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

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ID # FCP22

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

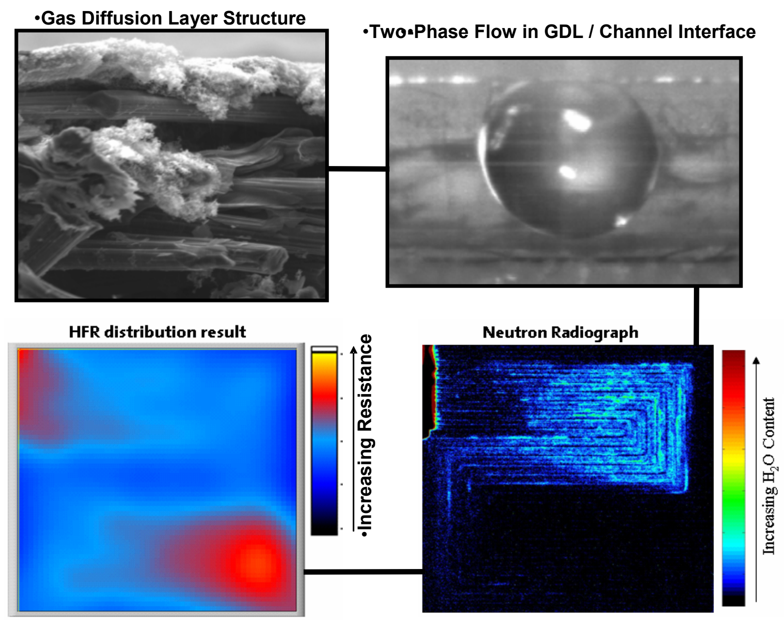
- Anode/cathode flow conditions
- Optimized combination of GDL, BPP and flow conditions
- Freeze-thaw performance

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

•3 year, $3.5 Million Program

•Visualization of Fuel Cell Water Transport and
•Performance Characterization



•Participants

R·I·T

GM

MichiganTech

•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

Baseline System Definition

1. Flow Field

Parameter	*Data or constraints considered*
Cathode channel / land width	• Published channel / land optimization studies • Minimize gas diffusion layer intrusion
Anode channel / land width	• Diffusion coefficient of H_2 relative to O_2 • Maintain large land-to-land contact area to reduce ohmic loss • Maintain high volumetric flow rate per channel
Channel depth	• DOE FreedomCAR volumetric power density target = 2 kW/L • Bipolar plate thickness and manufacturing tolerance
Channel pattern	• Minimize channel water accumulation • Minimize reactant pressure drop • Insensitivity to plate misalignment
Active area aspect ratio	• Assumed 200V stack (0.6V per cell) at peak power • Assumed 40% stack volume in gas/coolant headers • Square active area, from which a 50 cm^2 "slice" is defined
Channel – to – header geometry	• OEM patent literature on methods for directing flow around plate seals

Baseline System Definition (cont'd)

2. Gas Diffusion Layer (GDL)

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

3. Membrane electrode assembly (MEA)

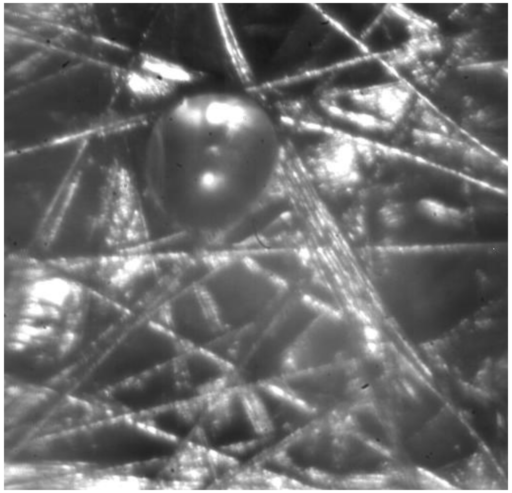
Availability	• Commercially available material, with commitment from manufacturer to supply for at least 3 years
Pt loading	• Thrifted platinum content, moving toward DOE target of 0.25 mg/cm^2 total
Performance	• At or near benchmark performance under relatively dry (~80% exit RH) and wet (~120% exit RH) conditions

