First Conference Session

September 2018

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Dissemination Level	
PU Public	X
PP Restricted to other programme participants (including the Commission Services)	
RE Restricted to a group specified by the consortium (including the Commission Services)	
CO Confidential, only for members of the consortium (including the Commission Services)	

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This report has been produced as part of the project "*Low energy solutions for drinking water production by a REvival of ElectroDialysis systems*" or **REvivED water** for short. The logos of the project partners are shown below. More information is available at www.revivedwater.eu

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1. Introduction

The "Desalination for the Environment: Clean Water and Energy" conference was organised by the European Desalination Society (EDS) from the 3rd until the 6th of September 2018, at the Divani Caravel Hotel, in Athens, Greece. The conference attracted more than 350 participants. All of them got informed about the project, as the REvivED water leaflet was included in the conference bag. In addition to that, the project was promoted through presentations during the conference programme and through the presence in the exhibition areas as described in the following sections.

2. REvivED water session

As part of the conference, one session was fully dedicated to the REvivED water project. The session took place on Tuesday September 4th, from 14:00 to 16:00 and was chaired by Abdulsalam Alhadidi (FUJIFILM) and Michael Papapetrou (AquaTT). Below are introduced the five presentations were included in the session.

2.1 The REvivED water project

(N. Tiggelman and M.Papapetrou)

In the first presentation, Michael Papapetrou (on behalf of the project coordinator Natalie Tiggelman), started by introducing the context. Despite remarkable progress so far, the high costs and energy requirements are still critical factors preventing the wider adoption of desalination. Continuous innovation is necessary to make the desalination technology more affordable.

Then it focused on introducing the REvivED water project. It is a European Commission-funded pilot project led by Fujifilm Manufacturing Europe BV, focusing on the potential of electrodialysis for desalination applications. The project builds on the progress achieved in the performance and cost of ion exchange membranes. This allows the industry to benefit from the inherent advantage of electrodialysis, whereby only the ions (salt) flow through the membranes, rather than the water.

The application of these innovative ion exchange membranes will allow for the use of electrodialysis to desalinate seawater. The REvivED water project will go one step further, applying a reverse electrodialysis (RED) unit as a pre-desalination step, for sites where a low salinity water stream (such as treated wastewater) is available. The RED pre-desalination step can also be used in (existing) reverse osmosis plants.

If there is no treated water available, a simple electrodialysis system can be added to reverse osmosis plants to pre-desalinate the sea water. The hybrid system with electrodialysis as a pre-desalination can increase the water recovery of reverse osmosis systems, producing more drinking water from the same amount of seawater at low energy consumption and at affordable costs.

The REvivED water project is also addressing the brackish water desalination field, where it brings together past experience and new technological developments in solar powered system targeting remote areas in developing countries that are threatened by water stress.

Finally, the project tests the application of the electrodialysis principle for water softening.

It was explained that all system configurations will be tested in real conditions, demonstrating the operation of electrodialysis in different settings and for various applications. The seawater desalination solutions will be tested in Europe. The brackish water systems powered by solar energy will be tested in remote locations of developing countries in Africa and in Asia.

2.2 Donnan Dialysis for tap-water softening

(A. Brys, L. Pinoy, A.M.M Alhadidi, R>Gueccia, A. Cipollina, J.W. Post)

In this presentation, Abdusalam Alhadid, started by introducing the problem of hard water in both domestic and industrial applications, caused by an excess of calcium and magnesium ions. It significantly decreases the lifetime and efficiency of equipment which has negative technical and economic consequences. Existing water softening technologies have several disadvantages, such as a high chemical use (crystallization, ion exchange), water and energy consumption (nanofiltration).

A promising technology for the softening of tap water is based on Donnan dialysis (DD). DD is a separation process with which divalent cations can be removed from tap water using cation-

exchange membranes (CEMs) and a concentrated salt solution (receiver). No external driving force is used in DD, ion-exchange is only due to a chemical potential gradient across the CEMs.

A lab-scale setup for DD was used to investigate the operational parameters that influence the hardness removal and ion fluxes. This was combined with the theoretical modelling. Accumulation of divalent ions in the CEMs was discovered, therefore a conditioning step was required to have the same starting point in every experiment. In contrary to theory, it was observed that higher salt concentrations in the receiver did not improve the performance, it even deteriorated at high concentrations. The influence of the receiver composition showed that up to 8.4 g L-1 Ca^{2+} can be added before replacing of the solution is necessary. The driving force remains high enough to move Ca^{2+} against its concentration gradient. Corresponding to the theory it was observed that a decrease of the recovery and an increase of the flow rate both resulted in an increase of the removal. Different types of Fujifilm CEMs were examined. The electrical resistance (ER) and permselectivity (PS) of the CEMs were found to be crucial as they directly determine the ion flux, a higher ER results in a decrease of the ion flux. Influence of water permeability (WP) was not noticed due to the fact that the experiments performed with a relatively short residence time. The DD process can soften hard water in one pass through the system if sufficient CEM area is available. Theoretical modeling enables to predict equilibrium and ion fluxes, these ion fluxes were validated by experimental results.

