Visualization of Fuel Cell Water Transport and Performance Characterization Under Freezing Conditions

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Overview

Timeline

- Start date: 03/01/2007
- End date: 02/28/2010
- Percent complete: 3%, 1 month/3 years

Barriers

- Barriers addressed:
  - C: Performance
  - D: Water transport within the stack
  - E: System thermal and water management

Budget

- Total project funding
  - DOE: $2.68M
  - Contractor: $0.8M
- FY06: $1.4M
- FY07: $0.99M

Partners

- Collaborations:
  - RIT, GM, MTU
- Project management:
  - Monthly teleconferences
  - DOE quarterly progress reports
  - DOE meetings and conferences
Objectives

**Overall:** To gain a fundamental understanding of the water transport processes in the PEMFC stack components

To minimize fuel cell water accumulation while suppressing regions of dehumidification by an optimized combination of:
- New gas diffusion layer (GDL) material and design
- New bipolar plate (BPP) design and surface treatment
- Anode/cathode flow conditions

**2007:** Novel characterization techniques and baseline performance characterization:
- Ex-situ and in-situ visualization and characterization
- Fluorescence microscopy
- Neutron radiography
- Local current density and HFR distribution
Approach

Experimental: This project will provide a framework for combining component-level research into workable fuel cell stack concepts.

Fundamental research  ➔  Fuel cell concepts

**Component-Level Study**
- GDL
  - Structure
  - Morphology
  - Wettability
- Flow channel
  - Size and Geometry
  - Header design
  - Surface treatment

**Combinatorial Study**
- Water transport within GDL
- Fluorescence microscopy
- Infrared imaging
- Water transport on the GDL surface and in channels
- High speed visualization
- Neutron radiography
- 3-D microscopy

**Fuel Cell-Level**
- Anode/cathode flow conditions
- Optimized combination of GDL, BPP and flow conditions
- Freeze-thaw performance

Modeling: The ex-situ experimental data and modeling efforts of the component-level studies will be integrated into a comprehensive two-phase flow performance and stability engineering model.
Collaborative Research Plan

- **Participants**
  - R·I·T
  - GM
  - Michigan Tech

- **3 year, $3.5 Million Program**
  - Visualization of Fuel Cell Water Transport and Performance Characterization

- **Deliverables**
  - Optimized materials, design features and operating parameters under normal & freezing conditions

- **Impact**
  - Low-cost, robust systems
  - Faster commercialization
  - US technological leadership in fuel cell industry

- **Gas Diffusion Layer Structure**
- **Two-Phase Flow in GDL / Channel Interface**
- **HFR distribution result**
- **Neutron Radiograph**
# Baseline System Definition

## 1. Flow Field

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Data or constraints considered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cathode channel / land width</td>
<td>• Published channel / land optimization studies&lt;br&gt;• Minimize gas diffusion layer intrusion</td>
</tr>
<tr>
<td>Anode channel / land width</td>
<td>• Diffusion coefficient of ( H_2 ) relative to ( O_2 )&lt;br&gt;• Maintain large land-to-land contact area to reduce ohmic loss&lt;br&gt;• Maintain high volumetric flow rate per channel</td>
</tr>
<tr>
<td>Channel depth</td>
<td>• DOE FreedomCAR volumetric power density target = 2 kW/L&lt;br&gt;• Bipolar plate thickness and manufacturing tolerance</td>
</tr>
<tr>
<td>Channel pattern</td>
<td>• Minimize channel water accumulation&lt;br&gt;• Minimize reactant pressure drop&lt;br&gt;• Insensitivity to plate misalignment</td>
</tr>
<tr>
<td>Active area aspect ratio</td>
<td>• Assumed 200V stack (0.6V per cell) at peak power&lt;br&gt;• Assumed 40% stack volume in gas/coolant headers&lt;br&gt;• Square active area, from which a 50 cm² “slice” is defined</td>
</tr>
<tr>
<td>Channel – to – header geometry</td>
<td>• OEM patent literature on methods for directing flow around plate seals</td>
</tr>
</tbody>
</table>
## Baseline System Definition (cont’d)

