Modeling the Effect of the Inlet Gas Humidification on PEMFC Behavior and Current Density Distribution

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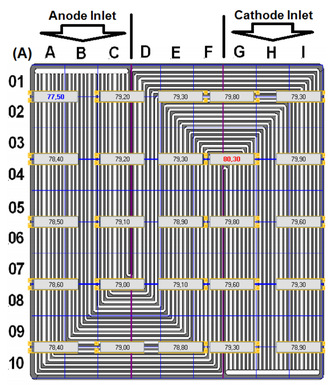
Abstract

An in-house single cell fixture developed at DLR has been tested experimentally under different temperatures and anode/cathode humidification conditions. The cell was equipped with a segmented board [1-3] to perform current density distribution measurements. Maps of fuel cell responses for cell temperatures of 80ºC and 60ºC and various anode/cathode humidifications have been obtained. The experimental results are compared with a global water balance model that takes into account the water mass flow rates carried by the streams entering/exiting the cell, as well as the water produced at the cathode by the Oxygen Reduction Reaction (ORR).

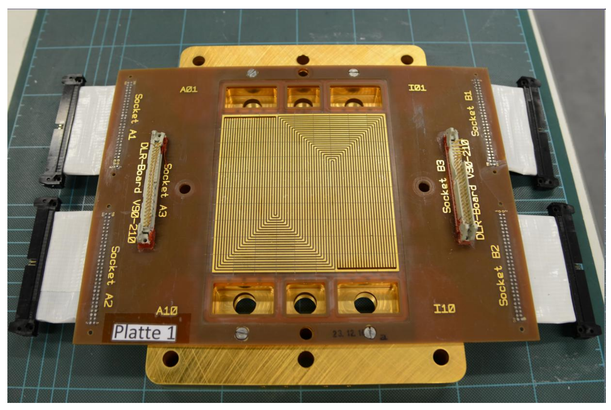
Experimental setup

The cell was operated in galvanostatic mode (100A) with a fixed stoichiometry of the inlet gases (1.2A/2C). Reference humidity conditions were fixed at RH 50 % on both sides.

Experimental Conditions	
Temperature	60ºC / 80ºC
Hydrogen / Air flow	840 / 3320 ml min^{-1}, 1.5 bar
Current	100 A
Surface	142 cm^2
Membrane	Nafion© XL
Catalist Layer	0.3 mgPt cm^2 (Ion Power Inc)
Gas Diffusion Layer	Sigracet 25 BC (SGL Group)



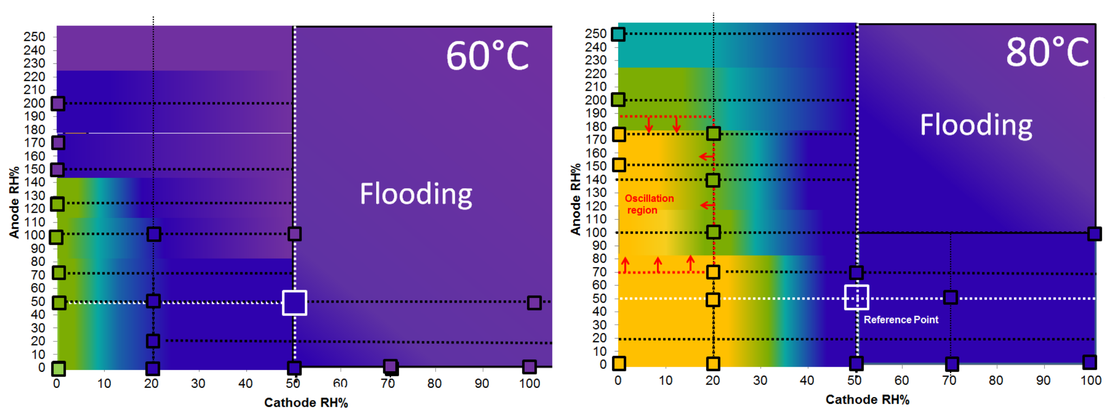
Segmented Board



A segmented printed circuit board (PCB) was used as anode bipolar plate. The printed board features 25 integrated temperature sensors [2, 3]. The plate is further divided into a matrix of 10×9 segments that provides local current density measurements. Using this data, deactivated zones of the membrane can be easily identified. For the flow channel geometry considered here, each segment has a unique channel direction.

This configuration also provides good information along the channel direction.

