[431]

Mechanical-fluid dynamics coupled model for profiled Ion Exchange Membranes design

G. Battaglia*, M. Ciofalo**, A. Cipollina**, A. Di Matteo*, L. Gurreri**, A. Pirrotta, A. Tamburini**, G. Micale*****

* Dipartimento di Ingegneria Civile, Ambientale, Aerospaziale, dei Materiali (DICAM), Università degli Studi di Palermo – viale delle Scienze Ed. 8, 90128 Palermo, Italy
** Dipartimento dell'Innovazione Industriale e Digitale (DIID), Università degli Studi di Palermo – viale delle Scienze Ed. 6, 90128 Palermo, Italy
*** Department of Mathematical Sciences, University of Liverpool, Liverpool, United Kingdom

Keywords: Ion exchange membrane; electrodialysis; reverse electrodialysis; deflection; CFD.

Introduction

Profiled ion exchange membranes (IEMs) avoid the use of net spacers in electro-membrane processes. Profiled IEMs have been widely tested at laboratory scale, showing the possibility to improve the process performance, e.g. in stacks of electrodialysis (ED) for water desalination and of reverse electrodialysis (RED) for energy production from salinity gradients. Features of membranes and channels are crucial for the behaviour of the system, e.g. affecting Ohmic resistance, diffusion boundary layer resistance and pumping consumption. In addition, differential pressures over the membrane may generate a deformation, thus changing the nominal channel geometry. Nevertheless, membrane mechanical properties and their influence on process operation have been poorly studied so far.

In this work, we developed an advanced model useful for the design of profiled IEMs, based on the coupled simulation of local mechanical deformations and of fluid dynamics and associated mass transport phenomena within deformed channels.

Modelling strategy

Two-side profiled membranes with Overlapped Crossed Filaments (OCF) were investigated by simulating 3-D periodic domains (unit cells, Fig. 1).

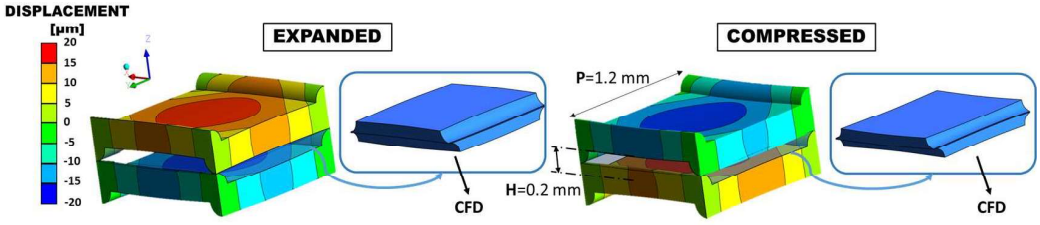

Figure 1. Displacements of OCF-IEMs under a pressure of 0.4 bar and corresponding fluid domains.

A maximum threshold value of differential pressure between two adjacent channels in real units of 0.8 bar was assumed. By applying this load on the IEM surface in the simulations, the largest distance between profiles allowing membranes do not touch each other was assessed. The identified OCF-IEM geometry ($P = 6H$, see Fig. 1) was then simulated in order to predict deformations under pressures up to ±0.4 bar. Finally,

computational fluid dynamics (CFD) simulations of the deformed channels were carried out. The *Ansys Mechanical 18* and the *Ansys CFX 18* software was used.

Results and Discussion

Maximum displacements of 20 µm are reached in the central region of the unit cell (Fig. 1). However, the minimum distance between IEMs in the compressed configuration is located at the centre of the profiles. The topology of flow channels (expanded and compressed) under an imposed load on the membranes is obtained.

CFD simulations show that pressure drops increase from the most expanded to the most compressed channel, being ~20% lower and ~40% higher than in the undeformed channel, respectively (Fig. 2 left). Similar, but slightly smaller, effects on the bulk-wall mass transfer rate are found at low Re numbers, while a more complex influence occurs at higher Re numbers until the trend is even reversed (Fig. 2 right).

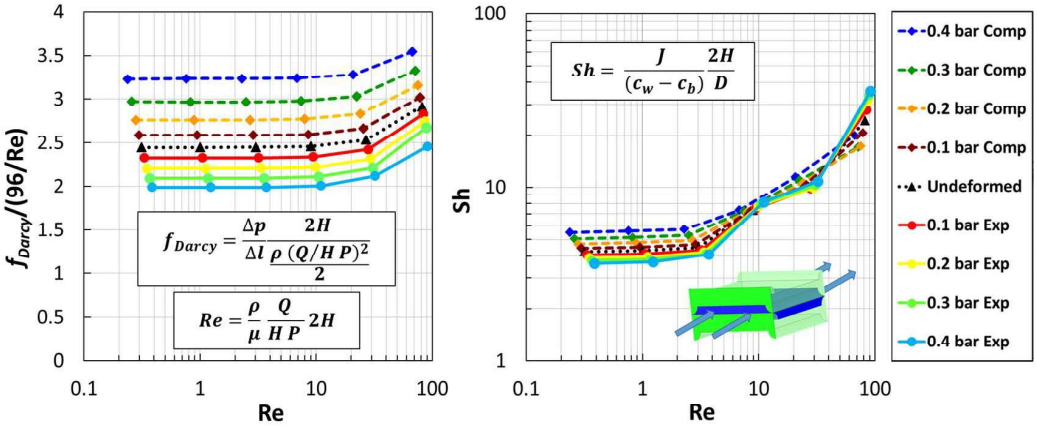

Figure 2. Friction factor normalized with respect to that of the empty channel (left) and Sherwood number (right) for deformed channels as functions of the Reynolds number.

Conclusions

Channel deformations affect largely fluid dynamics and mass transfer characteristics. Therefore, any change of nominal geometry, e.g. due to differential pressures over the membrane, may lead to significant variations in the overall process performance parameters. The present model constitutes a new brick to build a multi-scale process simulator, comprising several sub-models, for design and optimization studies. Results will be also used to implement a novel simulation tool for the prediction of flow misdistribution in RED\ED stacks (especially with cross-flow configuration) generated by membrane deformation.

Acknowledgements

This work has been performed within the RED-Heat-to-Power (Conversion of Low Grade Heat to Power through closed loop Reverse Electro-Dialysis) and REvivED water (Low energy solutions for drinking water production by a REvival of ElectroDialysis systems) projects, Horizon 2020 programme, Grant Agreement no. 640667 and 685579, www.red-heat-to-power.eu, www.revivedwater.eu.