The economical assessment in terms of CAPEX and OPEX showed that further improvement of DD is necessary to compete with other water softening technologies. Relatively high amount of salt usage comparing to the ion-exchange resin is the biggest issue that needs to be solved first.

2.3 Small-scale ED desalination systems for brackish water.

(T. Zwirner, H-J. Rapp, A. Al Habibi, L. Gutierrez, A. Cipollina)

This presentation, delivered by Tobias Zwirner, described the small-scale ED desalination units powered by Off-Grid solar systems for the use in developing countries, which were developed within the project. The system includes the following modules:

Pre-Treatment Unit: Slow Sand Filter and Active Carbon: The Slow Sand Filter technology and activated carbon was chosen out of seven pre-treatment options due to its robustness, simplicity, and economic viability.

Capacitive Electrodialysis (CED) desalination unit: A desalination unit with capacitive electrodes, new generation of ion exchange membranes and innovative stack design that is able to run three operation modes (single pass, batch, feed & bleed) was developed.

Post-Treatment: Chlorine Cartridge: A chlorine treatment of the out-coming water and for the system's cleaning purposes was chosen as the most viable option.

Concentrate Disposal: Evaporation pond for brine: The salt concentrate water as waste product of the system is being collected in an evaporation pond.

Solar Power Supply: The PV system to serve all power needs of the system was sized with the further developed EasySizing RevivED software.

Control and user interface: The remote monitoring and control software is in the process of being implemented in the system to offer the possibility to transfer data via GSM from all parts of the world.

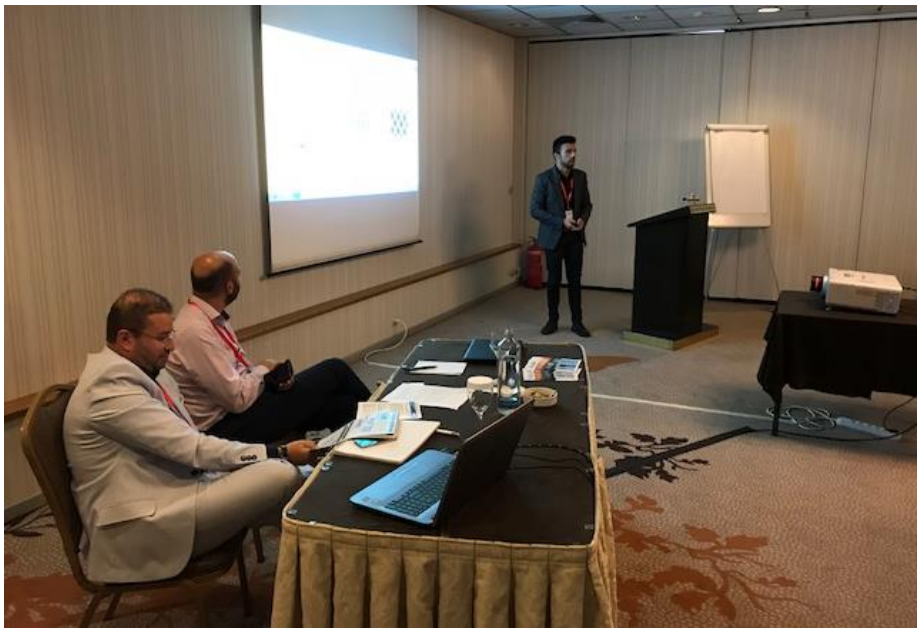
For the first field test a salted well in the desert of Somaliland was selected. The PV powered pilot plant was installed in May 2018 at the site in the village Beeyo Gulan to collect data from the operation under the Somali sun.

The presentation provided an insight into the technology used, the performance of the first pilot run in the field and the experiences collected during the preparation and operation of the field test.

2.4 Fluid-structure interaction in electromembrane processes

(G. Battaglia, L. Gurreri, A. Tamburini, A. Cipollina, M. Ciofalo, G. Micale)

The fourth presentation was given by Giuseppe Battaglia. Initially, it was explained how profiled membranes exhibit interesting performances and offer countless geometric alternatives, but their



the mechanical behaviour and their interaction with fluid dynamics has been poorly investigated so far. In membrane-based processes, a trans-membrane pressure (Ptm) between the different solutions flowing through a module may be a design feature or may arise for various reasons, including flow arrangement and differences in physical properties, flow rate or friction coefficient. This leads to local deformations of membranes and channels, affecting flow and mass transfer characteristics, thus causing uneven distributions of flow and mass fluxes, which worsen the process performance.