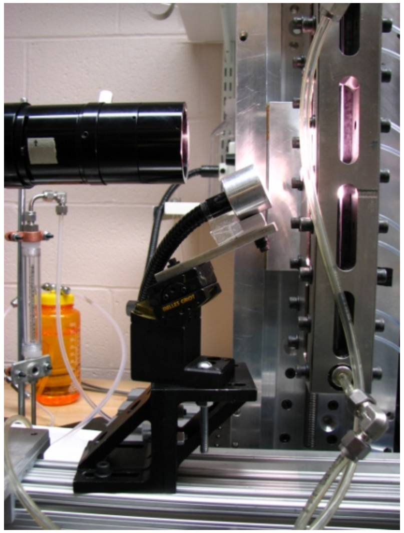
Ex-situ Experiment Design

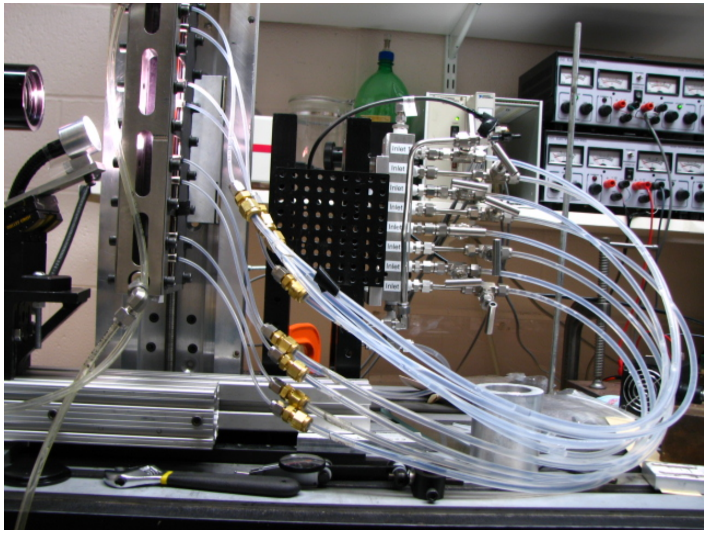
Objectives	1. To study two phase flow stability in each channel and establish two phase flow stability criteria. 2. To study water distribution in each channel.
Measurements	1. Water flow rate and pressure. 2. Gas flow rate and pressure drop. 3. Direct view of water droplets and films, their distribution 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.

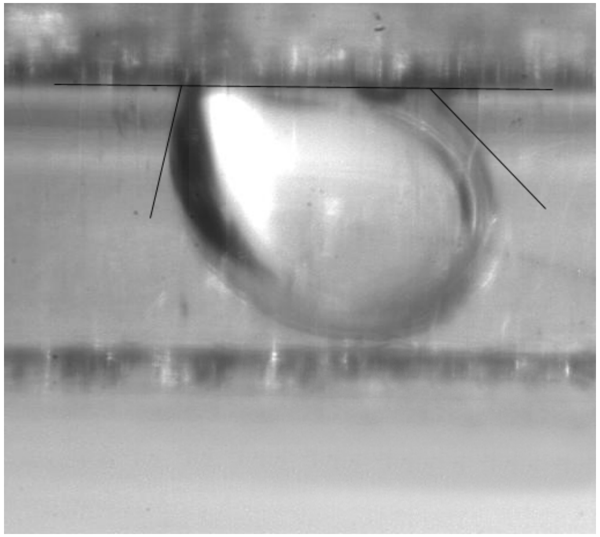
Water Droplet Visualization

- High speed imaging
- GDL/channel studies
- Single-channel, multiple channel and header flows
- Flow patterns, instabilities and pressure drop



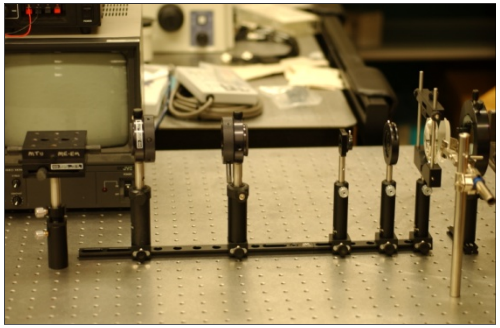




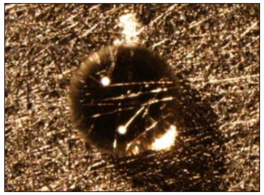


GDL Component Studies —Material Properties

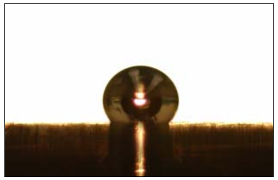
- Contact Angle Studies:
  - Developed Koehler illumination technique
  - Developing image processing technique
  - Developing GDL handling protocol to address contamination (see center image)
  - Started contact angle measurement calibration
  - Beginning GDL parametric studies