### 2. Gas Diffusion Layer (GDL)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Data or constraints considered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Availability</td>
<td>• Commercially available material, with commitment from manufacturer to supply for at least 3 years</td>
</tr>
<tr>
<td>Substrate format</td>
<td>• Roll-good, for relevance to scale-up to high-volume manufacturing</td>
</tr>
<tr>
<td>Treatment</td>
<td>• Internally developed hydrophobic treatment and microporous layer (MPL) formulation, so that material and application process parameters can be independently controlled</td>
</tr>
<tr>
<td>Performance</td>
<td>• At or near benchmark performance under relatively dry (~80% exit RH) and wet (~120% exit RH) conditions</td>
</tr>
</tbody>
</table>

### 3. Membrane electrode assembly (MEA)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Data or constraints considered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Availability</td>
<td>• Commercially available material, with commitment from manufacturer to supply for at least 3 years</td>
</tr>
<tr>
<td>Pt loading</td>
<td>• Thrifted platinum content, moving toward DOE target of 0.25 mg/cm² total</td>
</tr>
<tr>
<td>Performance</td>
<td>• At or near benchmark performance under relatively dry (~80% exit RH) and wet (~120% exit RH) conditions</td>
</tr>
</tbody>
</table>
# Ex-situ Experiment Design

| Objectives                                                                 | 1. To study two phase flow stability in each channel and establish two phase flow stability criteria.  
<table>
<thead>
<tr>
<th></th>
<th>2. To study water distribution in each channel.</th>
</tr>
</thead>
</table>
| **Measurements**                                                          | 1. Water flow rate and pressure.  
|                                                                          | 2. Gas flow rate and pressure drop.  
|                                                                          | 3. Direct view of water droplets and films, their distribution on GDL surface, and the water film thickness measurement.  
|                                                                          | 4. Simultaneously visualize parallel channel flow dynamics. |
| **Experimental setup**                                                    | 1. Transparent BPP.  
|                                                                          | 2. Top and side view by high speed camera.  
|                                                                          | 3. Infrared camera and imaging to detect presence of water film and measure the water film thickness.  
|                                                                          | 4. Mass flow rate and pressure drop at inlet and outlet sections. |
Water Droplet Visualization

- High speed imaging
- GDL/channel studies
- Single-channel, multiple channel and header flows
- Flow patterns, instabilities and pressure drop
GDL Component Studies — Material Properties

- **Contact Angle Studies:**
  - Developed Koehler illumination technique
  - Developing image processing technique
  - Developing GDL handling protocol to address contamination (see center image)
  - Started contact angle measurement calibration
  - Beginning GDL parametric studies

- **Structure and Morphology Studies:**
  - Students being trained on SEM’s
  - Developing handling/preparation protocols for SEM samples

Three water drops on a GDL, each with a different volume – each drop has a different contact angle due to surface contamination.
GDL Component Studies — Capillary Transport Model

2D Network Simulator

Boundary Conditions

Main Code

Time Integration (In development)

Linear System

![Diagram of 2D Network Simulator with nodes and connections labeled as Boundary Conditions, Main Code, Time Integration (In development), and Linear System.](image)
2D Network Simulator: Preliminary Results

M is the viscosity ratio
Ca is the Capillary number

M=10 Ca=∞

M=0.1 Ca=∞

M=0.1 Ca=1 θ>90

M=0.1 Ca=10 θ<90

M=0.001 Ca=10 θ<90
Future Work (FY07 - FY08)

• **Baseline performance characterization**
  - Ex-situ multi-channel performance (RIT)
  - Fuel cell experiments with visual access (RIT)
  - Freeze-thaw experiments with neutron radiography (GM)
  - Post-mortem analysis of baseline material set (MTU)

• **Parametric studies at component-level**
  - GDL component studies (MTU)
  - Channel component studies (RIT)

• **Combinatorial assessment on ex-situ apparatus**
  - Ex-situ multi-channel flow experiments (RIT)
  - Multi-channel two-phase flow model (RIT/GM/MTU)

• **Decision point #1 after combinatorial ex-situ assessment**
Summary

Impact:
- Low-cost, robust PEM fuel cell system
- Faster fuel cell commercialization

Approach:
- A framework for combining component-level research into workable fuel cell stack concepts
- Intense collaboration between RIT, GM and MTU

Deliverables:
- Optimized materials, design features and operating parameters under normal and freezing conditions
- Fundamental understanding of water transport processes in PEM fuel cells
- Novel characterization techniques