encourage cooperation and reduce future conflict.

The Water-Energy Nexus is being advanced in partnership with, and with the financial support of, the Konrad Adenauer Foundation (KAS). At present, a pre-feasibility study is being conducted on the technical, economic and geopolitical viability of a water-energy nexus arrangement between Jordan, Palestine and Israel. The study explores the water and energy economies in the three countries and will analyze the feasibility of future cooperation by linking regional water and energy resources through the trade in energy generated from renewable sources in Jordan and the West Bank (solar and wind) in exchange for natural or desalinated water from Israel and Gaza. The study is pioneering as it also explores the geo-political implications of natural resource inter-dependencies in the midst of a conflict zone, for the stated purpose of increasing shared prosperity and political stability. The issues and mechanisms explored in the pre-feasibility study have the potential to be extended in future to include Syria, Lebanon, Iraq, and Egypt.

The aim of this project is to investigate the potential feasibility for developing mutually beneficial exchanges of water and energy between the three countries. As a pre-feasibility study, it will develop various possible scenarios for types of water and energy facilities and their requisite distribution infrastructure, and will attempt to assess the technical, economic and political feasibility of their implementation.

As this is a first and very preliminary study, several guiding assumptions are necessary. The following are the primary assumptions made – technical, economic and political – in order to carry out this pre-feasibility study.

Technical

Given that the scale of projects being investigated, implementation cannot be undertaken immediately. As such, the study will take as a focal point for calculations the year 2030.

In terms of future population forecasts, the figures used will be based on official reports pub-

lished by the governments themselves. In the case of Palestine, we will use figures from the report Palestine 2030, published by the Prime Minister's Office and the UN. In the case of Israel, we will use the Central Bureau of Statistics medium range projection. In the case of Jordan, since no official documents taken into account current refugees and other non-Jordanian residents in their future population projections, we will use the current population figures given by the United Nations, including refugees and other non-Jordanian residents, and will apply government projections for rate of increase to calculate an estimated 2030 population.

In terms of determining the scale of desalination to investigate, the study will look at the amount of water needed to provide estimated populations in the year 2030 with 80 cubic meters of freshwater per capita per year for domestic consumption purposes, while leaving current levels of agricultural and industrial consumption undiminished (and quite possibly increased, should levels of wastewater reuse increase). This amount is slightly less than current levels of annual domestic per capita consumption in Israel today, but significantly more than current Jordanian and Palestinian consumption levels. It is assumed that all of this additional water will come from seawater desalination.

In terms of the amount of renewable energy to produce, two separate scenarios will be examined:

a) The first scenario is one in which the amount of new renewable energy produced is equalto the amount needed to cover the energy needs of the projected desalination (i.e,,to provide the said 80 cubic meters per capita for domestic purposes) and the transfer of this water. This figure of 80 cubic meters per capita annually relates to gross provision of water for domestic/ municipal purposes, and includes leakages and other non-revenue water.

b) In the second scenario the amount of renewable energy produced is equal to 20% of total projected electricity production for each country. This amount will be significantly more than in the previous scenario. The future energy needs will be taken from official government forecasts. In cases in which forecasts are not available, the study will use extrapolations based on trends over the period of 2005-2010, using either conventional parametric regressions or non-parametric (e.g. Kernal density or LOESS) regressions.

A guiding assumption with regard to both scenarios is that the renewable energy is a small enough share of the total energy consumption that it can be incorporated without need for storage.

In terms of transfers of water, in the case of Jordan, the pre-feasibility study will look only at the costs of transferring its share of water from the Mediterranean to the King Abdullah Canal or some other initial distribution point in Jordan. Likewise, in the case of Israel and Palestine, the study will estimate only the costs of transmission from Jordan to a single location within these countries. It will not look at the costs of transmission of water within Jordan or of electricity within Israel and Palestine.

In both cases the study will look at technologies already commercially available. In the case of desalination, we will take into consideration only reverse osmosis (R/O), given that this is the dominant technology already in place in Israel, and the technology planned for desalination in Gaza and Aqaba, and given that it is considered the most energy efficient of the currently commercially viable desalination methods (German Aerospace Center (DLR) et al, 2007). Currently, R/O desalination in Israel consumes between 3.4-3.7 kWh/m^3. While a certain amount of improvement in energy efficiency is likely by 2030, it is difficult to project what that might be. As such we will use a figure of 3.4 kWh/m^3. For the electricity needs of pumping, we will use 1 kWh/m^3 which is the current average energy consumption of water delivery in Israel (Hoffman, 2014).

Economic assumptions

The study will use current prices for desalination and solar (and possibly wind) energy. Though prices are likely to change by 2030, the extent to which they will is difficult to determine, and so we will base calculations on current prices.

For solar electricity, current capital and operating and maintenance costs for large-scale photovoltaic energy production will be used, as cost estimates for emerging technologies such as concentrated solar are still unreliable, especially in this region, as they have yet to be implemented at a commercial level. Further studies may wish to incorporate cost estimates for these alternative technologies.

The study will be done using a social discount rate of 4%. Further studies may wish to evaluate a range of discount rates that reflect actual cost of capital financing or other market features

Political Assumptions

The study will assume that there is the requisite political will for such a project.

It will assume that Palestine is a fully independent state and will include the population of East Jerusalem within this state.

It will assume that exchange of water and energy between Gaza and Israel, the West Bank and Jordan is feasible.

Keywords: Water energy nexus, Renewable energies, Desalination, Water security, Regional integration

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Capacitive deionization of aqueous solutions with a cation-anion–exchange membrane of mosaic structure

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The main problem of obtaining pure drinking water by capacitive deionization (CDI) technique is large energy consumption caused by essential ohmic wastes of energy due to high resistance of pure water. Earlier we showed that thanks to the presence of ion-genic surface groups (SG) in activated carbons (AC) even in pure water the AC based electrodes conductivity high enough; it is also proportional to exchange capacity [1]. In such conditions ionic conductivity almost equal to surface conductivity (SC), which is determined by SG existence. That is why at the final step of deionization during clean water obtaining energy loses are limited not by low ionic conductivity of AC electrodes but practically zero ionic electro-conductivity of water which contains in pores of spacer (separator) located between two electrodes. To significantly decrease energy loses in CDI unit during clean water obtaining instead of using usual spacer which is commonly used in CDI we for the first time used specially received cation-anion-exchange membrane of mosaic structure or shortly "mosaic membrane" (MM). MM consists of homogeny mixed with each other

particles of cationite and anionite. Research took place both in static electrochemical cell without hydrodynamic fluid flow and in dynamic CDI cell with to be deionized water solution pump. In static cell experiments we used two types of MM: 1. Film MM was produced by homogeny mix of anion-exchange resin AV-17 and cation-exchange resin KU-2 in 70%:30% ratio. These resins were mixed with particles of polyethylene as binder and were rolled as film. 2. Fibrous MM was produced on the basis of matrix made by phenol-formaldehyde fibers on which were synthesized cationite resin KU-1 and anionite resin EDE-10P. It was shown that membranes of both types even in pure water have sufficient ionic conductivity due to functional groups presence. Along the research we used two types of electrodes based on such AC as: Kuraray-50 with 8% binder (PTFE) and Norit with 6% binder. By using of method of standard contact porosimetry (MSCP) [2] the porous structure of mosaic membranes and AC electrodes was studied in from 1 nm to 10^5 nm range. AC Kuraray-50 is a micro-meso-porous carbon with total specific surface of 1020 m^2/g and hydrophilic surface of 710 m^2/g. Norit is a microporous carbon with total specific surface of 1200 m^2/g and hydrophilic surface of 820 m^2/g. Film MM had porosity of 56% and fibrous MM of - 73%. Values of cation-exchange capacity (CEC) and anion-exchange capacity (AEC) were investigated and showed that all AC based electrodes and MM have both types of exchange capacity. For AC based electrodes Kuraray CEC = 0.56 mg-eq/g, AEC = 0.2 mg-eq/g; for fibrous MM CEC = 0.96 mg-eq/g, AEC = 0.65 mg-eq/g.

Static cell consisted of two identical AC electrodes with MM between them; electrode and membrane pores were soaked by clean twice distilled water with 2 mkSm cm^{-1} conductivity. As a result high capacity of (52-56 F/g AC) was obtained which witnesses that even in pure water such cell is able to work. During the research we established the mechanism of electrochemical cells of both types performance with pure water. When electric field is on counter-cations migrate along the electrode by relay-mechanism using SG and then they migrate to MM, where they migrate same relay mechanism to counter electrode. Simultaneously counter- anions of migrate along the cell by relay-mechanism in opposite direction. Thus the electric double layer charge on both electrodes occur. Measurements in dynamic cell with MM showed that such cell is suitable for pure water obtaining. It was shown that sum of energy consumptions on water solution deionization significantly (more of 50%) decreases using circuit closing on concentration (desorption) stage. Thus the results for static and dynamic electrochemical cells investigating showed much perspective of MM using for pure water gaining.

Keywords: Capacitive deionization, Cation-anion-exchange membrane of mosaic structure, Surface conductivity, Carbon activated, Method of standard contact porosimetry

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Two-stage anaerobic fluidized-bed membrane bioreactor with zeolite as carrier to treat campus domestic wastewater

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A two-stage anaerobic fluidized-bed membrane bioreactor (SAF-MBR) system with zeolite as carrier was used to treat the campus domestic wastewater at ambient temperature (20–35°C). This system consisted of an anaerobic fluidized bed reactor (AFBR) followed by an anaerobic fluidized membrane bioreactor (AFMBR) was operated under 1-day hydraulic retention time (HRT) in semi-continuous mode during start-up and gradually reduced the HRT to 3 h in continuous mode operation. Nonfat dry milk (NFDM) of 1000 mg COD/L was fed into the system during start-up phase whereas the campus domestic wastewater (73–220 mg COD/L) was used as a substrate when the operation shifted to continuous mode. The results indicate that the COD removal efficiency of 95% for AFBR was achieved in 30 days since start-up. It is apparent that the use of zeolite as carrier for the attached growth of anaerobic microbes could shorten the start-up period for the AFBR. For the entire system, the optimal performance was observed at 3.5-h HRT which the COD, BOD, and TSS were removed by 84, 87, and 96%, respectively. The corresponding effluent COD, BOD, and TSS concentration could achieve to 20, 8, and 2 mg/L, respectively. Meanwhile, this organic removal from the campus domestic wastewater resulted in the specific methane yield of 0.13 L CH_4/g CODremoved. In addition, it was observed that the trans-membrane pressure (TMP) in AFMBR remained lower than 0.2 bar at the membrane flux of 10 L/m^2/h. This operation could be sustained for 333 days without chemical cleaning the membrane. Overall, although the pumping energy of 0.015 kWh/m^3 was needed, this system generating the methane energy of 0.0024 kWh/ m^3 reduced the total energy demand for the system operation. The SAF-MBR is an efficient energy-saving system for treating the campus domestic wastewater.

Keywords: Fluidized bed bioreactor, Membrane bioreactor, Municipal wastewater

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Integrated reverse osmosis and membrane cleaning systems for fouling prevention

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Over the past 60 year, reverse osmosis (RO) became the most worldwide practiced membrane technology for diverse applications of desalination and water treatment. The greatest drawback of this technology since inception relates to membrane fouling and some performance loss even after rigorous CIP procedures. Removal of fouling deposits off membrane surface at their infancy, once a day or several days, under mild conditions by a brief (< 8 min) membrane cleaning (MC) procedure should prevent the need for rigorous CIP and conserve membrane activity over longer

period of time by avoiding irreversible damage membranes due to the accumulation of irremovable fouling constituents. This approach for fouling prevention is illustrated in the context of the in the context of closed circuit desalination (CCD).