In this work, an integrated model was developed for the numerical simulation of local mechanical deformations and of fluid dynamics and associated mass transport phenomena inside deformed channels. Two diverse profiled membrane types ("overlapped cross filaments", OCF, and "round pillars", RP) were simulated under conditions representative of (reverse) electrodialysis and under the assumption of perfectly elastic behaviour. 3-D simulations of a couple of membranes and of the interposed fluid were conducted by the unit cell approach (periodic domain). The Ansys Mechanical 18 (Workbench) and the Ansys CFX 18 software was used.

The selected geometries were simulated under Ptm ranging from -0.4 to +0.4 bar, computing expanded and compressed configurations. Then, CFD simulations of the deformed channels were performed, showing significant effects of the deformation on fluid flow and mass transfer. The influence of Ptm was to increase friction under compression conditions (up to 2.2-2.5 times) and to reduce it under expansion conditions (but to a lesser extent, i.e. up to 50-60%). Overall, compression enhanced mass transfer and expansion reduced it, but with smaller and more complex effects than on friction. The influence of the flow attack angle was negligible for friction, but more significant for mass transfer.

2.5 Impact of pretreatment on fouling of ionic exchange membranes in RED systems

(L. Gutierrez, M. Vanoppen, L. Ma, A. Verliefde)

Leo Gutierrez presented the w2ork on pre-treatment. Reverse electrodialysis (RED) is an electrochemical membrane technology that has received significant research attention for pre-desalination of seawater/brines. The use of impaired water (e.g. secondary treated wastewater) has been suggested as an appropriate option as a low salinity stream for RED processes. Although electrochemical membrane systems (i.e., Ionic Exchange Membranes-IEMs) are less prone to fouling compared to pressure-driven membrane systems, an adequate pre-treatment would be required for both low and high salinity streams. In the current study, robust pretreatment strategies were performed on secondary-treated wastewater (i.e., River bank Filtration-RBF, Rapid Sand Filtration-RSF, or 100 □m cartridge filtration) and on seawater (RSF, bead filtration, and UV disinfection); where their performances were compared to RED efficiency without pretreatment (Reference), during six weeks of experiments, using commercial Fujifilm IEMs type-10. Also, a microscopy study were conducted on fouled membranes to assess the efficiency of pretreatments.

Both 100 µm filtration and RSF significantly reduced fouling on IEM surfaces, resulting in lower pressure drops, lower frequency of cleanings, and a higher permselectivity (Figure 1). RBF showed no improvement compared to Reference, possibly due to the difficulties in reproducing this technology on a lab-scale and the nature of the feed water (i.e. wastewater). Pretreated seawater

also considerably reduced fouling on IEMs. The gross power density was comparable for all pretreatments and slightly decreased during experiments.

The pressure drop had an impact in the net energy. Specifically, the pumping energy increased 22-fold over the course of the experiment for the reference stack, while only 5-fold and 4-fold after RSF and 100 µm filtration, respectively. Also, membrane autopsies were conducted on all IEMs. ATP (Adenosine Tri-Phosphate) and carbohydrates concentrations were considerably higher on reference samples and inlets, indicating favorable conditions for biofilm formation. Quantitative Nanomechanical analysis (Atomic Force Microscopy) of the foulant layers were conducted. At the microscale, foulant layers covered from 14-37% and 3-15% of membranes subjected to reference and pretreated-feeds, respectively. At the nanoscale, the morphology and nanomechanical properties of foulant layers highly differed from those of virgin membranes; indicating stiff, low elastic, and highly adhesive fouling layers (i.e., high Modulus, dissipation energy, and adhesion force, respectively) (Figure 2). The presence of these foulants after extended operation and chemical cleaning and their high adhesion would be a nanoscale evidence of irreversible fouling.

This study provided insights into simple, robust, and inexpensive treatment methods and their ability to ensure a stable long-term RED operation, which is valuable information considering any type of application using ion-exchange membranes with natural water.

2.6 Discussion and other presentations

A discussion followed the presentations. There was a lot of interest from the audience, especially from a group of MIT researchers who work on similar topics. The discussion focused on the definition of the ideal recovery rate for every case and the possible problems with scaling. With

regards to the small autonomous system, the discussion focused on how to decide whether to include a battery.

In addition, another presentation including project results was delivered in a session dedicated to Innovative Technologies. The details of this are provided below: Modelling hybrid systems for seawater desalination: electromembrane processes (RED, ARED and ED) coupled with RO (M. La Cerva, L. Gurreri, A. Cipollina, A. Tamburini, M. Ciofalo, G. Micale)

Exhibition Area

The REvivED water project was promoted through presence in the exhibition area, where it shared a booth with other European funded projects. As part of the booth, there was a large area presenting the main concept of the project. Consortium members were always present in the booth, informing conference participants about the project objectives and the progress achieved so far.