Heat and mass transport phenomena in polymer electrolyte membrane fuel cells micro/nano porous layers

Sina Salari, Claire McCague, Mohammad Ahadi, Mickey Tam* and Majid Bahrami
School of Mechatronic Systems Engineering, Simon Fraser University, Surrey, Canada
**Automotive Fuel Cell Corporation, Burnaby, Canada*

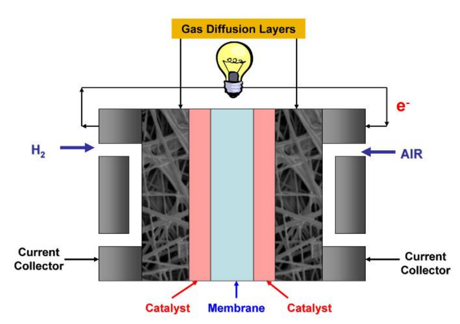
SFU

Polymer Electrolyte Membrane Fuel Cells

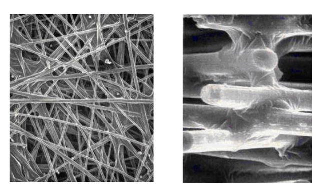
Objective:

Perform cutting-edge research on PEM fuel cell materials focused on analytical modeling and experimental investigation of the transport properties of micro/nano structured fuel cell components, including:

- Thermal conductivity
- Diffusivity
- Permeability
- Interfacial resistance
- Electrical conductivity



Membrane electrode assembly (MEA)



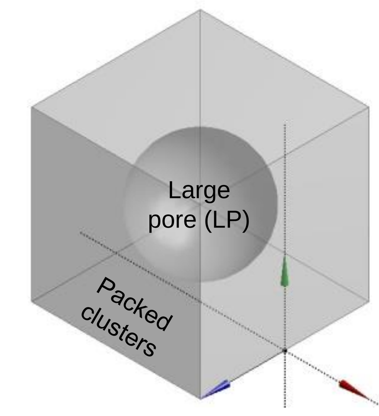
Gas diffusion layer (GDL) surface and cross section

- The performance of a PEMFC relies on the effectiveness of the transport of heat, mass, and charge in membrane-electrode assembly (MEA)
- Diffusion is the mechanism through which gas of reactants reach Pt nanoparticles in catalyst layer (CL)
- The better design of the CL, the more active Pt nanoparticles, the less Pt loading required in CL, and the lower the production cost

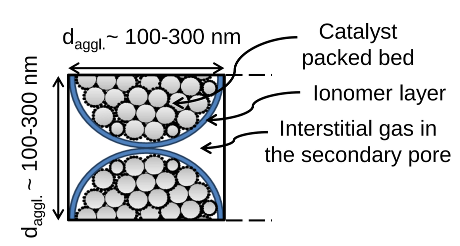
Heat Transfer Model for Catalyst Layer

Modeling by a multi-scale unit cell approach:

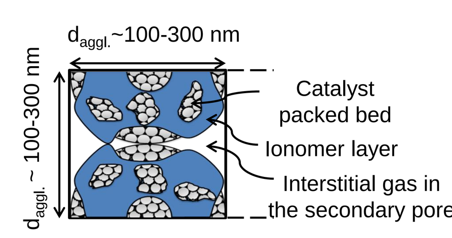
- Unit cell of the catalyst layer at micro-scale
- Unit cell of the agglomerates clustered around pores at nano-scale
  - Agglomerates fully covered by ionomer
  - Agglomerates partially covered by ionomer
- Unit cell of carbon supported platinum particles (Pt/C) inside each agglomerate at nano-scale
- Fundamental heat transfer and elasticity laws are used to model the local properties and transport phenomena within each unit cell
- The unit cell models at multiple scales are integrated to obtain the heat transfer model of the whole catalyst layer