The illustrated integrated system for fouling prevention comprises a CCD unit with membrane cleaning (MC) means which are activated briefly (< 8 min) on a frequent basis, once a day or several days, for removal of fouling and/or scaling deposits off membrane surfaces created during the elapsed time interval and thereby, avoiding their accumulation and the need of CIP. MC proceeds in a tie-line sequence with different reagents solution in permeate known to affect the removal of common fouling and/or scaling constituents from membrane surfaces such as organic and/or bioorganic substances and/or inorganic scaling constituents including silica and polymerized silica coatings with either metal hydroxides or organic substances. Removal of silica containing deposits from membrane surfaces proceeds by a brief exposure to diluted hydrofluoric acid solution in permeate in the absence of interfering metal ions (e.g., Ca). The MC sequence incorporate both reverse osmosis (RO) and direct osmosis (DO) principles, the former to enable an effective contact of the cleaning reagents with membrane surfaces and the latter for inside-out backwash of semipermeable membranes with permeate.

The fully computerized inventive system should enables a near perfect removal of all fouling and/or scaling constituents off membrane surfaces at an early stage on a regular basis before their accumulation and thereby, preventing the need for CIP and avoiding irreversible damage membranes as result of accumulation of irremovable fouling constituents.

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KURIVERTER RC – membrane rejuvenation technology

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Applications using reverse osmosis membrane technologies are everywhere in our lives – from tiny under counter units polishing our drinking water through industrial units preparing water for processes or purifying effluents for reuse and massive seawater desalination plants producing hundreds of m^3 of drinking and irrigation water every day. The membranes used in this technology face many potential problems, namely scale and deposits, biofouling, physical stresses and chemical damage. For many of these problems we have developed preventive solutions, in the form of pretreatment, antiscalants, dispersants, biocides and better operating procedures. Membranes that suffered chemical damage and resulting increased salt passage however, were simply replaced with the associated high cost and lost production. But now there is an alternative – KURIVERTER RC technology by KURITA. This Technology allows us to rejuvenate the membrane, restore salt rejection and postpone membrane replacement until it is budgeted for and convenient. This at a fraction of the replacement cost and an easy to apply CIP process. This presentation discuss the chemistry, mechanism and case histories regarding the application of KURIVERTER RC technology.

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KURIVERTER IK 110 – biofouling removal and prevention in membrane systems

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Biofilm and biofouling impact dramatically on the efficient operation of a membrane process. The conditions within a membrane are typically ideal for the proliferation of bacteria. Growth is exponential and quickly reduces flux and increases differential pressure. This requires that the system be shut down and the membranes chemically cleaned, increasing the cost of operation.

Controlling bacterial growth in a membrane is not easy since oxidizing biocides typically damage membrane material of construction leading to high salt passage. The use of non-oxidizing biocides add significantly to operating costs.

KURIVERTER IK 110 was designed by KURITA to penetrate biofilms and has the action of peeling the biofilm off the membrane, exposing a clean surface and restoring flux and differential pressure.

KURIVERTER IK 110 is a combined chlorine compound which does not "burn-off" on the biofilm surface leaving the basic biofilm unaffected. Rather it penetrates the biofilm and creates an environment which discourages biofilm attachment without presenting any risk to the membrane material.

This presentation will discuss the Chemistry, Mode of Action and case histories for the application of Kuriverter IK 110..

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Water status and the opportunities of solar water desalination in the Gaza strip

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Many countries around the world, especially developing countries and countries in the Middle East and the Gaza strip in particular, suffer from a scarcity of fresh water. The rapid increase of population in the Gaza Strip is expected to increase to 2.1 million by 2020; with the UN reporting that Gaza will no longer be habitable by 2020. The ground water of the Gaza strip which is the only water resource is currently overexploited, with total pumping exceeding total recharge. Meanwhile more than 45% of the available groundwater is being severely exploited for agricultural irrigation, while the remaining is used for domestic water supply and industry. Urgent measures to address the prevailing water crisis in the Gaza Strip are being considered to secure safe water for the people of the Gaza Strip. However, Gaza has been experiencing a shortage of fossil fuels and inadequate and unreliable power supply for 10 years. This has affected negatively water desalination since it is energy consuming processes. The integration of renewable energy resources in desalination and water purification is becoming more viable as costs of conventional systems increase, commitments to reducing green house gas emissions are implemented and targets for exploiting renewable energy are set globally. Thus, solar energy could provide a sustainable alternative to drive the desalination plants in the Gaza strip since Gaza lie on the solar belt with an annual sun light of about 3500 h/y and an average daily solar insolation of about 5.6 KWh. The recent world's

advances in desalination technology and the rapid growth of solar industry have significantly reduced the cost of fresh water produced by solar water desalination technology. This paper explores the challenges and opportunities of solar water desalination in the Gaza strip. It presents the water status and the ongoing and planned water desalination projects in the Gaza strip.

Keywords: Solar, Water desalination, Gaza , Energy

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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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Theoretical modeling and verification of reverse osmosis membrane element under variable operating conditions

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Sea water reverse osmosis (SWRO) desalination unit combined with renewable energy (RE) technologies, such as photovoltaics and/or wind generators, offers an attractive solution, especially in remote areas such as islands and coastal regions, due to the fact that these areas are characterized by lack of access to both electricity and low quality of available potable water. Experimental studies showed that a direct connection of a SWRO unit with RE technologies can result in lowering the specific energy consumption due to the part-load operation of the desalination unit. However, due to the variable nature of RE, the membranes could operate outside of their nominal operating

ranges. This operation of the membranes usually could increase the possibility of fouling and scaling and compaction of the membranes.

This paper regards a dynamic mathematical model development, of a spiral wound reverse osmosis membrane module investigating the effect of the operating parameters in order to predict the performance of the membrane under variable operating conditions. The simulation implemented in MATLAB programming environment using differential equations. The model results verified with experimental data of a spiral wound membrane element (Filmtec, SW30-4040) of a small-scale SWRO desalination unit, which is installed at the Agricultural University of Athens, as well as with results provided by industrial membrane software ROSA. This study will provide new knowledge on membrane characteristics such as lower response to hydraulic resistance and durable surface texture that should be modified for the development of RO membranes capable of working under non constant conditions with minimal fouling.

Keywords: Spiral wound membrane element, Theoretical modeling, Verification, Variable operating conditions

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Treatment of oil–water emulsions by adsorption onto resin and activated carbon

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Water is essential in most of the industrial processes in order to guarantee proper production. Minimizing waste is one of the principles behind any of the circular economy initiatives. Typically industrial waste water contains oil and grease, BTEX (benzene, toluene, ethylbenzene and xylenes), high dissolved solids, suspended solids, heavy metals, high content of biochemical oxygen demand (BOD) and chemical oxygen demand (COD). In order to be discharged or reused, waste water needs to be treated to meet the regulations. Emulsified oil in waste water constitutes a severe problem in the different treatment stages before being disposed off in a manner that does not violate environmental criteria. Several technologies are already in place to treat refinery waste water. One commonly used technique for remediation of petroleum contaminated water is adsorption.

The main objective of this study is to examine the removal of oil from oil–water emulsions by adsorption on Dow adsorbent resin and activated carbon. Experiments were performed at the Dow Water and Process Solutions (DW&PS) Global Water Technology Center in Tarragona, (Spain) in order to evaluate the removal of hydrocarbons from real oily water samples from the refinery industry using Dow Optipore L493 and commercial granulated activated carbon. The results gave evidence of the ability of the adsorbents to adsorb oil and that the adsorptive property of the adsorbents is influenced by different factors such as contact time, weight of adsorbents, etc. The present paper includes the details of the results of this study.

Keywords: Hydrocarbons, Activated carbon, Emulsified oil, Wastewater

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Very high salinity water treatment by nanofiltration membranes

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High salinity waters come up from the fracture wells as produced water during shale gas recovery. The properties of produced water vary depending on the geographic location of the field, the geological host formation, and the type of hydrocarbon product being produced [1]. Salinity or salt concentration, described as TDS (Total dissolved solids), can vary in conventional oil and gas well produced waters from 1,000–400,000 mg/L [2]. Variations in TDS are related to geologic variations between basins, well location in a well field, and the resource produced. These solutions are difficult to handle because of their high salinity and they cannot be discharged or reused without previous treatment.

This paper covers the experiments that were completed in order to investigate performance of two Dow nanofiltration membranes in high salinity conditions. Two nanofiltration membrane types NF345 and NF270 were tested in 8 inch commercial element configuration. The feed water salinity in terms of TDS was over 100,000 ppm during the initial trial and later on up concentrated until 125,000 ppm. Feed solution was synthetically prepared based on actual produced water composition data obtained from the real field. Nanofiltration elements were operated between 20 and 30 L/m^{2}h flux at 25°C.

The conclusions that can be derived from this study were:

1. Nanofiltration is able to operate well at high salinity water conditions of around 100000 ppm with relatively high flux (30 L/m^{2}h).
2. Total TDS rejection of a single element system varied between 25% and 35% although the divalent ions rejection was over 70%.
3. Total dissolved solids rejection in terms of percentage is lower for high salinity waters (>100,000 ppm) than in seawater conditions (34,500 ppm).
4. Among the two membranes studied, NF345 present better TDS rejection.
5. Precipitation of calcium carbonate was a challenge during the early part of the experimentation. Lowering the pH of the feed solution helped to reduce the problem of precipitation.
6. High salinity water can be pretreated with NF membrane before fed to a reverse osmosis system.

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Optimal operating conditions analysis for a double-effect absorption heat pump coupled to a multi effect distillation plant

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Thermal distillation techniques are considered energy inefficient because of the high energy consumption, wich represents approximately the 50 % of the total fresh water production cost. One way to reduce the energy consumption is to couple the distillation plants with heat pumps. In the last decades absorption heat pump technology has awakened interest when are coupled to thermal disti- llation plants due to the fact that it has shown high efficiency and the possibility to operate at partial loads [1].

Carrying on the work started by Carballo et al. [2] where the optimal ope- rating conditions were determined in the multi-effect distillation plant (MED) located at CIEMAT-Plataforma Solar de Almer´ıa (PSA), a new optimization study has been performed in a double effect absorption heat pump (DEAHP) coupled to such plant (see Fig. 1). According to energetic and exergetic crite- ria, the optimal operating conditions aim to reduce energy consumption and to increase the fresh water production of the whole system. The optimization has been performed using genetic algorithms.

For accomplishing this work, the previously models of a MED and a DEAHP developed by de la Calle et al [3, 4] have been modified and coupled. These models were implemented using the object-oriented modeling Modelica language and were validated by experimental data measured in the real facilities.

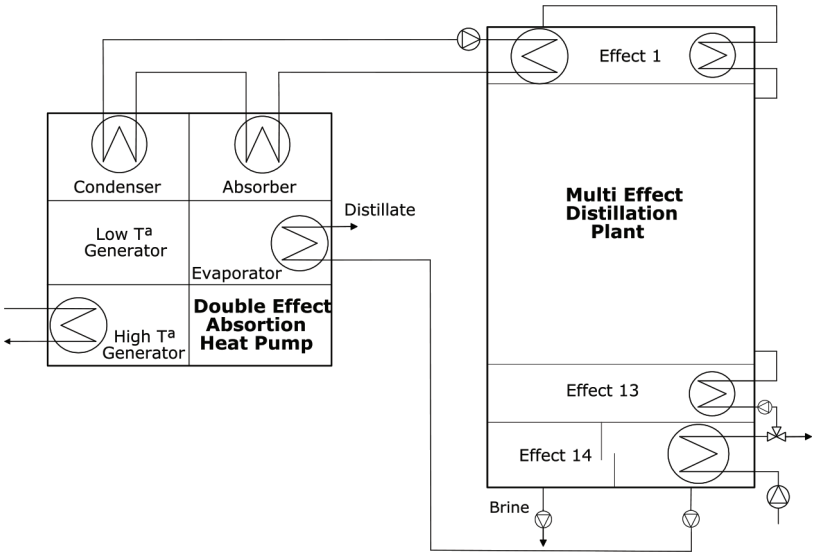

Fig. 1. System scheme.