Experiments

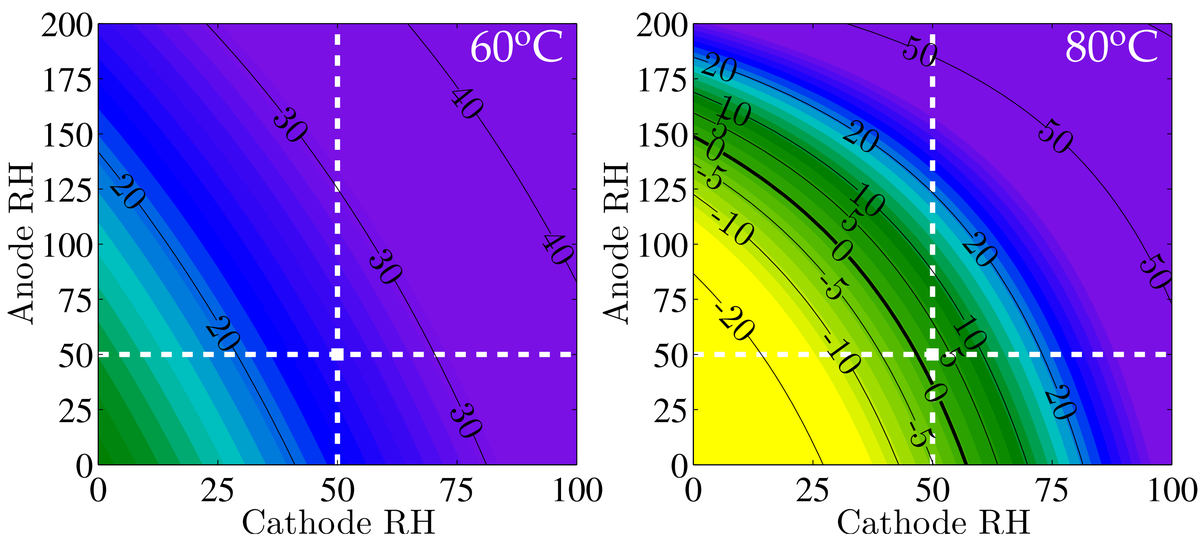


Several experiments were performed at different humidifications conditions. They are identified with square symbols in the left plots. A color legend was used to indicate the behavior of the cell: ■ indicates **stable** behavior, ■ is used for **flooding** conditions, ■ for slight performance losses, and ■ for drastic deactivations.

At 80ºC drastic cell deactivations were observed at low cathode humidifications [1] due to the high drying capacity of the cathode gas stream. Conversely, at 60ºC no fully deactivated conditions were found at low cathode humidification; only local deactivation of the cell was observed, leading to a slight drop in the cell performance.

Completely dry conditions can be operated at 60ºC with slight performance losses. At 80ºC no stable condition was found below RH 20 % in cathode side.

Model Results



A global water balance model can be derived from a control-volume approach

$$BOW = \underbrace{\dot{m}^a_{W,\text{in}} - \dot{m}^a_{W,\text{out}}}_{\text{Anode water removal}} + \underbrace{\dot{m}^c_{W,\text{in}} - \dot{m}^c_{W,\text{out}}}_{\text{Cathode water removal}} + \underbrace{\frac{I\mathcal{M}_w}{2F}}_{\text{Production}}$$

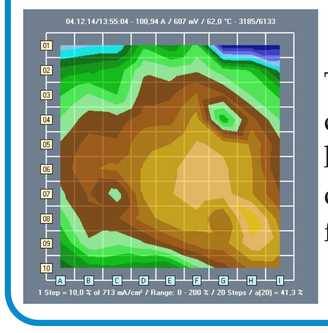
which states that the mass of water that accumulates in the cell per unit time is equal to the water flow rates provided by the anode and cathode feeding streams, minus those leaving the cell with the outlet gases, plus the water production rate due to the ORR. The water content is calculated using the molar fraction of water χ_W and the mass flow rate of the other species

$$\dot{m}_W = \frac{\chi_W}{1-\chi_W}\mathcal{M}_W\left(\sum_k \frac{\dot{m}_k}{\mathcal{M}_k}\right) \qquad k = \begin{cases} H_2 & \text{Anode} \\ N_2, O_2 & \text{Cathode} \end{cases}$$

The model considers the outlet gases as fully saturated, and takes into account the hydrogen and oxygen consumption rates for the evaluation of the water flow rates leaving the cell. The global balance of water (BOW) is negative for drying and positive for hydration conditions. The figure shows BOW calculated in gr/h for 60ºC (left) and 80ºC (right).

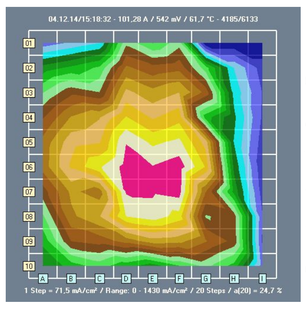
Segmented board results

Reference condition: 50 % - 50 % @ 60ºC



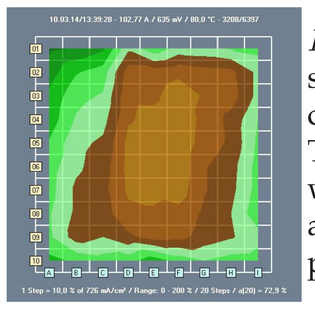
The current density distribution is nearly homogeneous. Small deactivations in the flow field corners.

Dry condition: 0 % - 0 % @ 60ºC



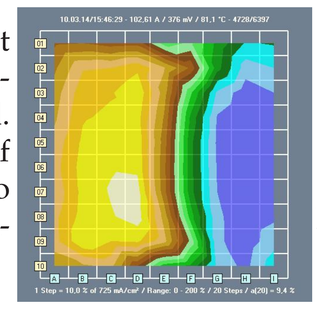
BOW is still positive. Only small losses are observed. The water produced at the cathode is enough to auto-humidify the cell.

20 %Anode - 50 %Cathode @ 80ºC



BOW is negative but small. No performance losses are observed. The back-diffusion of water from cathode to anode plays an important role.

50 %Anode - 20 %Cathode @ 80ºC



BOW is largely negative. Dramatic voltage drop. The graph shows the current density distribution just before complete deactivation, starting at the cathode inlet.

Conclusions

A global water balance model can explain the qualitative behavior of the cell in most cases. Unbalanced conditions (those with a big difference in water content between sides) shows the worst agreement. Flooding conditions are not well represented either due the absence of water evaporation/condensation effects. Further work is still needed to explain cell behavior under these conditions.

Future Work

The water transport through the membrane should be incorporated to the model so as to explain cell behavior in unbalanced conditions, where water transport plays a key role. Several complex models have been developed to describe water management in PEMFCs [4, 6] but none of them consider the channel evolution and therefore the downstream variation of the current density. At least a 1D+1D model (across+along the channel) should be considered in future work.

References

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