Current distribution in PEMFC:
I-Validation step by ex-situ and in-situ electrical characterization

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Plan

• Introduction
  • Why Current Density?
  • Current Density measurements, State Of Art

• Reverse method approach
  • Methodology
  • Wires’ instrumentation
  • Electrical Model

• Preliminary results and validation
  • Preliminary results
  • Model sensitivity
  • Potential measurements’ validation

• Conclusions & perspectives
Why the current density?

- Key output of a PEMFC:
  - Globally: « Visualize » the cell performance
  - Locally: understand the non uniformity of the electrochemical reaction (rib/channel effect, flooding/drought aspect,…)
  - Contribute in understanding local transfer phenomena

- Feed/validate multi-physics models in our lab
  - Rib/channel scale: polarization curves not enough
  - All transfer phenomena into account
  - Improve modeling predictability

JG Pharoah et al., 2006, JPS, 161
Current density measurements, State of Art

Partial Catalytic Deposit

- L. Wang et al., JPS 180 (2008)

Segmented Electrodes


Magnetic field Method


Wire approach

- Stefan A. Freunberger et al. (2006)

Spatial resolution of measurements evolved from centimeters to a sub-millimeter scale
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- Conclusions & perspectives
1/ Potential measurement between each wire and monopolar plate

2/ Implementation of the potential profile as a boundary condition in an electrical model

3/ Determination of local current density thanks to the model via Laplace Equation:
\[ \nabla (-\sigma \nabla V) = 0 \]

Reverse Method: **Potential** → **Modeling** → **Current density**
Wires’ Instrumentation

- Potential Probes:
  - Tungsten (W) wires insulated by a polyimide layer
  - Diameter: 25 µm of tungsten + 5µm of polyimide
  - Insulating layer removed from the measurement zone
  - Minimal achievable distance between two wires: 115µm

Improvement of the spatial resolution of potential measurements (500µm until now)
Electrical Model

- Software: Comsol Multiphysics

- Boundary conditions:
  - Rib: Contact Resistance
  - MPL outer boundary: Measured potential profile

- Model Inputs:
  - Electrical conductivity tensor (measured in-house under stress by 4-points sensors)
    \[ \sigma = \begin{pmatrix} \sigma_{//} & 0 \\ 0 & \sigma_{\perp} \end{pmatrix} \]
  - Electrical contact resistance (in-house values)

- Computing of the electrical potential field “V”
  - Current density calculation in a post processing step: local Ohm’s law
    \[ J = - \sigma \nabla V \]
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Preliminary results

- Electrical potential higher under the channel in both studies
- The same order of magnitude of potential difference between the wires encountered in the PSI study (some mV)
- Two operating phases:
  - At low loads: current density higher under the rib
  - At high loads: current density higher under the channel
- Interesting technique: understand local transfer phenomena

Our approach is based on experimental measurements that feed an electrical model. We need to evaluate the model sensitivity towards measurements' uncertainties.

Four measured parameters:
- Electrical potential measured locally: $V_{\text{meas}}$; [0; 34 mV]
- Through plane electrical conductivity: $\sigma_\perp$; [70; 200 S/m]
- In plane electrical conductivity $\sigma_\parallel$; [8400; 10600 S/m]
- Contact Resistance between the BPP and the GDL: around $R_c = 2.10^{-7}\text{ohm.m}^2$

We vary each measured parameter separately and we observe the relative change in current density profile ($\Delta J/J$).

**Model Sensitivity**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$\Delta J/J &lt; 10%$</th>
<th>$\Delta J/J &lt; 5%$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{\text{meas}}$ (µV)</td>
<td>+/-100</td>
<td>+/-10</td>
</tr>
<tr>
<td>$\sigma_\perp$ (S/m)</td>
<td>+/-10</td>
<td>+/-1</td>
</tr>
<tr>
<td>$\sigma_\parallel$ (S/m)</td>
<td>+/-1000</td>
<td>+/-100</td>
</tr>
<tr>
<td>$R_c$ (ohm.m$^2$)</td>
<td>+/-0.1*10^{-7}</td>
<td>+/-0.01*10^{-7}</td>
</tr>
</tbody>
</table>

Electrical model strongly depends on the electrical contact resistance. In plane conductivity $\sigma_\parallel$ isn’t a sensitive parameter.
Potential measurements’ validation (1/2)

• **Why?**: Small potential difference between the wires + Model sensitivity towards the measured potential
  
  Need to validate the in-situ potential measurements

• **Idea**: Verify electrical conductivity of some known materials via potential measurements

• **HOW?**: confront the experimental and the theoretical potential profiles

• Case1: electrical conducting liquids
  
  • Isotropy
  
  • Homogeneity
  
  • Environment continuity at the scale of tungsten wires (25µm)

• The choice of the liquid
  
  • High electrical conductivity
  
  • Wettability

• Liquids used: Aqueous solutions e.g. (K⁺;Cl⁻); Ionic liquids

  Experiments and results’ exploitation in progress
Potential measurements’ validation (2/2)

- Case 2: Through plane conductivity of a GDL, $\sigma_{\perp}$

- Confronting theoretical and experimental potential profiles

- Potential Profiles’ fitting

Satisfying conductivity values with a good approximation

The wire system can be used as a 4-points sensor

Conclusions

• A very interesting approach to understand local transfer phenomena in the PEMFC’s core
  • Efficient tool in the future for on-line diagnosis of an operating stack

• A reverse method has been set up to determine current density distribution

• The sensitivity of the electrical model towards measured parameters used was studied

• Improvement of the spatial resolution of the in-situ potential measurements 115µm instead of 500µm

• A validation procedure was initiated in order to verify the potential measurements’ quality
Perspectives

- The reverse method will be used to determine a local current density distribution in a PEMFC
- Finalize the validation step
- Implementing wires in an operating cell
- Results and model exploitation
- Coupling local thermal measurements
- Tests on an instrumented stack