Keywords: Optimal operation, Thermal distillation, Energy consumption, Exergy, Multicriteria optimization, Modelica

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Effect of spacer geometry on limiting current density and pressure drop in electrodialysis

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Originally designed open-channel spacer of 0.35 mm thickness and two commercial spacers of 0.35 and 0.40 mm thickness were examined in electrodialysis process. Laboratory tests were carried out in an ED unit having four pairs of PC-SK/PC-SA PCA ion-exchange membranes of 3 cm active membrane length. Limiting current densities were determined at salinity equal to 0.4 g/L and linear flow velocities in the range 1.0–4.0 cm/s. Additionally, pressure drop was measured in a unit of 0.7 m channel length. It was found that 0.35 mm open-channel spacer shows best performance: limiting current density 26-48 A/m^2 in the investigated flow velocity range. Same thickness commercial spacer showed similar limiting current density, but three times higher pressure drop, while 0.40 mm spacer showed ca. 25% lower limiting current density and ca. 50% higher pressure drop.

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Direct driven small scale sea water reverse osmosis desalination unit powered by PV: Case study of an Aegean Sea Island, Greece

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The fresh water management and supply is a significant problem in many areas of the world such as islands and coastal regions. These areas are characterized by water scarcity and also face electrical grid problems. Sea water reverse osmosis (SWRO) desalination coupled with renewable energy technologies such as photovoltaics is a very attractive solution to decrease the imbalance between water demand and supply in these areas. When the SWRO unit is direct driven by re-

newable energy systems (RES), the seawater feed flow, feed pressure and fresh water production (operation under variable load) fluctuates since the power production by RES depends on the weather conditions. Nevertheless, variable load operation has been proved to be technically and economically viable for the operation of SWRO units with intermittent power sources, such as renewable energies and at some conditions has also shown lower specific energy consumption as compared to nominal load operation.

This paper presents the experimental investigation of a SWRO desalination unit for operation at variable power input at a range of pressures imposed while producing fresh water with sufficient quality. The SWRO unit tested in the lab is a small-scale desalination unit with a capacity of 150 L/h and is equipped with a hydraulic energy recovery device of the Clark pump type which plays also the role of the high-pressure pump in a conventional RO unit. The SWRO unit operation and performance was also examined for different feed water temperatures and the temperature effect on its operation is presented.

The application of such SWRO desalination unit at a stand-alone mode, powered by photovoltaics without the use of any electrical storage system, was examined for an island of Cyclades complex, Aegean Sea, Greece. The results of the system testing are very promising with regard to the overall technical, environmental and economic performance of the system. Furthermore, in comparison with the cost of transported water to the islands, the stand-alone SWRO desalination system showed a lower cost for a 20 year investment period. The cost of the produced fresh water per m^3 is less than the cost of the transported water by 60% for the first year operation and the total gain for 20 years operation is calculated to be 63%. The PV-SWRO desalination system, without the use of any conventional energy storage systems, undoubtedly constitutes an economical viable solution to water scarcity in islands, producing fresh water of acceptable quality at all operating conditions.

Acknowledgment

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Application and characterization of self-support carbon nanotube microporous membrane for water and wastewater filtration

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A self-support carbon nano tube (CNT) laminates and their modifications were characterized in terms of water permeability and selectivity. Molecular weight cut off (MWCO) of the membranes was estimated based on rejection of proteins and fluorescence beads. The MWCO of the membranes corresponded to the selectivity range of tight ultrafiltration (UF) membranes (absolute pore rating about 20-40 nm). The CNT laminates displayed outstanding properties comprising very high permeability of 120-400 LMH/bar for the same separation selectivity of existing commercial

UF membranes. This combination of features offers a unique opportunity of application in the UF range, and especially at the harsher conditions such as wastewater treatment and purification (effluents filtration, MBR). In addition, the chemical stability of CNT laminates towards acid (HCl), base (NaOH) and oxidants (NaClO) were tested at 24 h exposure at 4-10 fold higher concentrations than commercially employed for cleaning in membrane filtration. It displays the performance of UF membranes in terms of selectivity and permeability with the additional qualities of the CNT. In addition to these qualities, the conducting features of the CNT could be used to control biofouling during wastewater filtration with application of low voltage electric field.

Keywords: Carbon nanotube, Biofouling control, High permeability, MWCO, Self-support membrane

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Membrane distillation for the treatment of high-salinity aqueous solutions in the regeneration of salinity gradient resources

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Membrane distillation (MD) has been used with good results in the treatment of high concentrated saline sources that cannot be handled efficiently by other membrane-based desalination technologies. However, in thermal desalination processes the nature of the salt and the increase of the ionic concentration in an aqueous solution have both an influence in the boiling point elevation, what causes a reduction in the distillate production due to the inherent decrease of water activity in the treated solution.

The aim of this study is to assess the performance of the MD process for the treatment of high-concentrated saline solutions, in terms of operational conditions and module configuration. This was done for several solutions in the context of regeneration of salinity gradients in a novel process of power generation by closed-loop reverse electrodialysis (RED). In this sense, several salts were chosen previously in accordance with their physical properties. The distillate production was evaluated using each salt individually in solutions with a large range of feed water activities.

Experiments were performed in two bench-scale test rigs equipped with plate and frame MD cells of effective membrane areas 250 and 375 cm^2, respectively. Separated cooling and heating circuits allowed working steadily in different operational modes, i.e. air gap (AGMD), permeate gap (PGMD), and vacuum-enhanced AGMD. An experimental comparison between the performances of the modes AGMD and PGMD was firstly made in the smallest module using aqueous sodium chloride in a wide range of feed concentrations, temperatures and velocities. The module configuration was also changed varying the gap width in both referred modes. Due to its better performance dealing with the most concentrated feed solutions, AGMD was chosen for performing subsequent tests with different concentrations of salts and operating conditions, and for assessing the effect of using different salts in the distillate production. Finally, several tests were made in the second test rig for PGMD, AGMD and vacuum-enhanced AGMD applying different levels of vacuum in the gap, in order to evaluate its effect in the distillate production and its electrical conductivity.

Keywords: Membrane distillation, Thermal desalination, High concentration saline solutions, Salinity gradient regeneration

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This work has been performed within the RED-Heat-to-Power project (Conversion of Low Grade Heat to Power through closed loop Reverse Electro-Dialysis) - Horizon 2020 programme, Grant Agreement n. 640667.

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Zero liquid discharge desalination: brine treatment based on electrodialysis metathesis and valuable compound recovery

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It is well known that desalination plants generate huge amount of brines which are discharged into the receiving environment. Nowadays it is necessary to adopt new brine management strategies to minimize their negative impact. In this sense, LIFE+ Zelda project aims to demonstrate and disseminate the technical feasibility and economical sustainability of decreasing the overall environmental impact of desalination systems by adopting a new brine management strategy based on the use of electrodialysis metathesis (EDM) and valuable compound recovery processes with the final aim of reaching a zero liquid discharge process (ZLD).

Differently from conventional electrodialysis, the EDM configuration is designed to separate the EDM concentrate in two waste streams of highly soluble salts: one contains sodium with anions (Na-mixed stream) and the other contains chloride with cations (Cl-mixed stream). This way, the sparingly soluble salts such as $CaSO_4$, $MgSO_4$ or $CaCO_3$ are not produced in either of the two concentrate streams. Once the brine has been treated with the EDM, the two generated concentrate streams will be treated by a compound recovery process in order to obtain valuable compounds and reach a ZLD desalination process.

The technology of ZELDA project is being tested and optimized in the seawater desalination plant of Almería (Spain). There, brines from both brackish water and seawater desalination plants are being treated by the EDM-ZLD technology. In November 2016, the evaluation of brine from brackish water desalination finalized and currently brine from the seawater desalination plant of Almeria is being treated.

In the case of brackish water desalination, brine from Helios Thermosolar Plant (Arenas de San Juan, Spain) has been evaluated. For the EDM stage, optimal conditions (current density and voltage applied) have been defined to reach a concentration factor above 4 for multivalent ions in the two concentrate streams and a conductivity of 5 mS/cm for the dilutes to allow their discharge into the sewer. Once optimized, the EDM process achieved 80% of water recovery with an overall concentration factor of 4.6. The energy consumption per m^3 of Helios brine treated was on average 11±3 kWh. The energy consumption per m^3 of concentrates was on average 0.14 ± 0.05 kWh/kg TDS (total dissolved solids).

To recover valuable compounds from the Na-mixed stream and the Cl-mixed stream and accomplish a ZLD process, technologies such as crystallization, evaporation and advanced solar evaporation have been applied. The overall EDM-ZLD process would allow to recover 90% of

water. Per m^3 of brine treated several valuable compounds have been recovered: around 1.7 kg of Na_2SO_4 (95% purity), 2.7 kg of mixed salts (Na2SO4 and NaCl), 6.3 kg of $Mg(OH)_2$ (95% purity) and 17 kg of NaCl (93% purity).

In order to quantify the environmental benefits and the economic impact of the new EDM-ZLD process, the Life Cycle Assessment has been performed.

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Automatic cartridge filter performance analysis for RO membrane protection, demonstration of comparison with cartridge filters in BWRO plant

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Comparison of 5-micron disposable cartridge filters versus self-cleaning thread filter as pre-treatment to RO membranes in BWRO. The comparison was carried out with Mekorot in Lahat BWRO Plant. Items of interest were reduction of disposal and labor costs, energy cost reductions by decreasing the average pressure loss across the filter system and finally, effluent water quality differences.

Results show that the automatic thread filters provide many benefits when considered as an alternative to the standard 5 micron cartridges. The thread filters are not a consumable, but a self-cleaning media which eliminates disposal costs and drastically reduces labor costs. The thread filters are designed to operate with a low pressure loss of 0.3-3 m whereas the cartridge filters operate in a higher range of 1.5-16 m pressure loss, leading to a reduction of energy costs. Finally, the thread filters provide superior water quality: stable effluent quality with fewer total solids and better protection on RO membranes as indicated by the differential pressure (Dp) gradient increase along time and first membrane autopsy.

Background

Cartridge filters (5-micron nominal typically) are usually installed prior to RO membranes and regarded as a safety stage acting as a barrier against sand particles or other debris that may be released from brackish wells or system pipes. The cartridges are not intended to perform any significant part of the RO protection filtration, but regarded as an absolute solution for particles which are larger than its micronic rating (5 um for 5 um cartridge filters).

In cases where due to different disturbances higher loads of particles are present in the inlet water, the cartridge filter stage will become a secondary filtration stage and will also be tasked with removing solids and reducing SDI. The result will be a high frequency of cartridge replacement which in turn increases cartridge purchases, costs of labor associated with cartridge replacement and plant down-time (cartridge replacement rates at the BWRO Plant average about 3-4 times per year on a regular basis and up to 6 times per year, during periods of deterioration in the raw water quality). A secondary cost of increased dependence on the cartridge filtration stage is increased pressure loss over the system as the cartridge filters trap solids and therefore increased energy cost demands (average of 9 m with a range of 1.5-16.5 m over use-time).

The goal of this piloting was to analyze if replacement of the standard 'safety stage' 5 micron cartridges with automatic self-cleaning thread filter would improve total system performance by eliminating the costs associated with cartridge replacement as well as reducing the average pressure loss across the pre-treatment stage. Advanced monitoring and testing compared the filtration performance of the two solutions (cartridge and automatic thread filter) by following parallel isolated RO pressure vessels (composed of 8 commercial membranes each) which were installed after the tested pre-treatment technologies.