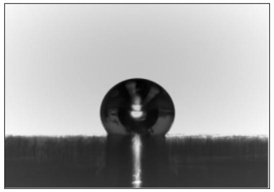
Koehler Illumination Apparatus



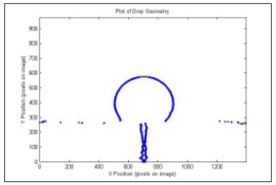
Top View of Water Drop on GDL



Side View - Raw Image

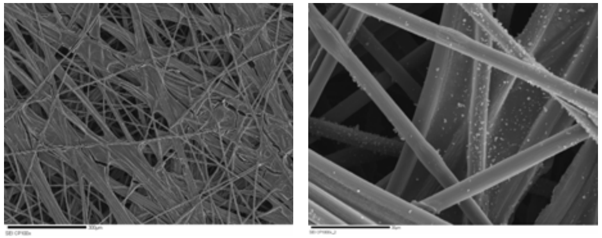


Side View - Gray Scale

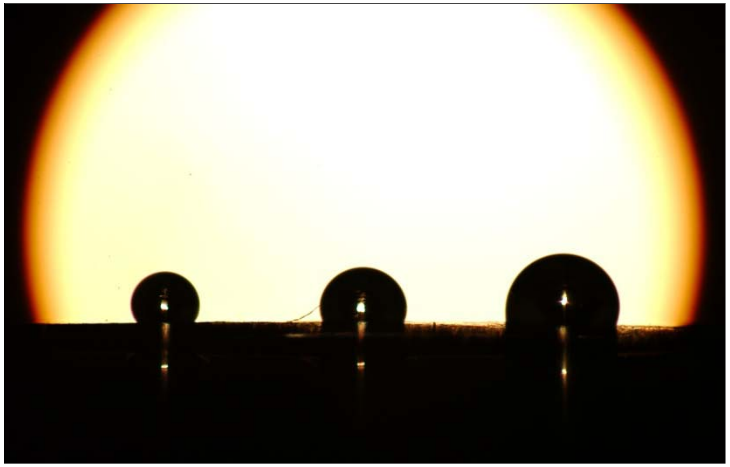


Edge Detection of Drop

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



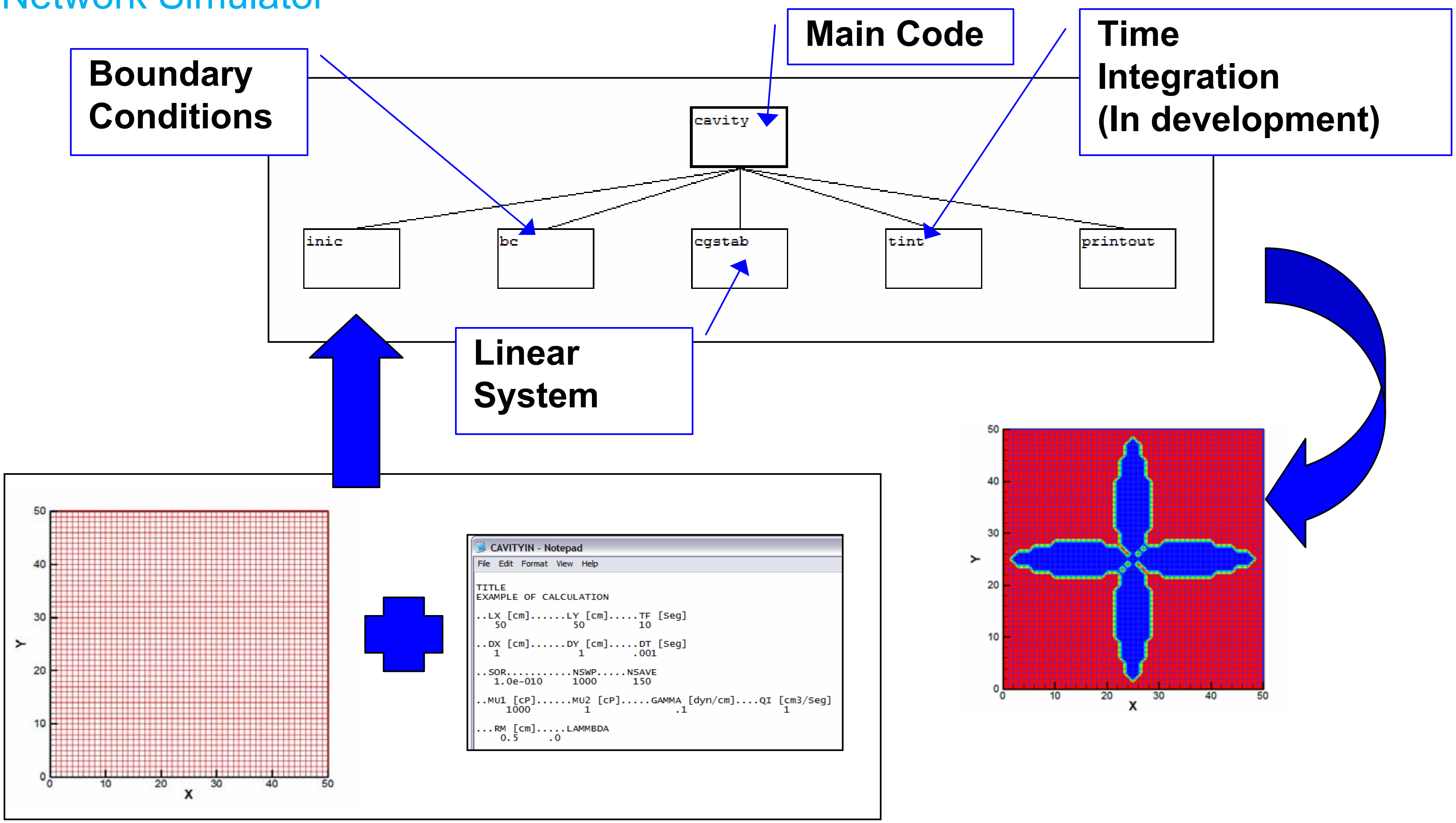
SEM Images of GDL



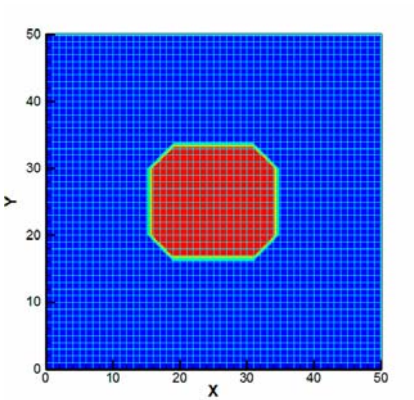
