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3-D simulation of water and heat transport processes in fuel cells during evaporative cooling and humidification

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1. Introduction

Evaporative cooling is a promising concept improve the efficiency and reduced costs of polymer electrolyte fuel cells (PEFCs) using modified gas diffusion layers with hydrophilic and hydrophobic lines (Fig. 1a) [1]. Water is wicked from a water channel into the hydrophilic lines (Fig. 1b), where it evaporates in contact with the dry gas channel. This concept has been] demonstrated to simultaneously achieve cooling and membrane humidification in experiments [2-3. We have developed a 3-D numerical model of such an evaporative cooling cell to address remain questions from the experiments:

- How exactly are heat flux and evaporation rates connected?
- How much water reaches the anode and cathode gas channel outlets?
- What is the main water vapor transport mechanism ?
- What is level of membrane hydration?
- What is temperature drop inside the cell related to a certain heat flux?

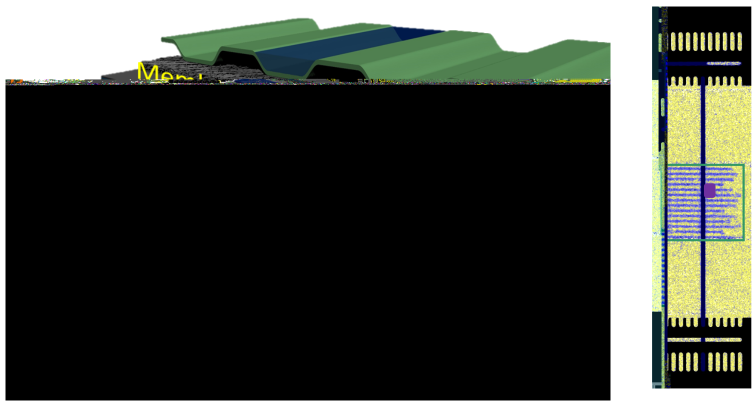

Figure 1: (a) PSI evaporation cooling concept, (b) Electron radiography image (rotated by 90 degrees), illustrating the presence of water in the hydrophilic lines (light blue) and water channel within the flow plate. The hydrophobic base material of the gas diffusion layer is yellow.

2. 3-D model of an evaporative cooling cell

- Model setup consists of flow channel plates and a membrane electrode assembly with one hydrophilic line in the anode gas diffusion layer (GDL) (Fig. 2)
- The model is macro-homogeneous, coupling the steady-state transport equations for
- Two-phase flow of gas and liquid water (Brinkman equations)
- Convection and diffusion (Stefan-Maxwell) of gas species: H_2, H_2O on anode, H_2O, N_2 and O_2 on cathode side)
- Convection and conduction of heat
- Diffusion of water dissolved in the membrane
- 2 phase changes are included: water vapor – liquid water + water vapor – dissolved water
- The model is implemented in COMSOL Multiphysics Version 5.4
- A finite-element mesh is constructed. Increasing spatial resolution leads to a convergent solution.

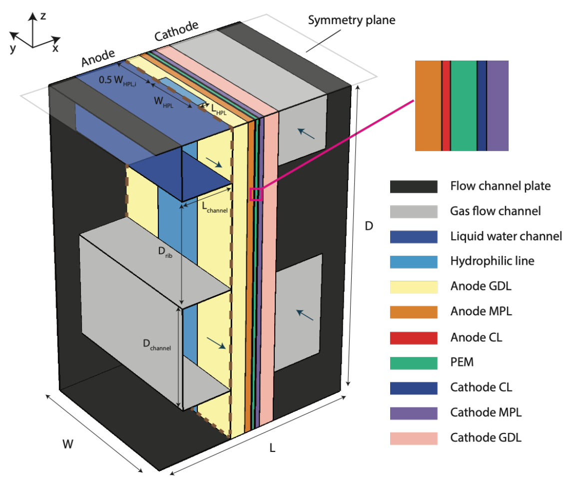

Figure 2: 3-D model setup

3. Results and interpretation

- Only ~5% of generated water vapor passes the membrane and leaves the cell at cathode gas channel outlets (Figure 3a)
- Water evaporates mostly along the interface between hydrophilic line and gas channel, but also along interfaces between hydrophilic line and GDL (Figure 3b)
- Generated water vapor is transported both by diffusion and convection to the anode channel (see streamlines in Figure 3b)
- Membrane water content (λ) varies between ~12 below the hydrophilic lines/ribs and ~2 below the gas channel (Figure 3c)
- Temperature decreases locally by more than 10°C. Heat flux varies spatially with highest values below the ribs.

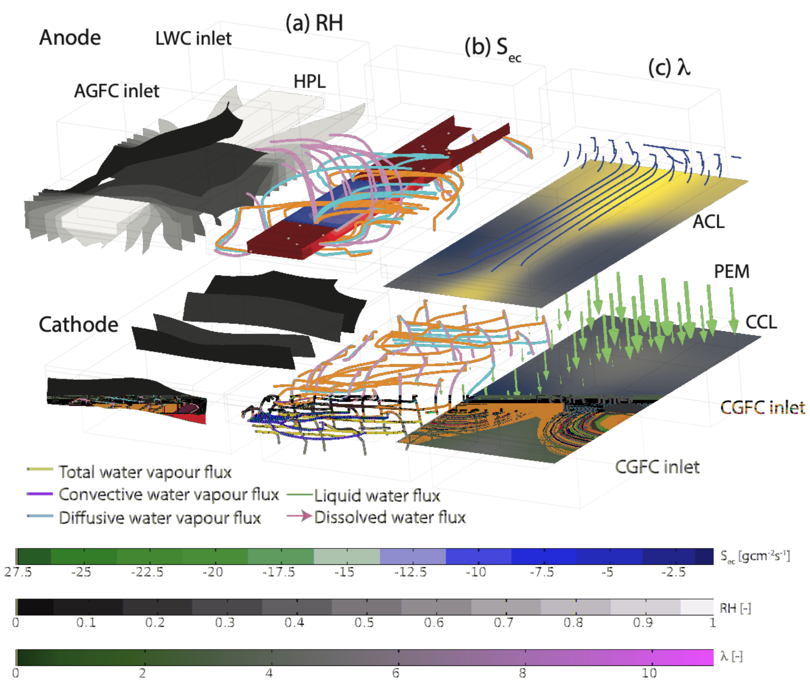

Figure 3: Water management in the simulated evaporation cooling cell: a) Relative humidity, b) evaporation rates and water vapor flux, c) membrane water content and flux

4. Conclusions and outlook

A 3-D model of an evaporation cooling cell has been developed to better understand the water and heat management. Further collaboration between ZHAW and PSI, established during SCCER Mobility, will clarify the level of evaporation rates.

References

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[2] M. Cochet, A. Forner-Cuenca, V. Manzi, M. Siegwart, D. Scheuble, P. Boillat, "Novel concept for evaporative cooling of fuel cells: an experimental study based on neutron imaging", *Fuel Cells* (2018)

[3] M. Cochet, A. Forner-Cuenca, V. Manzi, M. Siegwart, D. Scheuble, P. Boillat, "Enabling High Power Density Fuel Cells by Evaporative Cooling with Advanced Porous Media", *Journal of Electrochemical Society* (2020)

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