Keywords: Desalination and the environment; Brackish water desalination; Pre-treatment and post-treatment; Energy reduction

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Hydraulic-arm aided closed circuit batch-RO desalination apparatus of lowest energy and highest recovery prospects amongst existing methods

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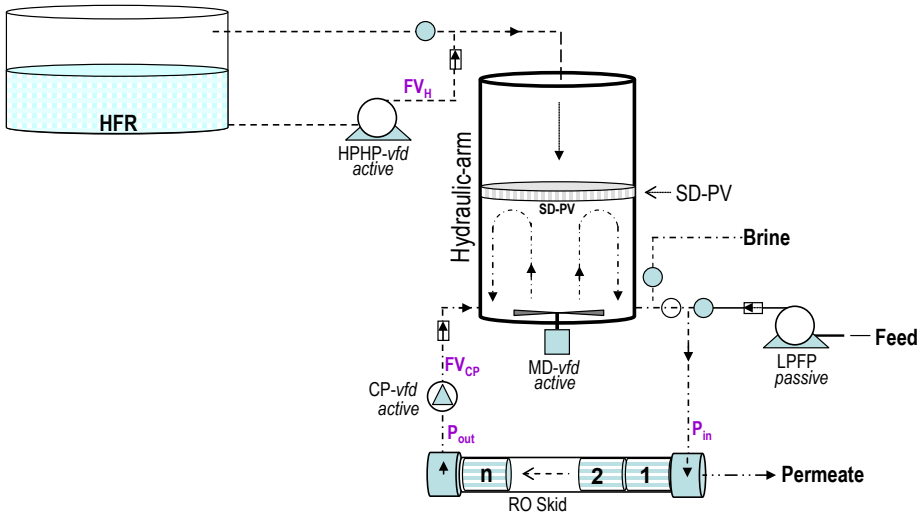
A newly inventive apparatus for closed circuit batch-RO desalination comprising a RO-skid with membrane elements and circulation means for the recycling of RO concentrates through membranes and a designed hydraulic-arm with a disc separating between a section of pressurized hydraulic fluid created by a high pressure hydraulic pump under fixed flow and variable pressure conditions and a section of RO recycled concentrates. The batch desalination sequence is completed when the entire hydraulic-arm volume is filled with hydraulic fluid and thereafter, desalination is stopped, said apparatus decompressed, brine removed and hydraulic-arm recharged with fresh feed before the initiation of a new batch sequence. The inventive apparatus enable RO desalination under the lowest energy and highest recovery prospects not possible by any other RO technique. The practical aspects of batch-RO of zero liquid discharge (ZLD) prospected are exemplified by 95% recovery of 3,000 ppm NaCl at flux of 15 lmh with 0.42 kWh/m^3 specific energy consumption in a single-module RO-skid of 3 elements with an effective permeate production of 1.67 m^3/h (40.2 m^3/d).



Keywords: Closed circuit desalination (CCD), semi-batch RO, batch-RO, Low RO energy, High RO recovery, Zero-liquid-discharge (ZLD)

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Measuring ATP and AOC in seawater reverse osmosis plants

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Controlling biological fouling in reverse osmosis (RO) at an early stage is very important for successful and cost effective operation of membrane based desalination systems. Standard procedures or methods to monitor and predict biological fouling of RO membranes do not exist. Controlling assimilable organic carbon (AOC) of RO feed water is important as it is directly related to the bacterial (re)growth potential of the water. AOC measurements are widely and successfully applied in determining biological stability and biofilm formation in drinking water distribution networks (van der Kooij, 2002). Recently, two methods based on the natural bioluminescence of specific bacterial species *i.e.*, *Vibrio*, have been developed for AOC measurement in seawater (Jeong et al. 2013, and Weinrich et al. 2011). These methods are fast and have low limits of detection, but the use of a single bacterial species may not represent the carbon utilization of indigenous bacteria in natural seawater.

In this study, AOC measurement in seawater using an indigenous bacterial consortium is proposed. However, natural bioluminescence cannot be employed to monitor the growth of indigenous bacteria in seawater. Thus, the first objective of this work is to develop a new method to measure ATP in seawater and thereafter, to apply the method to measure AOC in seawater. Current methods for ATP measurement are not applicable in seawater as the high concentration of salt substantially reduces the luminescence during the enzymatic ATP luciferase-luciferin reaction which leads to underestimating the ATP concentration in seawater (Amy et al. 2011).

A method which enables bacterial ATP measurement in seawater without the influence of salinity was developed. The key to this development is the application of seawater-specific reagents for extracting and detecting ATP from marine bacteria. ATP is directly extracted from the biomass in the seawater sample followed by detection of the ATP. For measuring AOC, the bacteria in seawater were inactivated by pasteurization at 70°C for 60 min. Afterwards, a natural consortium of the bacterial population from seawater was inoculated with 1×10^4 intact cells/mL (measured by flow cytometry). The samples were incubated at 30°C and bacterial growth was monitored for 6 d using the newly developed ATP detection method. The AOC was determined based on the maximum bacterial growth. The ATP and AOC methods were tested at three different locations in: the Netherlands, Australia, and the Middle East.

The new method to determine ATP in seawater is direct, fast (<5 min), and sensitive (LOD = 0.25 ng/L ± 0.03) and correlated (n=100 samples, R^2 = 0.72, p-value<<0.001) with intact cell concentration measured by flow cytometry. Furthermore, ATP and AOC were monitored in coastal

North Sea water (Zeeland, the Netherlands) for a period of 7 months, which showed microbial ATP concentration ranging from 20 ng/L in winter to 1000 ng/L in spring and growth potential ranging between 14 µg C/L (winter) to 500 µg C/L (during the algae bloom period in spring). Furthermore, the new ATP and AOC methods were successfully applied to monitor the bacterial activity and bacterial growth potential at full scale seawater reverse osmosis (SWRO) plants in Australia and the Middle East. The measured ATP concentrations of a desalination plant in Australia in October showed a daily variability of the water quality where the highest ATP concentration was observed immediately after coagulation (20 – 80 ng/L). The AOC concentration through the RO pre-treatment process ranged between 100 and 250 µg C/L in the desalination plant in Australia and between 90 and 280 µg C/L in the desalination plant in the Middle East.

Overall, the new ATP method for seawater is a *very promising tool* that can be measured on-site in desalination plants. ATP can also be used to measure AOC in seawater allowing optimization of pre-treatment processes to reduce biological fouling, chemical cleaning and frequent membrane replacement of downstream reverse osmosis membranes.

Keywords: Adenosine tri-phosphate, Seawater, Assimilable organic carbon, Biofouling potential, Microbial activity, Seawater reverse osmosis

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Multi-effect distillation for regeneration of saline solutions used in a RED close-loop process

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Multi-effect distillation (MED) technology is proposed for the regeneration process of non-conventional salt solutions in a close loop reverse electrodialysis (RED) system within the context of the European project RED-Heat-to-Power. This project aims to implement electricity generation from salinity gradients using a RED device within a closed-loop configuration.

The focus of this work is to investigate the potential of MED for the regeneration of different salt solutions selected in accordance with their physical properties. For this purpose, a steady state mathematical model of a forward-feed MED plant has been developed based on models already published in the desalination literature [1-4] and adapted to the new conditions of the RED process. The potential has been assessed by computing simulation, investigating two key parameters: the specific thermal consumption and the specific heat transfer area of the MED plant. The simulations

were performed for a wide range of operating conditions, varying the following parameters: the recovery ratio (RR), from 10 to 70%, the inlet concentration of the saline solution, from 0.5 M to 3.5 M, and the temperature of the heat source, from 60°C to 100°C. In all cases, the number of effects of the MED unit was established to achieve a theoretical temperature difference between effects of 2.5°C, although for high concentrations it was limited by the boiling point elevation (BPE) of the salt solution (BPE limits the maximum driving force of the MED process).

The results showed that the potential of the MED plant surpasses the target of the project with minimum values of specific thermal consumptions of 21.3 kWh/m^3 (being the target 25 kWh/m^3) at initial concentrations of the salt solutions lower than 2 M with thermal energy input at 100°C and RR>50%.

Keywords: Regeneration process; Reverse Electrodialysis; Close-Loop; Energetic analysis

Acknowledgements

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Development and investigation of a new multi-channel spiral wound DCMD module for large-scale application

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Membrane distillation (MD) is still not a separation technology which penetrated the market on a large scale but still received significant awareness during the past decade. For sea water desalination MD seems to be most appropriate where waste heat is available for very low or zero costs in order to become competitive with RO. In contradiction to the mainly cost driven sea water desalination market, in industrial applications MD covers technical advantages which promise to become a state of the art technology on large industrial scale soon. Compared to RO, MD e.g. can process salt solutions on very high concentration levels close to saturation and is highly corrosion

resistant for salts, low PH acids and high PH bases. Generally it can be expected that membrane contactors, due to their selective separation properties, will play an increasing role in industrial fluid treatment processes in the future since on the one hand environmental requirements find increasing awareness and on the other hand the recovery of valuable substances from waste streams will provide economically sound solutions to reduce production costs.

Today there are only a view companies producing "real scale-commercial" MD modules but even these modules have sizes not sufficient for large scale industrial applications. Even if low cost waste heat will most likely be the prime mover also for applications in industrial environment, energy efficiency and heat recovery respectively will play an important role since on the one hand the available resources might be shared with other users and on the other hand the production capacity of the MD plant might be limited by the amount of available heat.

Basically there are two different module concepts using flat sheet membranes namely plate and frame modules and spiral wound modules. The spiral wound configuration allows the construction of very long channels which enable an efficient heat recovery in counter flow mode between evaporator and condenser. Fraunhofer ISE developed such spiral wound modules with GOR values up to 7 in the past which were commercialized by SolarSpring. The drawback of the applied design is that only one set of channels (one evaporator and one condenser channel, optional also one distillate channel in PGMD or AGMD configuration) can be integrated. Due to the rising pressure drop of the module, which is proportional to the channel length, these modules are limited in size and not valid for real upscale. While SolarSpring developed advanced plate and frame MD modules for large scale industrial applications, Fraunhofer ISE constructed new "multi-channel" spiral wound MD modules for the company MAHLE Industriefiltration GmbH. Multi- channel (multi-envelope) configurations are well known from RO modules and were transferred into a DCMD module design for sea water desalination. Prototype modules were designed by means of multi parameter simulations, built and experimentally investigated. Two of these new modules with a membrane area of 27.5 m^2 each in 6 parallel channel sets were implemented in a demonstration system constructed by the Technical University Hamburg- Harburg (TUHH). The pre-evaluation of the demonstrator was conducted by Fraunhofer ISE under lab conditions. At 80°C top brine temperature and a conductivity of 50 mS, a production capacity of about 5 m^3/d was achieved. The corresponding GOR value was about 2.8. Subsequently the demonstrator was installed on board of a container vessel and investigated under real conditions by TUHH on the way from Rotterdam to Shanghai. On board the demonstrator was supplied with waste heat from a diesel engine. The MD modules were returned to Fraunhofer ISE after dismantling the demonstrator from the container vessel in Shanghai. Performance validation in the lab showed that the same productivity and energy demand were achieved which indicates that no performance degradation occurred during 6 months of onboard operation. Membrane autopsy by SEM and EDX was conducted in order to detect scaling, fouling and membrane degradation. Results from lab and onboard investigations will be presented in the conference.

Keywords: Membrane distillation, New module concept, Industrial up-scale

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Simulation of a real plant for the combined treatment of wastewaters and liquid wastes

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This paper presents the revamping of a real a domestic wastewater treatment plant, working in Southern Italy, modified to process in an integrated way municipal wastewaters together with liquid wastes, such as leachate and digestate streams. The two streams, civil wastewaters (WW) and liquid wastes (LW), undergo in a separate way the preliminary treatments, only grinding for WW while grinding, flocculation, biological pretreatment and advanced oxidation (Fenton process) for LW, before entering together a classical denitrification/nitrification section.

Several scenarios are analysed by using a process simulator (SuperPro Designer®): the concentrations of main parameters (BOD_5, COD, NH_4^+, NO_3^-, metals, SST) are estimated as a function of BOD/COD ratio, initial leachate volume and nitrate percentage in the recycle stream. In each case study the parameter values were compared with the law limits dictated by Italian Legislative Decree n. 152/ 06 for discharge in surface waters. Results obtained underline which are the intervals of variation of main process parameters, which in some cases don't permit to match the established limits, as for example in the denitrification step by reducing the nitrate recycle until 70% makes the concentrations of NO_3^- higher than those allowed. In all other cases investigated treated water specifics met D.lgs152/06 limits.