Three water drops on a GDL, each with a different volume – each drop has a different contact angle due to surface contamination.

GDL Component Studies —Capillary Transport Model

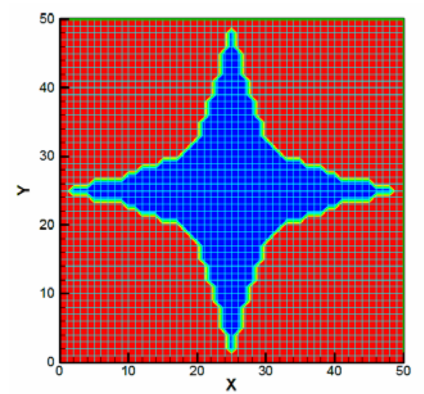
2D Network Simulator



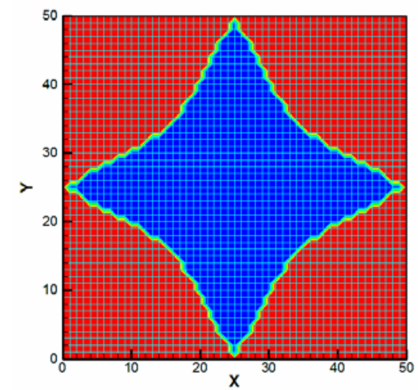
2D Network Simulator: Preliminary Results



M=10 Ca=∞



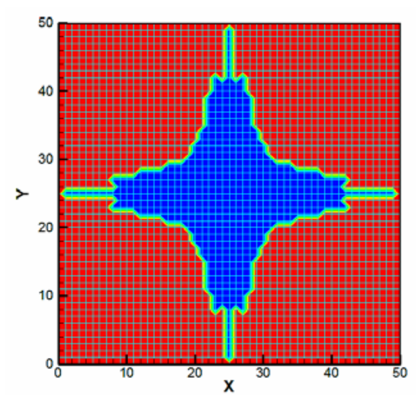
M=0.1 Ca=∞



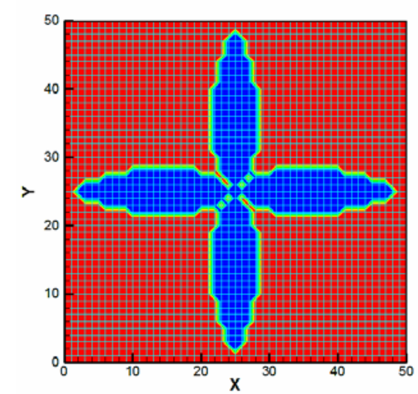
M=0.1 Ca=1 θ>90

M is the viscosity ratio

Ca is the Capillary number



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