Modeling Current Oscillations in Asymmetrically Humidified PEFCs: The Contest between a Saturated Anode and a Dry Cathode Feed Stream

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KEYWORDS: PEFC, modeling, water management, membrane

A two-phase 3D macroscopic model of a Polymer Electrolyte Fuel Cell (PEFC) is presented. The model is used to simulate the multiple solutions found in PEFCs operated with saturated anode (RH_a = 100%, condensing conditions) and dry cathode ($RH_c \approx$ 5%) feed streams. Previous experimental work has shown that the system tends to oscillate between two low- and high-performance levels due to the periodic shedding of water droplets at the anode inlet, which acts effectively as an intermittent water reservoir. This challenging two-phase scenario is modeled by incorporating (or not) a liquid water flux superimposed on the fully-humidified conditions that prevail at the anode inlet. According to the two-phase homogeneous flow theory, the inlet channel water flux is given as $Q_{lw} = \rho_{lw} u_{g,in} s_{in}$, where ρ_{lw} is the density of liquid water, u_g the feed velocity of the gas stream, and s_{in} the inlet saturation (defined as the ratio of water volume to void volume). As can be observed in the single-channel results shown in Figures 1 and 2 (counter-flow configuration), the low- and high-performance states are properly captured by the numerical model (steady-state solver). A low-performance level (extinction) arises when no water flux is imposed at the anode inlet (RH_a = 100%, $Q_{lw,a} = 0$, i.e., $s_{in,a} = 0$), characterized by a low cell humidification and a high membrane resistance. The membrane dry-out (decrease of current density) reaches its maximum near the dry cathode inlet, and progressively decays along the cathode channel due to the humidification of the membrane by the anode stream. By contrast, a high-performance level (ignition) is achieved when a sufficiently high water flux exists at the anode inlet (RH_a = 100%, $Q_{lw,a} > 0$, $s_{in,a} = 0.1$ in the calculations). This leads to a fully-humidified anode compartment, which increases the average cathode relative humidity and decreases the membrane resistance. The better humidification of the membrane results in a more uniform current distribution over the cell active area.

Figures

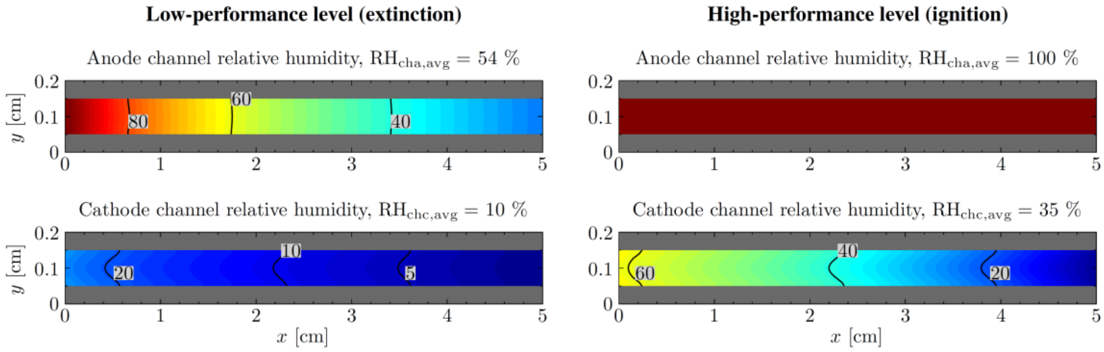

Figure 1: Anode and cathode channel relative humidity, RH(*x*,*y*), distributions corresponding to (left) a low-performance level (extinction) and (right) a high-performance level (ignition) of a single-channel PEFC operated with saturated anode and dry cathode streams, $RH_{a/c}$ = 100 (c. c.)/0% (c. c. stands for condensing conditions). The high- and low-performance levels are respectively modeled by incorporating or not a liquid water flux at the anode inlet (see text for details). The 2D RH distributions are obtained by local averaging the associated 3D fields in the through-thickness direction (*z*-coordinate) at every point (*x*,*y*). The global mean value (avg) of the distributions is also indicated in each case. The blue-red color scale ranges from 0 to 100% RH. Other operating conditions: voltage (V = 0.8 V), anode/cathode inlet flow rate ($Q_{a/c}$ = 15/60 ml/min), anode/cathode back pressure ($p_{a/c}$ = 1.5/1.5 bar), cell temperature (T = 80 °C), counter-flow configuration. Geometrical parameters: channel height (H_{ch} = 1 mm), rib/channel width ($w_{rib/ch}$ = 1/1 mm), GDL thickness (t_{gdl} = 200 µm), catalyst layer thickness (t_{cl} = 10 µm), membrane thickness (t_{mem} = 20 µm).

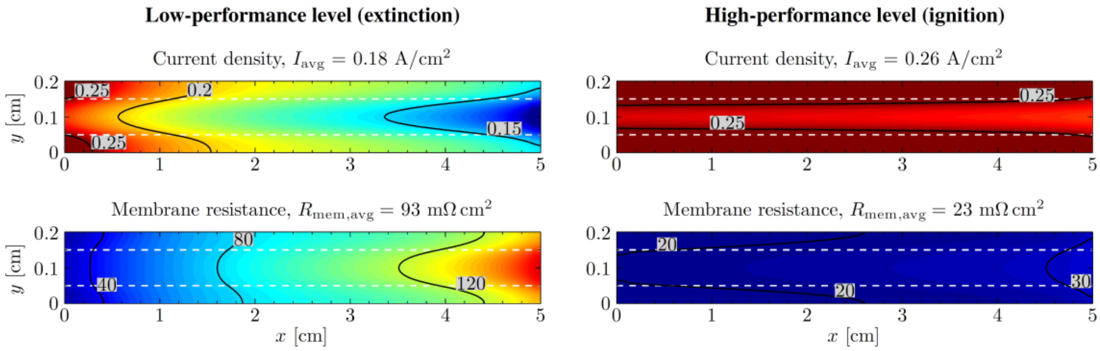

Figure 2: Current density, $I(x,y)$, and membrane resistance, $R_{mem}(x,y) = \int_0^{tmem} \sigma_{mem}^{-1}(x,y,z)\,dz$, distributions corresponding to the operating conditions indicated in Figure 1. The global average value (avg) of the distributions is indicated at the top of each plot using the same units as the highlighted iso-lines. The blue-red color scale ranges from 0.1 to 0.25 A/cm^2 and from 20 to 200 mΩcm^2.