Keywords: Leachate, Digestate, Municipal wastewaters, Process analysis

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On the effect of pH and TiO_2 on diclofenac photolysis removal

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Nowadays removal of emerging pollutants from effluents of municipal and industrial waste water treatment plants (WWTP) is one of the main research themes in the framework of protection actions for water environments. Among emerging pollutants, pharmaceutical compounds are some

of the most hazardous, due to their toxicity, persistence and bio-accumulative aptitude. One of the most frequently detected pharmaceutical contaminants in water is diclofenac, an extensively used non-steroidal anti-inflammatory drug.

In this paper, the effect of pH and TiO_2 on photodegradation removal of diclofenac was investigated by using a batch scale experimental set-up equipped with fixed UV light of 254 nm and the irradiation intensity of 400 mJ m^{-2}. Investigations were carried out by keeping constant the initial concentration of diclofenac and the volume of the diclofenac solution. Finally, the kinetic modelling of the diclofenac photolysis was carried out.

Keywords: Photodegradation; Diclofenac; Parametric variation; pH; Titanium dioxide; Kinetic modelling.

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Dynamics of oil droplets at a membrane surface: deformation, reversibility and implications for fouling

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Oily wastewater is a major by-product of many industrial processes such as oil and gas production, petrochemical and metal finishing. These difficult to treat wastewater pose significant environmental risks. Membranes are the leading technology to treat a range of emulsified oil droplets, from sub-microns to tens of microns. However, membrane operation is severely limited by oil fouling, which is poorly understood, particularly its dynamics on a micro-scale. The common indicators used to analyze membrane fouling propensity are contact angle, rejection, flux decline and recovery, which are controlled by operating parameters such as pH, temperature, cross-flow velocity, trans-membrane pressure and feed concentration. However, the strong tendency of oil droplets to deform and coalesce may influence the fouling characteristics, and an investigation of these may lead to an optimization of the operational parameters.

In the presented study, direct microscopic observation during filtration was used to quantify the dynamics of oil droplets on a micro-scale, as well as their impact on membrane performance on a macro scale, concurrently. Oil/water emulsions consisting of fluorescently-dyed hexadecane/ Triton X-100/ water were separated employing UF polyethersulfone membranes with a range of MWCO's (1,10,100 kDa). The shape of individual droplets was imaged in 3D, using confocal microscopy, as a function of the permeation rate (V), droplet radius (R). The results demonstrate a clear correlation between drop deformation from a sphere to an approximate hemisphere in response to increase in the permeation rate (see Fig. 1 for representative microscopic images) and droplet radius.

Furthermore, the reversibility of droplet deposition was assessed through image analysis of membrane surface coverage. The results demonstrate that at low permeate flux (~$2 \cdot 10^{-6}$ m/s), the droplets are easily removed by crossflow cleaning (0.3 m/s at zero applied pressure) leaving a clean surface, whereas at a high permeate flux ($8 \cdot 10^{-5}$ m/s), deposition is mostly irreversible (more than 80% of the original surface coverage remains post-cleaning). These results demonstrate that a 'critical' flux exists, and offer a first step towards revealing the physical-chemical-hydrodyanamic mechanisms at play, and their influence on fouling reversibility. Such insight may lead to better design of membranes and process conditions.

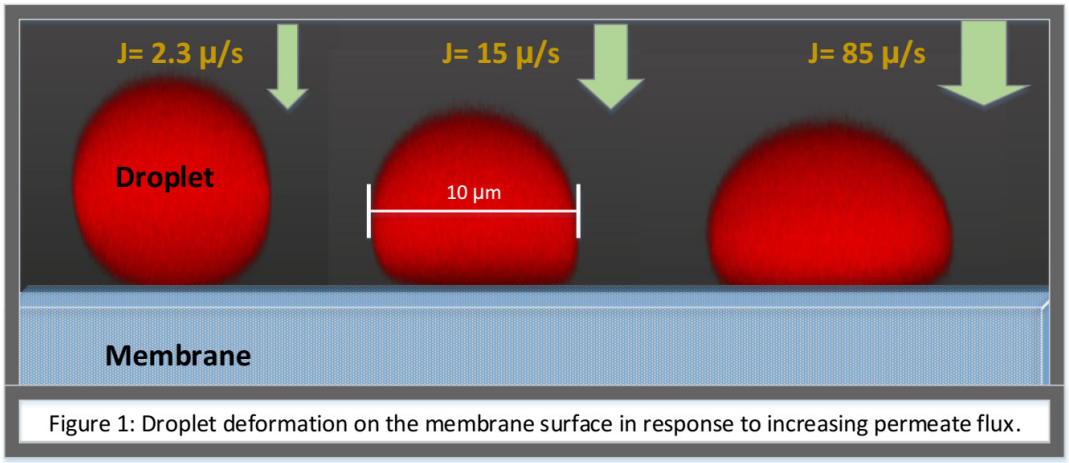

Figure 1: Droplet deformation on the membrane surface in response to increasing permeate flux.

Keywords: Oil - water separation, Ultrafiltration, Droplets dynamic, Fouling

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Desalination, (de)securitization and cooperation

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The concepts of securitisation and de-securitisation, drawn from the security studies in international relations, explain the discursive construction and deconstruction of security issues. The management of transboundary water resources has long been a national priority issue. By reducing the interdependence between States, large-scale desalination influences these processes associated with the management of transboundary water resources and tends to place them back in the normal sphere of politics. Scholars are inclined to describe securitisation desecuritisation as rather efficient or inefficient processes in terms of cooperation while actually failing to provide a pertinent analysis of the implications of desalination on state interactions. This paper intends to fill in the research gap regarding the nexus between desalination, water (de)securitisation and cooperation. It analyses the theoretical background of the securitisation and desecuritisation theories emanating from the Copenhagen School and applies it to the issue of desalination. Using the Red-Dead canal project between Israel, Jordan and Palestine, it illustrates how desalination can increase or decrease cooperation depending on the sociological context of the (de)securitisation move. Lines of research on the factors and implications of desalination on transboundary hydro-politics are also discussed.

Keywords: Transboundary hydro-politics, Desalination, Security studies, Water security, (De)securitisation theories, Cooperation

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Modeling of a parabolic solar-collector system for water desalination

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This paper presents the design of a parabolic-trough solar-collector system for water desalination in Gaza, Collector-aperture and rim-angle optimization together with the receiverdiameter selection are presented. A comparison of concentrating collectors against conventional flat-plate collectors is presented. It is shown that for large scale water production the parabolictrough collectors are more efficient than the flat plate ones. The analysis considers visible radiation transfer, IR radiation exchange, conductive and convective losses and energy transferred to a fluid flowing through the collector tube. The collector may have a tilted northsouth axis, an east-west axis or it may fully track the sun and geometric parameters associated with tracking the sun are considered.

Keywords: Parabolic-trough collectors, Solar radiation, Solar desalination

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Hierarchical modelling of electrodialysis desalination process

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In recent years, thanks to the development of ion exchange membranes (IEMs) manufacturing industry, Electrodialysis (ED) is spreading as a viable alternative to the more common membrane desalination processes. Therefore, many research efforts have been recently devoted to studying this process both via experimental and modelling activities.

In the present work a novel mathematical model for ED was developed using a multi-scale approach. This method allows to build a hierarchical simulation tool that is able to gauge the impact of all the phenomena involved in the process. The lower-hierarchy model describes the behaviour of the elementary unit of an ED stack, namely cell pair. This model is based on differential mass balance equations and accounts for transport phenomena including salt migration and diffusion as well as water osmosis and electro-osmosis. In addition, Kirchhoff's law together with the Nernst's law for the non-Ohmic voltage drop was used to determine the electrical behaviour of the equivalent circuit. Interestingly, the model makes also use of CFD correlations from a lower scale as input data in order to predict the effect of concentration polarization. In the higher-hierarchy model the whole stack was described, allowing the simulation of multiple cell-pairs together with the end electrode compartments. Again, CFD correlations were used to include the contribution of pumping loss in the overall energy consumption.

The model was implemented in PSE gPROMS Modelbuilder. Several simulations were carried out by changing flow arrangement (co-current, counter-current and cross-flow), operating conditions and stack features. Results showed that the model is able to reliably predict the effect of these variables on the performance of the ED unit investigated. In particular, the model was found capable of estimating the distribution of current density/voltage and concentration along the channels. In addition, stack resistance, overall and specific energy requirements were computed. Collected findings suggest that the model proposed might be a powerful tool to improve and optimise ED process.

Keywords: Electrodialysis, Multi-scale, Process simulator.

Acknowledgments

This work has been performed within the REvivED water project (Low energy solutions for drinking water production by a REvival of ElectroDialysis systems) – Horizon 2020 programme, Grant Agreement no. 685579, http://www.revivedwater.eu

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Water chlorination using in situ electrolysis

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The effects of electrolysis on water are well known since the mid 19th century. This paper will presents the findings of the pilot studies conducted in Israel and Malta to measure the efficacy of in situ electrolytic chlorination of drinking water, especially with low levels of chlorides. The pilots were conducted using a newly developed water electrolysis system which includes a continuous automated self cleaning system. It was determined that this technology can be used as an alternative to hypochlorite dosage for drinking water desalination and can provide the necessary level of chlorine for disinfection. Based on the results, it is suggested that electrolysis can also be used to chlorinate the permeate of the desalination process.

Keywords: Water chlorination; Electrolysis; Electrode fouling

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Microbial desalination for low energy drinking water

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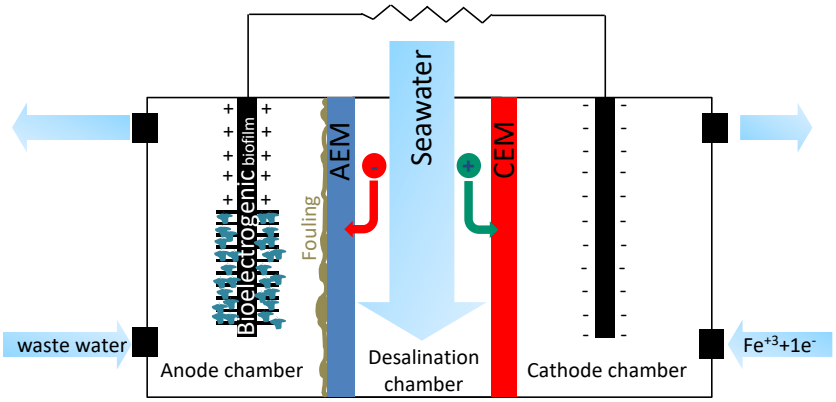
One of the major challenges facing the humanity on earth is the availability of fresh water over the world. Water desalination can fill the gap by producing fresh water from the brackish or even the seawater for drinking or industrial applications. The state-of-art shows that the conventional reverse osmosis (RO) cannot challenge the limit of minimum energy consumption of 3 kWh/m^3. A lot of work has been done in optimising the pump's design and operation for the RO systems. On the other hand, "hybrid systems" by combining the RO with other innovative desalination concepts show an optimistic solution to overcome the thermodynamical limitations of the RO. The microbial desalination cell (MDC) shows a good ability to treat wastewater and in the same time, generate energy to be used for desalinate the saline water using an elect-rodialysis concept incorporated within the MDC as a pre-softening step for the RO system as shown in Fig. 1.

The main goal of MIDES project is to develop the world's largest demonstrator of an innovative and low-energy technology for water production using the MDC as pre-treatment step for RO. Therefore, MIDES will focus on developing a new dedicated Ion-exchange membrane for MDC, new nanostructured electrodes, selection of specialized salt tolerant bioelectrogenic cultures and self-cleaning novel nano-coated ceramic membranes.