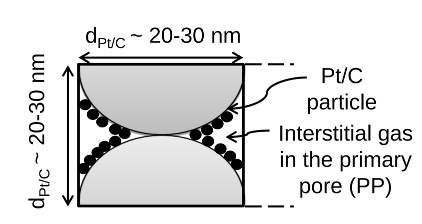
Unit cell of the catalyst layer



Unit cell of Pt/C for fully covered agglomerates



Unit cell of Pt/C for partially covered agglomerates



Unit cell of the packed Pt/C particles

Modeling the effect of ionomer coverage

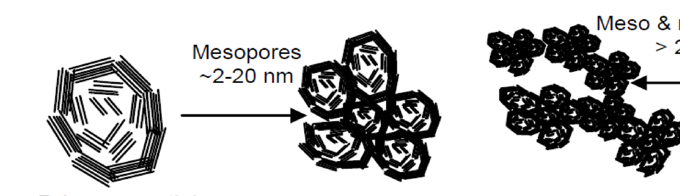
Diffusivity Model for Catalyst Layer

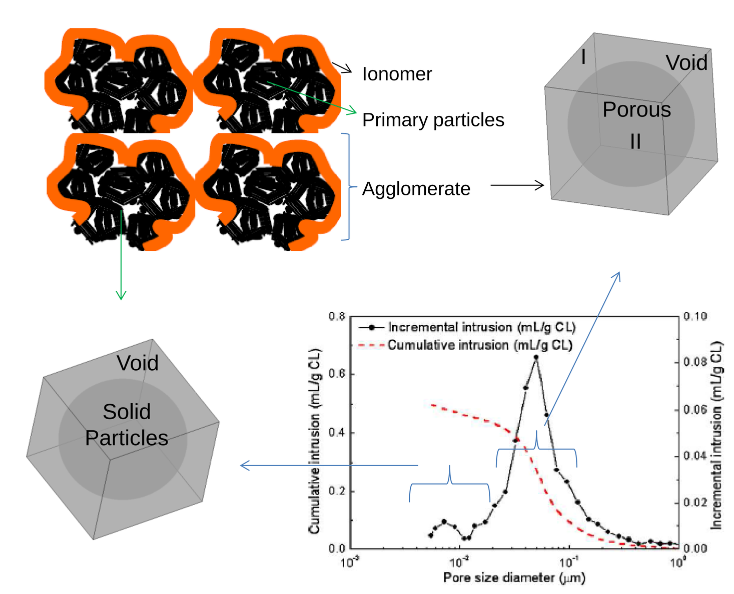
Different unit cells for pores with different equivalent diameters

- Unit cell around primary particles consist of solid and void parts (D<50 nm)
- Unit cell around agglomerates consist of porous and void parts (50nm<D<300nm)
- Unit cell around aggregates consist of porous and void parts (300nm<D<3μm)
- Considering both Knudsen and bulk diffusion mechanisms
- Considering temperature dependency

Future work

- Ionomer coverage
- Humidity
- Compression
- More realistic unit cell geometry



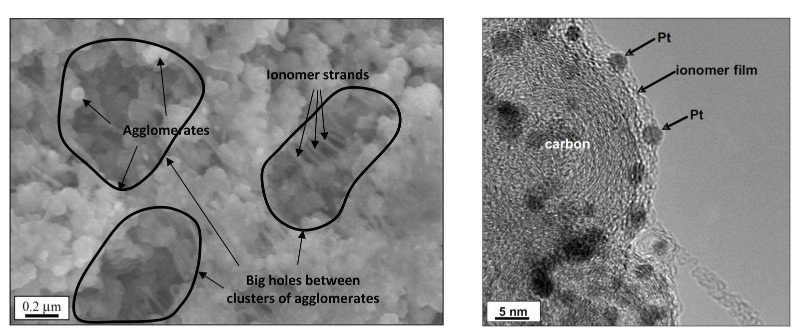


Platinum Catalyst Layer

Carbon supported Platinum (Pt/C)

In the catalyst layer, platinum nanoparticles are supported by carbon black particles which aggregate into agglomerates.

The agglomerates are connected by ionomer and reactant gases flow through pores in the layers.



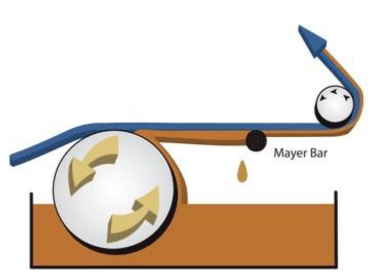
SEM (left) and TEM (right) images of the ionomer strands that bind Pt/C agglomerates together and the microstructure of Pt/C/ionomer at the surface of an agglomerate.

