# A SIMPLE THERMAL MODEL OF PEM FUEL CELL STACKS

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## INTRODUCTION

Fuel cells are generally composed of an assemblage of single cells. From a manufacturing standpoint, these single cells are not identical which can lead to performance inequalities during operation resulting in thermal, electrical and mass transfer gradients between cells, and therefore in cell interactions. Most fuel cell stack models do not completely address interactions between cells. An electrical interaction model was recently developed (1) whereas in this paper, a thermal interaction model is presented to investigate coupling phenomena within fuel cell stacks. Cell interaction is an important model feature, for example, to define manufacturing tolerances for cell components, to accurately predict stack behavior or to assess series reliability.

## MODEL

The core model element is the previously developed unit cell model (2) extended by a more detailed description of heat transfer. The main model assumptions are:

- Heat is removed from the cell only through the coolant stream
- Membrane ohmic heating is predominant
- Thermal effects of the channel gas streams are neglected except condensation in the cathode
- Anode channel stream is always under-saturated (no condensation)
- Temperature through the membrane direction does not depend on the channel to channel direction
- High fuel cell aspect ratio motivates consideration of a 1+1 dimensional model (along the flow field channel, through the membrane)
- Catalyst layers have zero thickness
- Water condensation occurs uniformly in the cathode
- A Nusselt number is used to describe heat transfer between coolant and bipolar plates
- Endothermic anode reaction (equivalent voltage $V_a$)

The temperature distribution along the cell channel is described by:

$$cQ_o \frac{dT}{dy} = (V_{tn} - V)i(y) + H_{vap}\Gamma \qquad [1]$$

The temperature distribution through the unit cell is a piecewise function, linear in the anode and cathode plates, and the anode electrode. In the membrane and cathode electrode, the temperature distribution is parabolic as derived from the following relations:

$$\kappa_m \frac{d^2\theta}{dz^2} = -\frac{i^2 R}{L_m}, \quad \kappa_g \frac{d^2\theta}{dz^2} = -\frac{H_{vap}\Gamma}{L_g} \qquad [2]$$

For the single cell case, the cathode and anode heat fluxes to the coolant are equal to the right hand side of equation 1. For a stack, this is no longer the case since some heat may be transferred from one cell to another. Extension of Equation 1 to a fuel cell stack leads to:

$$cQ_o \frac{dT^j}{dy} = Q_a^{j-1} + Q_c^j \qquad [3]$$

## RESULTS AND DISCUSSION

Computations were carried out using an anomalous cell with 4 times the base membrane resistance (Figure 1) and sub-saturated inlet reactant streams. Significant effects of water condensation/evaporation on temperature distribution are observed near the cell inlet (oxidant saturation point) and near the cell outlet (evaporative cooling). The disturbance created by the anomaly decreases in magnitude and virtually disappears after the third cell.

## NOMENCLATURE

| | |
|---|---|
| c | Coolant heat capacity |
| $H_{vap}$ | Water heat of vaporization |
| i | Current density |
| j | Cell number |
| $L_g$ | Electrode thickness |
| $L_m$ | Membrane thickness |
| $Q_a$ | Anode to coolant heat flux |
| $Q_c$ | Cathode to coolant heat flux |
| $Q_o$ | Gravimetric coolant flow rate |
| R | Area specific membrane resistivity |
| T | Average coolant temperature (y dependent) |
| V | Cell voltage |
| $V_a$ | Equivalent anode endothermic voltage |
| $V_{tn}$ | Thermo-neutral voltage |
| y | Along the channel coordinate |
| z | Through the membrane coordinate |
| $\Gamma$ | Water condensation rate |
| $\kappa_g$ | Electrode thermal conductivity |
| $\kappa_m$ | Membrane thermal conductivity |
| $\theta$ | Cell temperature (z dependent) |

## REFERENCES

1. P. Berg, A. Çağlar, K. Promislow, J. St-Pierre, B. Wetton, 'Electrical coupling in PEM fuel cell stacks', IMA J. Appl. Math., submitted.
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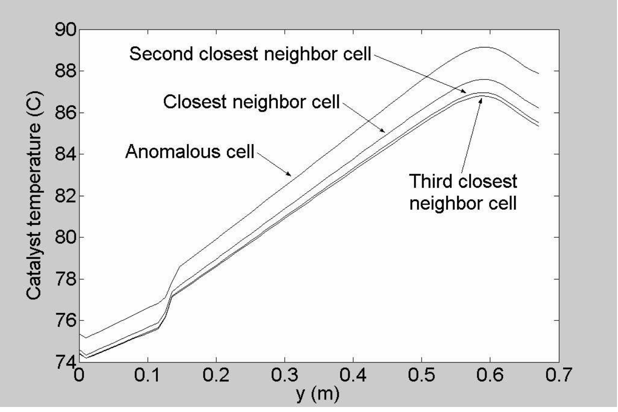

Fig. 1. Catalyst layer temperature for an anomalous cell and cells located near the anomaly (fuel in counter-flow with respect to both coolant and oxidant streams).