In this project, an automated and well controlled system will be developed and used as a smart energy management tool. Besides that, a simulation modelling tool will be used for optimizing the process performance.



Microbial Desalination Cell (MDC)

Fig. 1. Microbial desalination cell MDC concept.

The integration of the whole MIDES concept including MDC and RO, will be first validated at pre-pilot scale. The effectiveness of this innovative solution will be demonstrated at representative demo-sites in three international locations (Spain, Tunisia and Chile). The pilot-plants will be operated for 12 months with challenging target of desalination capacity of 150 l/h of fresh water at low energy consumption combined with WasteWater Treatment (WWT) of 1-3 m^3/d.

Acknowledgement

Partners involved in this project are: FUJIFILM, LEITAT, IMDEA, AQUALIA, SGL, MIKROLIN, SIMTECH, ON-CONTROL, UNESCO-IHE and University of Gabes.

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Membrane-based minimal liquid discharge (MLD) technology for wastewater treatment

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Local government regulations are driving the need for zero-liquid discharge (ZLD) for select wastewater treatment plants in order to protect natural water sources. For many, the expense of current ZLD technologies is cost prohibitive and leaves plant owners desperate to find alternative solutions. "Minimal liquid discharge" (MLD) for wastewater treatment is a membrane-based solution that reduces the volume of the residue stream from a wastewater treatment plant by converting more water to pure water and/or purified brine solutions for re-use. The latter is especially attractive because it also converts a portion of the dissolved solid waste into purified, non-hazardous re-useable material. MLD lowers the cost and environmental impact of traditional thermal ZLD by maximizing water recovery using energy efficient pressure driven membrane technology and leaves only a small volume of water for the final concentration step. Fundamental membrane science was used to design a family of membranes to enable reliable, high recovery performance in challenging waters of MLD systems. The concepts used in the design of the DOW FILMTEC™ FORTILIFE™ XC series products is discussed.

Keywords: MLD, ZLD, FORTILIFE, Reverse osmosis, Fouling, Wastewater

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Characterization of the water resources of the Kasai, Kwango and Kwilu rivers in Democratic Republic of Congo

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The Democratic Republic of Congo has considerable potential for water resources and aquatic ecosystems whose management, protection and enhancement are dependent on new challenges imposed by sustainable development, poverty reduction and climate change.

Unfortunately, the relative weakness of the hydrogeological studies so far carried out in the country means that only very limited data are available to assess the hydrodynamic and chemical characteristics of the rivers of the Democratic Republic of the Congo. For example, in the Democratic Republic of the Congo there is a lack of an adequate database, uncertainty in existing information, lack of adequate technical capacity (institution and human resources) to cope with water.

In addition, there is the lack of a regional approach to cooperation leading to the coordination of the various initiatives and capacity-building programs in the Congo basins. The consequence of this lack of tangible impacts on the land and even more worrying is the lack of research that can lead to the generation of knowledge about the water resources of the Democratic Republic of Congo, coupled with the lack of educational programs that Immediate and future needs for water resources management.

Scientific results

Our study on the characterization of the water resources of the Kasai, Kwango and Kwilu rivers is done thanks to the isotopic tool and the classical hydrogeological techniques:

- Physico-chemical parameters (pH, electrical conductivity, temperature) are measured
- The major ions (anions and cations) were assayed
- The level of water withdrawn
- The measured turbidity.

Keywords: Hydrogeological, Hydrodynamic and chemical, Kasai, Kwango and Kwilu rivers

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Recovery of reverse osmosis membranes at the end of their useful life. Life Remembrane Project

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The main objective of the LIFE+REMEMBRANE project is the recovery of reverse osmosis membranes used in desalination plants that have reached the end of their useful life after 5 to 10 years of operation. Currently, the management system of discarded membranes is through controlled deposits. What is considered a waste, with elimination and substitution costs of between €350 and €600 can become a valuable recovered product through the Remembrane process with costs of less than €100/module.

Many physical and chemical treatments have been developed in the Life+Remembrane project in order to recover these membranes. Once recovered, they can be reused in the same desalination process or in other applications that do not require a low salinity in the water product. The initially foreseen applications are those indicated in RD 1620/2007, regenerated water legislation. The RD establishes that tertiary and disinfection treatments are necessary to reuse water in certain uses: urban, both, residential and services, agricultural for the irrigation of crops; Industrial applications

in cooling towers or evaporative condensers, in ornamental fountains or golf courses, and for the recharge of aquifers.

To achieve these objectives, two equipped prototypes have been built to carry out the following activities:

The membrane recovery pilot plant allows to evaluate the condition of the membranes (production flow and salt rejection) before and after the cleaning treatments, using a standard test of brackish water. For that, in this prototype the chemical cleanings are tested for each fouling detected in the laboratory. Once done, the properties of the membranes are checked after their recovery.

The second prototype aims to continuously test previously recovered membranes in a reverse osmosis tertiary treatment. The effluent from the secondary decantation is introduced into the prototype where a pretreatment is carried out with a mesh filter to remove solids, a microfiltration and, finally, undergoes an inverse osmosis treatment. This plant is capable of producing regenerated water free from solids, contaminants and disinfected until it reaches the requirements of RD 1620/2007 that regulates regenerated water.

The results of the project have made it possible to obtain data to recover membrane modules through new washes at an economically viable cost. These procedures, also, improve the operations of conservation of the membranes and optimize the management of the purification facilities.

During the development of the project, several scenarios have been made, depending on the type of membrane and the associated fouling. As an example, the results of two type cases are shown: treatment by organic dirt and treatment of partial oxidation.

For organic dirt, a combination of alkaline washes and innovative acids was applied achieving a remarkable increase in the production of osmotized water and simultaneously maintaining and improving salt rejection.

Oxidizing treatments demonstrated membrane resistance far beyond the manufacturer's recommendations.

Furthermore, the Remembrane strategy avoids between 27 to 39 kg of equivalent CO_2 by recovered module, compared to the scenario without regeneration.

Keywords: Reverse osmosis, membrane, regenerated water, recovery, desalination, waste

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Installation of intakes and outfalls with trenchless methods: technologies and case studies

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From the mainland into the sea or vice versa. For a sea outfall, an intake or landfall, a pipeline is laid from the mainland out to sea. Such lines can be installed by trenchless technology using pipe jacking, segment lining or pipeline installation methods (HDD and direct pipe), according to requested diameter, length and geological conditions.

This paper shows different trenchless installation methods, also for large diameter pipelines. Practical examples show the multi-purpose use of the technology to lay sewage lines, desalination plants, water intakes or oil/gas pipelines beneath the seabed.

Trenchless installation methods have less impact on the environment and on the existing infrastructure than methods applying open-cut-trenching. They reduce environmental impact and can also be carried out in heavily built-up areas. Shipping and tourisms remain unaffected. The pipeline is better protected against damage and therefore has a longer lifetime. Due to the fact that the tunneled pipeline lays underground, it is safe and maintenance-free for decades.

Keywords: Tunnelled outfalls; Intakes; Landfalls; Horizontal directional drilling (HDD); Microtunnelling; Pipejacking; Segment lining; Direct pipe

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Single-pass zero thermal input membrane distillation (ZTIMD) for seawater desalination

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Zero thermal input membrane distillation (ZTIMD) is proven to be economically feasible by simulation based on a single-pass direct contact membrane distillation (DCMD) process using surface seawater as the feed and bottom seawater as the coolant. Thermal energy required for water distillation in the process was satisfied by extracting the enthalpy of the surface seawater using the bottom seawater as the heat sink. It has been demonstrated that, under one of the favorable conditions, the proposed ZTIMD process could produce pure water with an impressively low cost of $0.28/m^3, which is much lower than that of the currently dominating seawater desalination technology, reverse osmosis (RO), which has a cost ranging from $0.47-2.0/m^3. The simulation was based on literature data and a few justified assumptions.

Keywords: Membrane distillation; Zero thermal energy input; Desalination; Feasibility

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The effect of SRT on biodegradation of municipal wastewater with low COD/TKN ratio in a submerged MBR

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As known, the COD/TKN ratios of municipal wastewaters are typically ranging from 20/1 to 25/1, however, in some cases, municipal wastewater may have a lower COD/TKN ratio causing some operational problems. In the present study, the COD/TKN ratio of the wastewater, obtained from a large scale wastewater treatment plant, was varied between 4.15 and 6.05. In order to determine the optimum treatment conditions for this type of wastewater, the performance and activated sludge properties of the submerged membrane bioreactor (MBR) at different sludge retention times (SRT) were investigated. For this purpose, the MBR was operated at three different SRT values (20, 40 and 80 d), while the hydraulic retention time (HRT) was kept constant (7 h). The operational flux

value was kept at 15 LMH and the MLSS concentrations values under steady-state conditions were found to be 3500, 4200 and 6000 mg/L for SRT values of 20, 40 and 80 d, respectively. The COD removal efficiencies were quite satisfactory for all the SRT values studied. Likewise, the ammonia-N removal efficiencies in all the SRTs were over 80%. Apart from the conventional performance analyses, a number of analysis regarding activated sludge properties, such as EPS, SMP, hydrophobicity and CST were also carried out. The carbohydrate and protein fractions of EPS were found to be between 46.74 to 48.35 mg/g MLSS and 72.95 to 77.77 mg/g MLSS, respectively. The total EPS contents decreased gradually, as the SRT was increased. The relative hydrophobicity values were found to vary between 41–46% for different SRT values. As it was expected, the relative hydrophobicity values decreased with decreasing P/C ratio of EPS. The CST results obtained indicated that the filterability of activated sludge deteriorated as the SRT was increased.

Keywords: COD/TKN ratio, Sludge retention time, Municipal wastewater, Membrane bioreactor

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Seawater desalination in China: development status and prospect

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China has been facing severe water resource shortage due to the disparity between water supply and demand, especially in some coastal areas, such as Dalian, Qingdao, Rizhao, Zhejiang, Fujian and Hainan, etc. With the economic development, population growth and increasing urbanization, water demand has increased substantially. According to China Water resources Bulletin in 2014, the total amount of water resources in China was 2,726.69 billion m³ in 2014, 1.6% less than past years; per capita water resources was 1,998.6 m³, less than 1/4 of the global per capita water resources. The total water resource of the 11 provinces (autonomous regions, municipalities) in coastal areas was 730.28 billion m³ in 2014, per capita water resource was 1,523.2 m³ (76.2% of the national per capita water resources). Among the solutions, seawater desalination is of extreme importance to improve water supply, without impact on climate and precipitation, and with superior quality of output water, which can satisfy specific needs of some special industries, such as boiler and makeup water for power generation, steel manufacturing, and petrochemical sector, etc. As a result, seawater desalination, serving as a good water supply option, has received unprecedented attention in China, especially, in coastal areas, which, though experiencing rapid economic and social development, suffer from severe water scarcity. Under the circumstances, In December 2015, Planning for Seawater Utilization during the 13th Five-year Plan assumed that, By 2020 China's capacity of seawater desalination will reach 2.2 million m³/d, the capacity in coastal areas will add more than 1.05 million m3/d and the capacity in island areas will add more than 140,000 m³/d.