More, K.L., et al., *ECS Transactions*, 3(1), p. 717 (2006)

Catalyst layer preparation

Ink preparation:

- Mixing of Pt/C, ionomer and solvents
- Probe sonication of mixture
- Magnetic stirring



Mayer bar

Layer deposition on membrane :

- Fuji inkjet printer and Microfab printer
  - Good for small areas
  - Printing thin layers of catalyst
- Mayer bar rolling transfer
  - Good for mass production
  - Coating thick layers of catalyst

Fuji inkjet printer

Characterization:

- Scanning electron microscopy of epoxy mounted cross-sections to evaluate layer thickness
- N_2 adsorption porosimetery to evaluate pore size distribution and porosity
- FIB-SEM to study the structure of catalyst layer

In 2008, Ballard, Ford and Daimler formed the Automotive Fuel Cell Cooperation Corporation (AFCC). The LAEC-AFCC collaborative research project on transport phenomena in fuel cell porous layers began in May 2014.

Sources of waste heat generation in a PEMFC:

- Reversible heat of the electrochemical reaction (in **CL**)
- Irreversible heat due to activation losses (in **CL**)
- Latent heat due to phase change (in cathode **CL**)
- Joule heating in all of the fuel cell components (including **CL**)

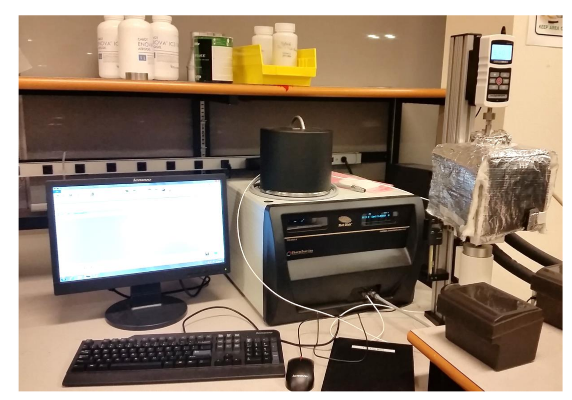
Local temperature variations affecting drying, flooding, and degradation phenomena

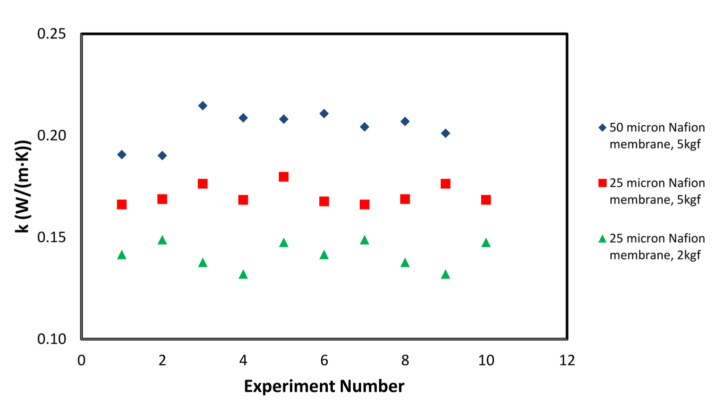
In situ temperature distribution are obtained from comprehensive mechanistic thermal conductivity models

