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Procedia Engineering 44 (2012) 1013 – 1016

Procedia Engineering

www.elsevier.com/locate/procedia

Euromembrane Conference 2012

[P1.139]
Sustainable energy generation by reverse electrodialysis

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The current global economic, ambient and political situation has motivated the search of new, environmentally friendly and more immediately available sources of energy. The European Union strategy for Energy until year 2020 known as “20-20-20” is mostly focused on development of wind and solar-based technologies for energy generation.

Another potentially sustainable source of energy is the chemical energy associated with solvation of salts. When two streams of different concentrations are brought in contact, they mix spontaneously and release energy (Gibbs free energy). In the nature, wherever two solutions of different salinity exist in proximity, e.g. where river water flows into a sea, a salinity gradient energy can be obtained. This is an energy source with a possible worldwide annual potential between ≈12000 and ≈23000 TWh that is able to cover all current global annual electricity demand (≈20000 TWh) [1]. Salinity gradient energy can be converted into power generation by reverse electrodialysis (RED). RED is a non-polluting, sustainable technology for controlled mixing of solutions and depends on several factors such as the membrane properties, the solutions composition, the type of the red-ox couple and the fluids dynamics [2-4].

The experimental work was performed with MEGA a.s. (Czech Republic) electrodialysis modules with heterogeneous cation- and anion-exchange membranes of the “Ralex” type, separated by 0.8 mm spacers. The total number of membrane pairs used was ten, applied either as one module or as two equal modules, five pairs each, connected in series. Samples of sea water and river water were taken from the Atlantic Ocean coast (Costa de Caparica) and the Tagus River (Lisbon), respectively. The pressure drop between inflow and outflow streams was measured by two pressure transducers (Druck, England). The electric measurements were performed with a Digital Multimeter (Kaito Electronics) in an OCV (open circuit voltage) mode with total recirculation of the two streams. As a redox pair, a homogeneous $K_4Fe(CN)_6/K_3Fe(CN)_6$ redox system was chosen, because it does not cause net chemical reactions and therefore the power losses are low.

In the present study, it was found that the presence of divalent ions increase the stack resistance and have a lowering effect on the generated power, especially if present in the dilute (low salinity) stream.

doi:10.1016/j.proeng.2012.08.659

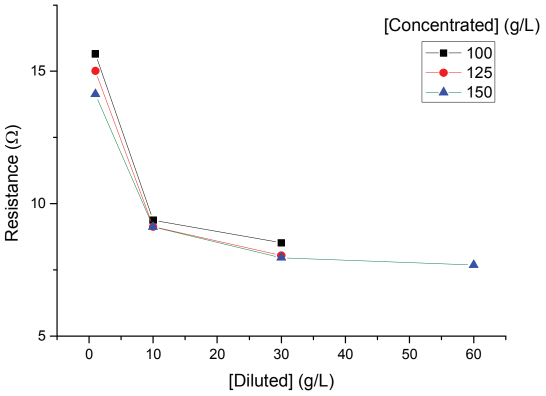

Figure 1 Variation of one (10-pairs) stack resistance with concentration of NaCl in model diluted and concentrated solutions.

Knowing the nominal resistance of the membranes, it can be concluded that the overall ohmic resistance of the stack is mostly due to the contribution of the sum of the resistances of the diluted stream compartments (Fig. 2).

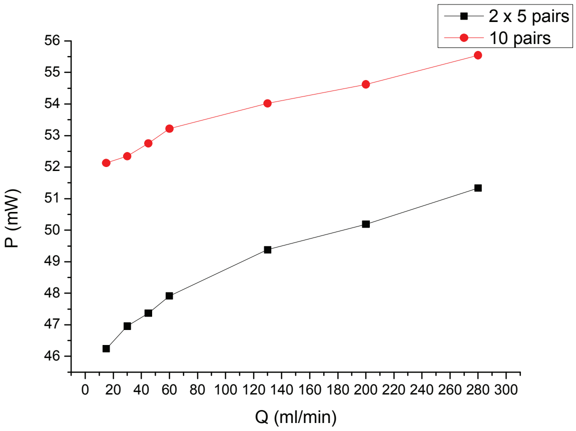

Figure 2 Dependence of the gross power output (P) with volumetric flow rate (Q) of diluted and concentrated streams for one stack with 10 membrane pairs, and two stacks in series with 5 membrane pairs each.

Utilization of one large stack, instead of a series of smaller stacks-in-series, appears to be preferable. The need of applying one additional membrane (in the case of two modules in series) and another pair of electrodes for the second module increase the global resistance, which is lowering the obtained power (Fig. 2). Another disadvantage for stacks in-series is a higher total pressure drop in such arrangement.

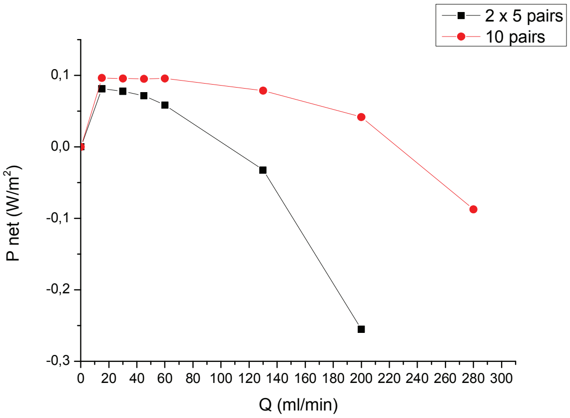

Figure 3 Dependence of the net power density (Pnet) with volumetric flow rate of diluted and concentrated streams for one stack with 10 membrane pairs, and two stacks in series with 5 membrane pairs each.

The net power density per unit membrane area (Pnet) was calculated by subtracting the power consumed for pumping from the gross power generated by the RED stack(s). The pressure drop increased with flow rate more rapidly than the corresponding increase in the obtained gross power (Fig. 2). This led to a negative net power balance at higher flow rates, and indicated that energy can be harvested only at relatively low solutions flow rates.

The results obtained confirm the current understanding that in plate-and-frame types of RED stack modules, the main ohmic resistance is located in the diluted stream compartments. The use of RED stacks linked-in-series was not found to improve the net power density, which was positive only at low Reynolds numbers. Reformulation of the diluted stream channel design and/or operation can be therefore considered essential for further optimization of the RED process.

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Acknowledgement

Sylwin Pawlowski acknowledges *Fundação para a Ciência e a Tecnologia*, Lisbon, Portugal for the PhD grant SFRH/BD/68649/2010.

Keywords: Reverse electrodialysis, Dialytic battery, Stacks-in-series, Fluid dynamics