After a decade of development, seawater desalination technologies and applications in China have been improved remarkably. The total capacity increased from 1,000 m³/d in 2000 to 119,6005 m³/d in 2016, up by 16.51% compared with 2015. In 2016, 8 projects were constructed with a newly added capacity of 169,460 m³/d. By now, 147 seawater desalination plants have been constructed in China, located at Tianjin (317,295 m³/d), Zhejiang (240,325 m³/d), Hebei (168,600 m³/d), Shandong

(260,735 m^3/d), Guangdong (97,260 m^3/d), Liaoning (83,534 m^3/d) Fujian (27,311 m^3/d), Hainan (11,445 m^3/d) and Jiangsu (5,100 m^3/d). By December 2016, China has completed 37 desalination projects of 10-kiloton or larger capacity. The capacity is 1080,268 m^3/d. China has completed 38 projects higher than kiloton but lower than 10-kilo-ton. The capacity is 123,340 m^3/d. 72 projects under kiloton have been completed, producing 16,585 m^3/d. At present China adopts mainly SWRO and MED technologies. By December 2016, there are 128 RO desalination projects with 825,515 m^3/d capacity accounting for 69.02% of the total in China; besides there are 17 MED desalination projects with 364290 m^3/d capacity accounting for 30.46% of the total desalinated water is used mainly in water-intensive industries like power, (33.88%), petrochemical and chemical (9.12%), and iron and steel (8.37%); as well as municipal use (33.04%). Only 0.73% is in other areas. With the implementation of the new development strategy of coastal areas, water demand will inevitably increase. Facing the challenge of water resources shortage, seawater desalination will become a necessity in China, and an inevitable national strategy to address the issue.

Keywords: Seawater desalination, China, Development status, Prospect

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Modeling of osmotic energy extraction and exploration of real PRO parameters

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Power density is of most interesting for application of pressure retarded osmosis (PRO) in potential salinity power generation. Since hydraulic pressure drop constitutes a direct loss of the power generated in PRO process, power density should be evaluated in a module scale where hydraulic pressure drop could be observed. In this paper, a numerical model, which takes into account the dilution effect and hydraulic pressure drop, has been developed from mass and momentum balances focusing on analyzing the effect of hydraulic pressure drop on power density in an empty rectangular module. The simulation results show that power density reduced about 35% even under a small hydraulic pressure drop of 5.91 kPa. The novelty of this work is the calculation and analysis of power density based on an overall PRO module energy balance. The developed model offers a useful tool of optimizing operation conditions and module size for enhancing PRO power density.

Keywords: Pressure retarded osmosis; Osmotic energy; Finite element PRO model; PRO process analysis; Power density

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Brackish water off-grid desalination systems for developing countries

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The REvivED water project aims to contribute to overcoming the drinking water challenge through desalination technology. The goal is to produce safe and affordable drinking water with a significantly reduced energy consumption compared to the current state-of-the-art technology. The overall project comprises several systems and applications with twelve pilots in total, ranging from Electrodialysis (ED) small systems for brackish water desalination to larger scale hybrid (RED/ED-RO) systems for sea water desalination.

Specific attention is devoted to develop energy efficient and robust brackish water desalination systems for application in developing countries.

To reduce the energy consumption of the desalination process, several design parameters have been optimized, e.g., membranes and spacers characteristics, stack configurations, flow path length. To assure the system robustness, several concepts have been investigated, including pre-treatment options, capacitive electrodes, one pass flow as well as gravity driven flow. Intensive modelling and experimental validation are being carried out for the process and system design.

The first brackish water desalination results demonstrate that up to a conductivity of ~4.000 µs/cm the project energy consumption target of 0.4 kWh/m³ can be achieved.

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Impact of module size on solar powered membrane filtration (UF-NF/RO)

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Integration of solar photovoltaic (PV) systems and membrane filtration technologies, namely nanofiltration (NF) and reverse osmosis (RO), has been suggested as a sustainable solution to provide drinking water to the remote locations where natural freshwater resources are scarce

and are far away from central water supply and grid electrical connections [1]. To increase the efficiency and decrease the cost of such systems it is recommended to avoid the use of batteries in PV-powered membrane systems. However, the NF/RO membranes integrated in directly coupled PV systems experience fluctuation in energy, and consequently in pressure and flow rate, which is due to landscape and weather conditions. Spiral wound (SW) elements of NF/RO membranes (commercially available in different sizes) have been used in most of PV-powered membrane systems [2,3]. However, relatively little is known about the effect of module size (with the same membrane area) on the performance of NF/RO SW modules, operating with fluctuating energy (variation of flowrate and pressure).

To investigate the impact of module size on variation of permeate flux, solutes retention and specific energy consumption (SEC), a directly-connected PV-powered RO membrane system was used in remote areas, under fluctuating solar irradiance conditions. The renewable energy (RE) powered membrane system consisted of two stages, ultrafiltration (UF) pretreatment followed by NF/RO, using NF270 and BW30 modules. Two different configurations were investigated: (1) one 4" NF/RO module (membrane area 7.2 m^2 (BW30) and 7.6 m^2 (NF270)); (2) three 2.5" modules connected in series (total membrane area 7.8 m^2). A high fluoride content (56 mg/L) brackish water (4100 mg/L TDS) from Mdori borehole, in a remote village near Lake Manyara (Northern Tanzania), was treated with a set point of 5.5-6.0 bar pressure and 600 L/h feed flow rate.

Permeate of the BW30 membrane had a higher quality (meeting the WHO fluoride guideline) and lower flux compared to the NF270 membrane (which could not produce drinking water quality), and consequently a significantly higher SEC. For both membranes the first and second 2.5" modules showed a better performance in terms of permeate flux, SEC and recovery than the single 4" module, while the last 2.5" module affected performance negatively.

Despite the better hydrodynamics, the overall performance of the triple 2.5" configuration did not improve which was due to the poor performance of the last module. Impact of module size on the cumulative permeate quality (especially fluoride concentration) was more significant for the NF270 than the BW30 membranes. This was attributed to the higher permeability.

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Computational fluid dynamics approach to determine membrane concentration polarization and module performance with fluctuating energy

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Membrane filtration modules, in particular spiral wound membrane modules, are widely used in water treatment and desalination. In order to understand the retention mechanisms in nanofiltration, knowledge of the wall concentration is essential. Given the uncertainty in hydrodynamics that are influenced by fouling or variation in pressure and flowrate cause by fluctuating energy, such calculations are challenging. Numerical flow simulations have been increasingly used in recent years, predominantly for the purpose of investigating the influence of different flow regimes on concentration polarization and fouling control [1].

A 2D-Computational Fluid Dynamic simulation was performed using OpenFOAM 2.1.0 to calculate the wall concentration and boundary layer thickness over the length of a module. The influence of module type was investigated using two system configurations, namely three 2.5" modules in series (BW30-2540 or NF270-2540) and one 4" module (BW30-4040 and NF270-4040) with total membrane areas of 7.8 m^2 and 7.2-7.6 m^2, respectively. Model data was compared to experimental data obtained with renewable energy powered system [2, 3]. Energy fluctuation results in fluctuation of pressure and flow as solar irradiance fluctuates over the course of a solar day and the passing of clouds. Experimental data was used to determine extracting performance at three energy scenarios, namely i) full power at maximum solar irradiance (1038.9 W/m^2), ii) medium level fluctuation (353.7 W/m^2), and iii) low level fluctuation (185.2 W/m^2).

The simulation results, for both membranes, at the highest energy level (532-610 L/h and 5.4-6.8 bar), showed that both bulk and wall concentration increased over the length of the module. In the system with three 2.5" modules the wall concentration was closer to the bulk concentration due to the higher flow velocity in a smaller channel. Indeed, the simulation of the 2.5" BW30 modules resulted in a wall concentration of 0.88% above the bulk concentration over the length of the module; in the case of the 4" module it was 2.33% above. This means that an almost complete absence of concentration polarization for the 2.5" BW30 system was determined. In the case of NF270 the boundary layer thickness decreased over the length of the module, for BW30 it resulted constant and almost zero. At the medium energy level (330-360 L/h and 2.8-3.9 bar), the simulation results regarding the wall and bulk concentration and the boundary layer thickness of the NF270 systems, are in agreement with that obtained at the highest energy level, although permeate flux decreased significantly due to the lower pressure. For the BW30 modules, the feed concentration

was constant over the length of the modules in both configurations. Indeed, at this energy level, the feed pressure was about 2.89 bar, and hence too low to overcome the osmotic pressure of 2.88 bar of this water. In consequence no water permeation occurred. At the lowest energy level (170-220 L/h and 1-1.5 bar), the feed pressure was well below the osmotic pressure. A negative permeate flux for the module 2.5"BW30 and 4" NF270 was obtained, while for the other two modules the simulation was interrupted because of numerical instabilities.

Results from this study show that the model is able to describe the filtration process in spiral wound membrane modules under fluctuating energy conditions and provide information about the wall concentration and boundary layer thickness over the length of a module by using experimental data. Further investigations on the possibility to modify the boundary conditions of the model are required in order to incorporate pressure drop along the module and allow for negative permeate flux.

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Desalination of real brackish groundwater using electrodialysis

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The provision of potable water is crucial in developing countries and isolated communities. According to the World Health Organization 748 million people are still lacking access to the improved sources of water [1]. The presence of inorganic trace contaminants in surface, brackish and groundwater are still a critical issue for environment and public health [1, 2]. In this work, the removal of inorganic trace contaminants from a real brackish groundwater originating from a remote Australian community ( ) using electrodialysis was investigated as a function of applied voltage and solution pH [3]. Detailed speciation of this very complex water was carried out and the impact on membrane deposition examined.

A higher applied voltage enhanced removal of some species (arsenic (V), boron, lithium, selenium (VI) and uranium) although the mass deposition was enhanced by the higher potential. The deposition of insoluble species at high voltage and their complexation with other contaminants resulted in membrane deposition in the form of adsorption and/or scaling. This influenced system performance in regards to an increase in stack resistance and decrease in removal of total dissolved solids (TDS). The removal of some ions was pH dependent (boron, lithium, sulfate, uranium, calcium, magnesium, strontium, zinc and selenium (VI)), while the removal of other species was pH independent (bromide chloride, fluoride and nitrate). The hydrated radius and strength of hydration shells played a minor role in the removal of ions from real water in comparison to the other parameters (voltage and pH).

Results from this study indicate that although electrodialysis is effective in the removal of contaminants from real waters, further investigation are required in regards to long-term membrane performance with contaminants adsorption and scaling for such complex waters.

Fig. 1. Pictures of Pine Hill Station in Central Australia during the 2005 drought (photo © Schäfer).

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Pro's and con's of inland BWRO-concentrate freeze desalination

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Freeze desalination processes have certain advantages over most other desalination processes, such as lack of costly metallic-heat-transfer surfaces or membrane-mass-transfer surfaces, which are also vulnerable to scale-deposition, fouling, deterioration and corrosion. Freeze Desalination methods, on the contrary, have the numerous tiny ice particles as separation surfaces – free-cost, renewable, self-generated, free of scaling, fouling and corrosion. This enables desalination at higher recovery ratio than RO or evaporative processes. In addition, the very low process temperatures and moderate pressures allow less expensive construction materials for the vessels and auxiliary equipment.

The resulting cost savings are, however, counter balanced by the relative complexity of the freezing process – more process-stages and equipment: freezing-solidification, heat pumping, melting, ice washing, feedwater precooling heat exchange, excess-heat removal, air removal and insulation, as well as the complex operation of at least three phases: solid ice [which occasionally tends to accumulate and adhere to pipes, valves, heat transfer surfaces or even rotating components], liquids,

vapor and sometimes immiscible refrigerant. All the many involved problems have been solved almost 50 years ago, but the accumulative costs of these solutions raised the total cost somewhat above the competing processes – reverse osmosis [RO], ED and MED.

However, the advantages can be utilized in special cases (a) where the feedwater is almost saturated by calcium and carbonates and/or sulfate ions that will result in scale deposition, and (b) where desalted water is essential. A classic case is brackish water RO [BWRO] concentrate as a potential feed, where both conditions exist. In particular, where the desalination plant is located inland, off shore.

Inland desalination plants are often challenged by the high cost of concentrate removal, unlike SWRO. This concentrate is forbidden by the authorities to be returned into the aquifer in many cases. The alternative solutions such as evaporation ponds, long distance pumping or transportation are very expensive. This may cost even more if the original BW feedwater is expensive [e.g. deep aquifer source].