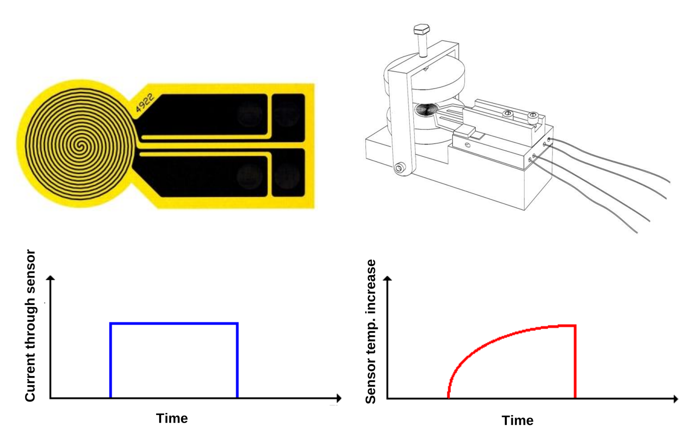
Thermal Properties Measurements

Transient plane source (TPS) thermal analyzer

- Utilizes a thin foil double-spiral of nickel to resistively heat the sample and monitor the temperature change as a function of time
- Bulk materials, thin films, liquids, powders and pastes
- Isotropic and anisotropic materials
- Determines thermal conductivity, thermal diffusivity and specific heat
- Thermal conductivity range of 0.005-1800 W/(m·K)
- Accuracy: ± 5%
- Reproducibility: ± 2%
- Temperature controlled chamber (-35 ˚C to 200 ˚C)



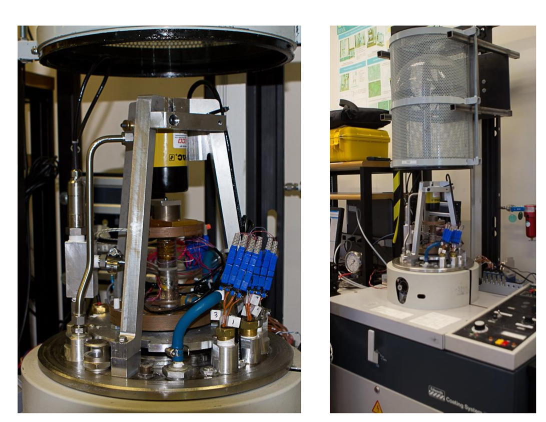




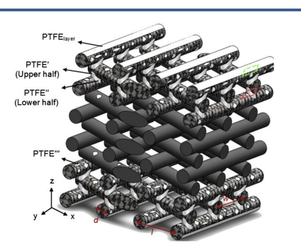
Transient Plane Source (TPS) 'Hot Disk' thermal conductivity, thermal diffusivity and specific heat analyzer

Guarded hot-plate thermal properties testing

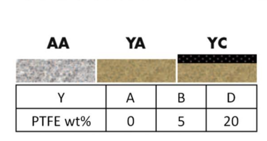
- Steady-state measurement of heat flow through sample compressed between hot and cold plates
- Measurement of thermal conductivity and thermal contact resistance
- Thermal conductivity range of 0.1-10 W/(m·K)
- Hydraulic sample compression
- Laser interferometric displacement measurement
- Vacuum system to eliminate convection
- Sealed flow cell for sample testing with controlled relative humidity



Custom-built guarded hot-plate instrument with compression control to measure thermal conductivity and thermal contact resistance

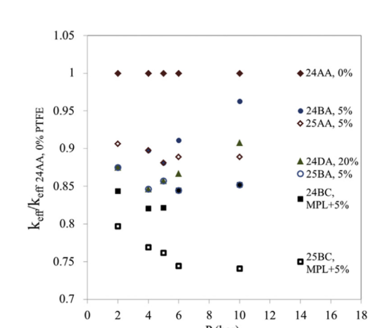


Geometric model of GDL treated with PTFE



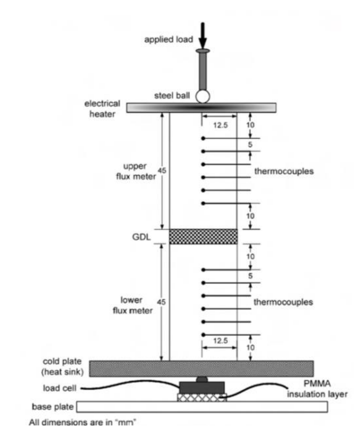
	AA	YA	YC
Y	A	B	D
PTFE wt%	0	5	20

GDLs of SGL AA, BA, DA, and BC (black layer = MPL)



Thermal conductivities of GDLs with PTFE and MPL compared to SGL 24AA (GDL with 0%PTFE, no MPL)

