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Multistage electrodialysis for low energy seawater desalination

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Motivation

Desalination of seawater and brackish water can significantly contribute to the global problem of water scarcity, but lowering the energy consumption of desalination technologies limits their application. Highly optimized state-of-the-art technologies, like pressure-driven reverse osmosis (RO), have an energy consumption for seawater desalination of 3 kWh/m^3, which is still a factor 3 off from the thermodynamic minimum of 1 kWh/m^3 of fresh water produced, assuming a water recovery of 50% [1]. A major part of the inefficiency of RO desalination can be attributed to a maldistribution of the water production over the installation. The first membrane element produces 10-20 times more than a last membrane element, just due to the fact that the driving force for desalination cannot be adjusted for each membrane element individually [2].

Technological challenge

Electrochemical desalination systems, on the other hand, can be operated with adjusted driving forces at each stage of desalination. Electrodialysis (ED) is applied for brackish water desalination and selective ion removal from industrial waste streams, but has not yet been used widely for seawater desalination. In this project we investigate multi-stage electrodialysis (ED) for seawater desalination. ED is an electrochemical desalination technology based on ion-selective membranes. A typical ED system consists of anion- and cation- exchange membranes alternatingly stacked between an anode and a cathode. Once an electric potential is applied, cations migrate in the direction of the cathode and anions in the direction of the anode. Our challenge is to design an upscaled multi-stage ED system which can be operated close to the lower limit of specific energy for seawater desalination.

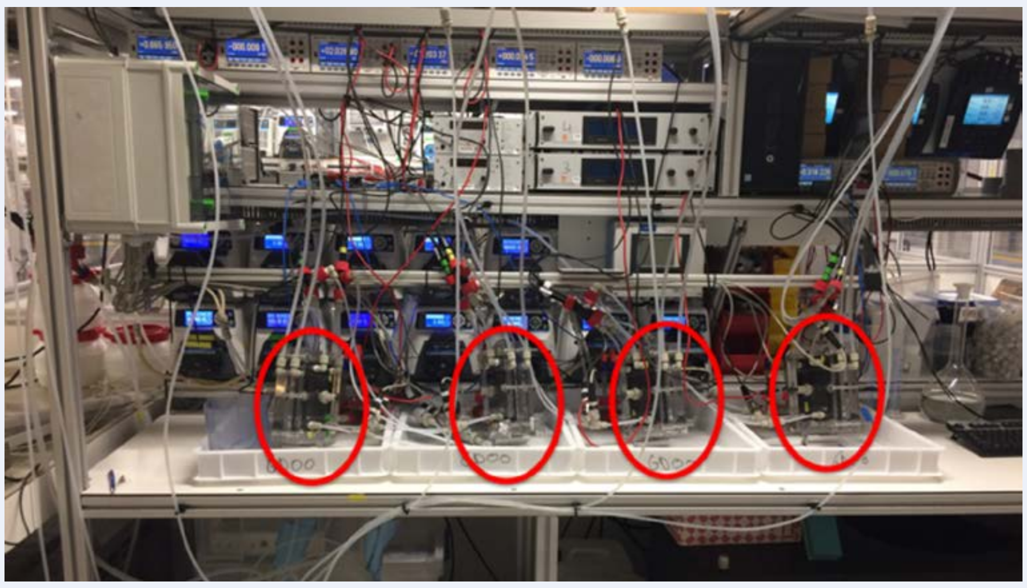

Fig 1. Experimental setup for a 4-stage ED that can be operated at co-current and counter-current staging.

Research goals

Along the different ED stages, desalination conditions vary. When operated in co-current, the first stage typically has a low internal resistance due to the high conductivity of both concentrate and diluate. Hardly any concentration gradient exists over the membranes. The last stage has a high internal resistance due to the decreased conductivity of the diluate and a high concentration gradient over the membranes. In case all stages are designed equally and operated at a single applied voltage, the ionic current will be unevenly distributed over the system leading to similar inefficiency as in RO. However, in order to get an efficient desalination process, each of the stages can be designed and operated separately and the goal of this research is to manipulate the current distribution per stage or even within each stage by further segmentation of the electrodes. Some examples of design parameters are given in figure 2a.

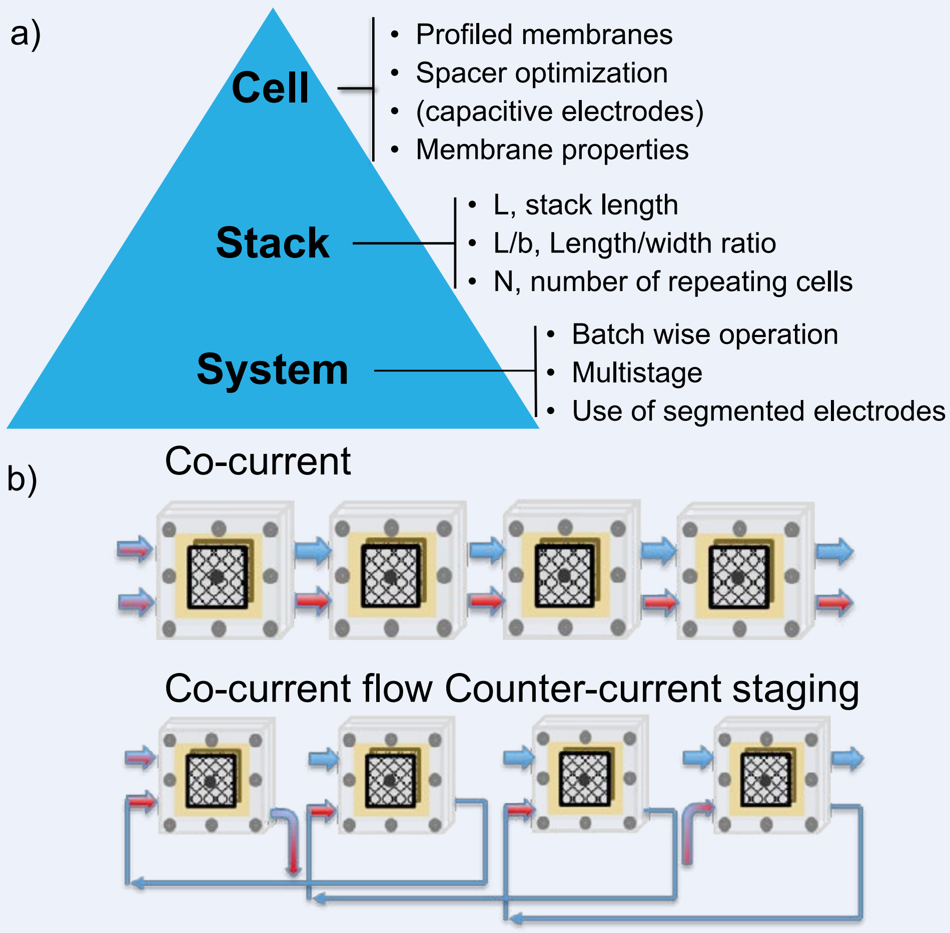

Fig 2. a) system parameters that will be investigated b) Multistage electrodialysis flow arrangement schemes for co-current flow, and co-current flow counter-current staging.

In addition operation parameters can be investigated, such as flow arrangements (figure 2b), retention times, and different current densities per stage. The ultimate goal is to obtain a seawater desalination with an energy consumption of <1.5 kWh/m^3.

[1] M. Elimelech, W. A. Phillip, Science, 333, 6043, 2011, 712

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