Thus, reducing the ratio of feedwater to desalted water from say 1.4, [scaling limit, typical for BW, recovery ratio ≈ 0.7] to about 1.1 by freeze-desalination of almost 70% of the BWRO concentrate, will save over 21% of the BW feed supply (BW wells, equipment, pumping-energy and pretreatment-chemicals). Even more so, the **main saving** will come from the huge reduction by 75% of the final concentrate rejection, which might be very expensive as mentioned above. Even if the "economy of scale" is negative for the RO part for identical total production rate, yet 20-25% of the total water cost may be saved under certain conditions.

Disadvantages: Complication of 2 technologies connected in series, the freeze-desalination quite complex by itself, although proven commercially in Eilat, Israel. However, the successful operating experience is of only few years with 3-4 parallel units. Also, very few potential manufacturers exist, as well as the scope of the potential market for such plants, which is questionable.

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A tribute to spectacular membrane failures

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The use of RO membrane has become ubiquitous in water treatme nt.

Membrane life depends on external factors such as : fouling, cleaning procedures, plant pretreatment, chemicals compatibility, etc…

Most RO membranes field papers revolve around case studies about membrane failure & plant performance recovery.

But sometimes membrane performance cannot be recovered.

Popular belief has it that membrane damage is usually caused by contact with oxidizing agents, but physical damage is much more common.

In some cases, the fouling can become irreversible despite very aggressive cleaning procedures, either due to the nature of the foulants or layer compaction.

In this paper, the authors review the most common types of irreversible failure encountered by Genesys during membrane autopsies, as a warning to plant operators.

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Coupling CFD simulation with a simplified process model for reverse electrodialysis units

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Salinity gradient between two solutions is a renewable source of energy. Among the technologies able to exploit the salinity gradient, reverse electrodialysis (RED) is an electrochemical process for electrical power generation through direct conversion. Ion exchange membranes, piled alternately and separated by net spacers or membrane profiles, are the key elements of a RED stack. A multiplex phenomenology occurs in RED units; Ohmic and non-Ohmic (due to concentration changes) voltage losses and pressure drop are the main issues, and the membrane/channel configuration is crucial for the stack performance. In this framework, mathematical modelling can be a powerful tool for predictive purposes and for optimization studies.

This work presents a coupled simulation strategy based on combining Computational Fluid Dynamics (CFD) modelling with a higher-scale simplified process model aimed at predicting the performance of RED stacks. Fluid dynamics and mass transport are simulated by solving 3-D Navier-Stokes and continuity equations along with a convective-diffusive transport equation in the periodic domain of the cell pair, including complex configurations with either spacers or profiled membranes. Correlations for the friction coefficient and the Sherwood numbers, related to pumping power losses and polarization voltage losses, respectively, are obtained. Moreover, simple 3-D finite volume methods are used to solve a Laplace equation for the electrical potential, thus providing Ohmic resistances of the cell pair. These results are provided as input data to the process simulator, which includes (i) mass balance equations along the channels, (ii) Nernst's law for the local electromotive force (inclusive of concentration polarization phenomena effect) and (iii) Kirchhoff's law for the equivalent circuit. The voltage-current and (gross and net) power-current curves are obtained as process model outputs.

Preliminary results show that spacers or profiles with large pitch to height ratios yield larger net power densities. The coupled computer-based simulation approach provides a predictive fast-running tool to investigate the potentials of alternative designs, to orient experimental activities and optimize real RED systems.

Keywords: Salinity gradient energy, Reverse electrodialysis, CFD, Process model.

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Experimental investigation and modelling of diffusion dialysis process for regeneration of acidic pickling solutions

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Pickling is one of the key steps in metal finishing industries, where HCl solutions are largely used thus generating significant amounts of spent waste solutions containing high concentrations of metals and acid. The recovery of acid from such waste solutions is thus one of the most beneficial steps for reducing the environmental and economical impact of these processes. 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, a single-cell diffusion dialysis module equipped with a FumaTech Anion Exchange Membrane (AEM), operated in a batch mode, has been employed in order to study the effect of some parameters on the efficiency of HCl recovery from waste pickling acidic solutions. In addition, a mathematical model, capable of simulate and predict this process, has been also developed and validated with experimental information.

The laboratory test-rig and procedures have been first evaluated and optimised by measuring salt and water fluxes with artificial NaCl solutions with different types of AEMs. Then, experiments with HCl solutions were carried out, at different compositions of diffusate and retentate streams, varying HCl concentration values in the range of 0.1-3 M. HCl and water osmotic fluxes were measured and their dependence on operating conditions was identified. Also the effect of the presence of selected iron salts were investigated in order to simulate the operation of the system when treating actual pickling solutions. In particular, the acid diffusion permeability as well as the water osmotic permeability tend to increase when increasing the solution concentration. In addition, an increasing HCl recovery is detected in the presence of iron chloride.

Keywords: Pickling solution, Diffusion dialysis, Hydrochloric acid recovery.

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Modelling reverse electrodialysis process via exergy analysis

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Salinity Gradient Power Heat Engines (SGP-HEs) represent a novel technology to convert low grade waste heat into electricity. Reverse Electrodialysis Heat Engine (REDHE) is one of the possible application of this concept, where a common RED unit is coupled with a thermal regeneration unit supplied with waste heat to restore the salinity gradient of the streams to be fed back to the RED unit. In a RED unit, anion and cation exchange membranes (AEMs and CEMs) are alternatively stacked and interposed between salt solutions at different concentration generating an electric potential difference over each membrane along with a selective transport of cations and anions from the concentrated solution to the diluted solution. The generated ionic current is converted by redox reactions into electric current at two electrodes placed at the end of the membrane pile. The performance of a RED unit may be reduce by some detrimental phenomena as (i) osmotic flux, (ii) salt flux and (iii) co-ions flux (due to a membrane permselectivity lower than one). The present work is devoted to identifying the impact of these irreversibility on the RED unit performance via Exergy Analysis: it represents a useful tool to recognize and quantify exergy destruction. The assessment of exergy destruction due to irreversibility occurring within a component provides fundamental information on the bottlenecks of the process, identifying possible design and operative improvements. RED exergy analysis outputs will be crucial for a reliable design of the whole heat engine.

Exergy analysis was carried out by developing an ad-hoc distributed parameter model which calculates all chemical exergy flows by taking into account all beneficial and detrimental phenomena occurring within the RED process. Efficiency indicators including exergy efficiency and dissipation are suitably defined to quantify how much each phenomenon affects process performance.

The effect of different operating conditions (i.e. external load, feed solution concentrations and flow arrangement) on power generation and performance indicators were investigated.

Keywords: Salinity gradient power (SGP), Reverse electrodialysis (RED), Exergy analysis; Energy productions, Irreversibility

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NH_4HCO_3–water solutions regeneration in RED closed loop applications

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Reverse Electrodialysis (RED) in closed loop arrangement (Reverse Electrodialysis Heat Engine - REDHE) is a promising technology to convert low-grade waste heat into electricity. RED is a membrane process exploiting the salinity gradient between a concentrated and a diluted solution to generate electrical current. Due to the transfer phenomena occurring in the RED unit, the two exiting solutions are partially mixed. Thermal regeneration processes can be used to restore the initial conditions of the two solutions, thus closing the loop.

In this regard, ammonium hydrogen carbonate (NH_4HCO_3) salt solutions are suitable for such applications, being able to decompose at temperatures above 40-45 °C into a gaseous phase containing NH_3 and CO_2. Low temperature waste heat (T<80°C) can be used in a suitable thermal regeneration unit to recover these gases contained in the dilute solution. The decomposed gases, once stripped, can be finally reabsorbed in the concentrate one, thereby restoring the initial concentrations.

The present work investigates two kinds of regeneration units fed by NH_4HCO_3-water solutions. More precisely (i) an air stripping column and (ii) a distillation column were designed, built and analysed both via experiments and process modelling. The effect of several operative conditions on the removal efficiency of the two systems was investigated. In particular, for the case of the stripping column the influence of flowrate (air and inlet solution) and regeneration temperature was analysed, while, for the case of the distillation column, different pressures and reboiler duties were tested. Effect of feed solution concentrations was studied in both cases.

Finally, two models were developed on Aspen Plus® software, one for each kind of regeneration unit. Model results were compared with the experimental ones and a good agreement was found, thus validating the two models proposed.

Keywords: Reverse electrodialysis heat engine; Salinity gradient power; Waste heat; Ammonium bicarbonate, RED, SGP.

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Ion exchange membrane deformation and its relevance in reverse electrodialysis

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Reverse electrodialysis (RED) is an innovative electro-membrane technology for electric energy generation from two salt solutions with different concentration. This different concentration is the driving force to a selective movement of ions from the concentrate channel to the dilute one oriented by Ion Exchange Membranes (IEMs). Typically, RED stack are made by piling alternatively cation exchange membranes and anion exchange membranes with the aid of spacers or profiles built on the membrane surface. Two electrodic compartments are placed at the two ends of the stack, where the ion flux generated is converted into an electric current able to circulate through an external load connected to the stack.

Several studies have been recently focused on the RED process optimization with the aim of increasing the net power density produced. On the one hand, the geometries and the hydraulic losses relevant to spacers, the fluid dynamics behavior of the solutions into the channels and the electro-chemical phenomena in the stack have been thoroughly analyzed. On the other hand, membrane deformation has been poorly studied, despite membrane deformation may strongly influence the performance of RED units by affecting shape and dimension of the channels, thus changing their hydraulic losses and electric resistance.

In the present work, an experimental and theoretical assessment of the deformation of a class of IEMs has been carried out, through a combined approach involving theoretical analysis, numerical modelling and experimental campaign focused on the characterization of IEMs under typical RED operation conditions. A Finite Element Method model was developed and experimentally validated allowing for a detailed prediction of membrane deformation within the RED stack and for an effective integration with a separately developed multi-scale modeling tool able to predict the power generation performance of a RED unit.

The effect of different channel configurations and operating conditions on membrane deformation and, consequently, on pressure drops and electrical variables characterizing the RED operation is thoroughly investigated and presented.

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ResourSEAS Company: Sustainable magnesium hydroxide extraction from salty solutions via a novel membrane reactor

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About 71% of earth is covered by water and about 97% of this water is salty while only the 0.65% of the fresh water is directly available as the remaining part is trapped within polar caps. Thus, Salty water is thus really abundant, but it is as abundant as underutilized.

ResourSEAS S.r.l. is a novel spin-off company of the University of Palermo in Sicily (Italy) which was just born to offer services aimed at extracting as many resources as possible from seawater according to social, environmental and economical sustainability. ResourSEAs members have gained a consolidated experience in water technology in the last ten years and have developed the idea of a *seawater integrated cycle* allowing the integrated extraction of fresh water, table salt, raw materials (e.g. magnesium) and energy (via salinity gradient power technologies) following the circular economy concept.

Magnesium extraction is at the moment the core business of the company. This compound has been judged as one of the 20 critical raw materials for the European Commission because it has high economic relevance, yet high supply risk. ResourSEAs have recently developed and patented a membrane reactor allowing the extraction of magnesium hydroxide from seawater or brines.

Traditional reactors perform the magnesium extraction via a reactive precipitation where the salty water (rich of magnesium chloride) is mixed with an alkaline solution. Reaction occurs and magnesium hydroxide, once formed, precipitates thus resulting into an easy separation process. On the other hand, direct mixing between solutions cause the formation of by-products which are more complex to be separated leading to high process costs or to a low purity product. This disadvantage is more troublesome, when low cost reactant as lime is used.

ResourSEAS reactor is named Crystallizer Ionic Exchange Membrane (CrIEM) and takes advantage from the use of ionic exchange membranes. For the case of magnesium extraction the reactor is equipped with anion exchange membranes separating the salty solution from the alkaline solution. Thanks to the selective membrane only anions are allowed to pass through thus avoiding the direct mixing of the two solutions and the consequent by-products formation. This great advantage may even allow the use of low cost reactant as lime without affecting product purity and granulometry.

Keywords: Magnesium extraction, Seawater resources, Raw materials.

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