H. Sadeghifar, N. Djilali, M. Bahrami, *J. Power Sources* 248, p. 631 (2014)

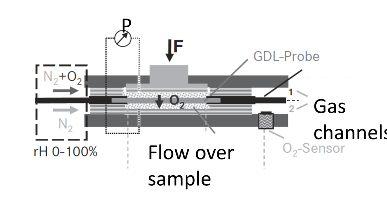


Schematic of guarded hot-plate thermal properties analyzer

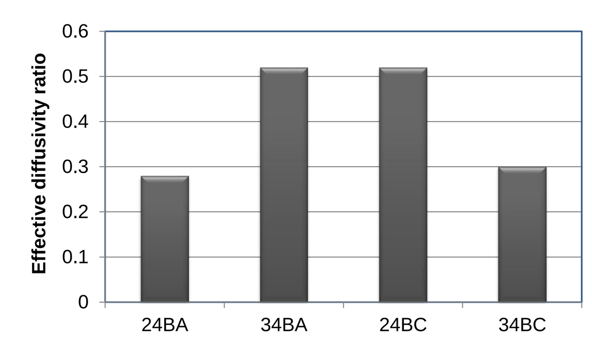
Diffusivity Measurements

Dry Diffusivity Test bed

- Two different known gas flows pass steadily over a thin porous sample
- Each gas penetrates through the sample
- The steady state concentration of each gas in the other flow is measured
- Based on a theoretical method the mass transfer resistance of the sample is calculated
- Knowing the thickness of the sample, the effective diffusivity is calculated



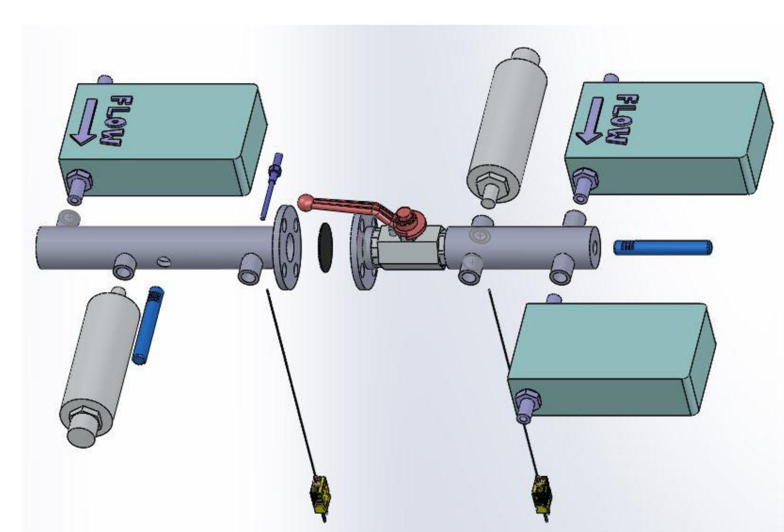
Dry diffusivity test bed

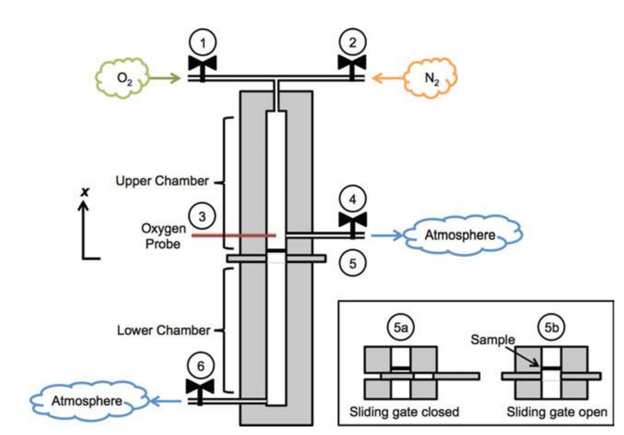


Modified Loschmidt Cell

- Two chambers filled with different gases
- A thin porous sample and a closed valve is between chambers at t=0.
- Valve is opened at t=0 and each gas starts to penetrate the other chamber through the sample
- Concentration of each gas at a specific location is measured as a function of time
- Based on a theoretical, mass transfer resistance of the sample is calculated
- Knowing the thickness of the sample, the effective diffusivity is calculated

	24BA	34BA	24BC	34BC
GDL thickness μm	190	280	190	280
MPL thickness μm	0	0	45	45





Schematic of the Loschmidt cell diffusion instrument

Support

NSERC CRSNG
AUTOMOTIVE FUEL CELL COOPERATION
4D LABS