Cause and Effect: Flow Field Plate Manufacturing Variability and its Impact on Performance

2012 DOE Hydrogen and Fuel Cells Program Review

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Overview

Timeline
October 1, 2009
September 30, 2012
80% Completed

Barriers
B. Lack of High-Speed Bipolar Plate Manufacturing Processes
F. Low Levels of Quality Control and Inflexible Processes

Overall Budget
Total Project Funding $1.5 M
Funding Received FY11 - $200 K
Funding for FY12 - $175 K [FY11 deferred]

[Cost share not required but NIST contribution to effort estimated at ~ 40% to 50% matching, Subproject P1 Manufacturing Variability Study – 100% NIST funding in FY11 & FY12]

Partners
Subproject #1 Only: LANL – Tommy Rockward (Funded $75K)
Other Interactions & Collaborations addressed in each subproject section.

Initial Proposal Allocation

- P1: Mfg Variability
- P2: Non-Contact/Smart Assembly
- P3: OSM/NREL Collaboration

FY09 FY10 FY11
$K
0 100 200 300 400 500
P1 Cause-and-Effect: Flow Field Plate Manufacturing Variability and its Impact on Performance

**Objective:** Develop a pre-competitive knowledge base of engineering data relating performance variation to manufacturing process dimensional variability.

**Approach:** Using a statistically based design-of-experiments, fabricate experimental “cathode” side flow field plates with various well defined combinations of flow field channel dimensional variations; then through single cell fuel cell performance testing using a robust protocol, quantify the performance affects, if any, and correlate these results into required dimensional fabrication tolerance levels.

**Benefits (Relevance):** Provide bipolar plate manufacturers and designers/modelers with the data necessary to make informed tolerance decisions to enable reduction of fabrication costs.

_NIST_  
- Dimensional Metrology  
- Manufacturing Metrology  
- Statistical Engineering

_LANL_  
- Operational Knowledge  
- Advanced Testing Facilities
Cell Specifications

- 50 cm² Hardware (Teledyne CH-50)
- Gas Diffusion Media: SGL 25 BC
- Commercially Available CCM 0.1 / 0.2 mg/cm²…Anode and Cathode
- Hydrogen Electrolysis-Grade) and Air (oiless-compressor)
- NIST Fabricated Reference Anode Plate and [10] Cathode Experimental Plates (POCO AXF-5QCF), Triple Channel Serpentine Design

Experimental Parameters and Level of Variability

Fractional Factorial Design of Experiments 2 (4-1)

- Sidewall Taper 0° to 10°
- Bottom Straightness 0 to 50 um
- Sidewall Straightness 0 to 50 um
- Variation-in-Width 0 to 100 um

Beginning-of-Test (BOT) and End-of-Test (EOT) Diagnostics – MEA Q.C.

- Electrochemical H₂ Crossover
- Cathode Side Active Area Measurements

Performance Testing (Gas Access and H₂O Mgmt Impacts)

- Polarization curves in air measured in both directions
- AC-Impedance measurements
Overview - Initial Protocol

- Conditions 80°C and 60°C, 50% and 100% RH
- Data collected in constant current mode with 2 minute settling times
- Utilization Rates 83.3% H2 and 71% Air
- CCM Usage:
  - Replaced between testing of each plate
  - Replacement from same batch and repeatability previously tested (< 5 mV)
- 25 psig back-pressure on both anode and cathode outlet sides

Technical Accomplishments and Progress

Initial Protocol Results (All Plates)

- Status:
  - LANL polarization data [Presented 2010]
  - NIST initial factor sensitivity statistical analysis [Ongoing 2012]

- Take Away
  - Factors and levels do have a noticeable impact
  - Reviewers in 2010 raised concerns about appropriateness of 25 psig back pressure
  - Incorporated an additional experiment with subset of plates for back pressure sensitivity testing [10 psig and ambient]
**Revised Protocol [Back Pressure Sensitivity Experiment]**

Experiment involved worst performers 3C & 7C along with best performer 5C tested at 10 psig and ambient back pressures (anode and cathode)

**Status:**
- 3C & 7C tested, 5C broke during cell assembly *(Presented 2011)*
- 5C replacement
  - Plate material changed from POCO AXF-5QCF to AXF-5Q (for neutron imaging purposes)
  - Fabrication capability re-established *(10/2011)*
  - 5C fabrication completed *(1/2012)*
  - Dimensional verification *(3/2012)*
  - Pyrosealing by POCO (TBD) (additional sealing process due to material change)
  - Polarization curves by LANL (TBD)
    - Result correlation between materials (25 psig repeat)
    - Completion of back pressure sensitivity experiment

**Take Away:**
- Overall performance of each plate decreased along with back pressure [anticipated]
- Performance differences between plates remained, tracking nicely between back pressures
  - 5C testing not expected to change this conclusion
Neutron Imaging Experiment

Additional experiment based on questions raised at FreedomCAR Technical Team Presentation (3/2011)

Experiment planned using subset of plates representing best and worst performers along with the nominal design plate (rectangular cross-section with minimal dimensional variations) [1A, 1C, 3C, 5C, 8C]

Integrated 5C replacement with this activity to achieve two objectives
1. Repeat testing at 25 psig back pressure will serve to correlate any new results with previous results – eliminating material/material processing variable
2. Use replacement 5C, complete back pressure sensitivity experiment and this plate will be used in the neutron imaging experiment

Status:
- Proposal for beam time experiment submitted (10/2011)
- Proposal approved (1/2012)
  - With positive reviewer comments
- NIST NCNR Imaging (NIST & LANL 7/2012 – Tentative)
- Modifications required for imaging (in-process)
  - Aluminum endplates to replace original stainless steel (12/2011)
  - Replicate plates for experiment must be made from POCO AXF-5Q rather than original AXF-5QCF due to hydrocarbon content of cured floran sealing material (fabrication, dimensional verification, and sealing – in process)
Interaction 12 or 34 or some combination of 1234 is most important

\[1 = \text{sidewall straightness and } 2 = \text{phase of the sidewall straightness of one side in relation to the other (width variation and wiggle OR just wiggle)}\]

\[3 = \text{bottom straightness (variation in depth) and } 4 = \text{sidewall taper}\]

- Factor 3 = bottom straightness (variation in depth)
- Factor 1 = sidewall straightness

* Inconclusive: A potential result of a fractional factorial experiment is that some two factor interactions can be “confounded”

** One negative aspect: although the relative importance of these three parameters is strongly suggestive the Fcdf statistic does not meet the criteria of being statistically significant > 95%.
Conclusions

- From VI data for both 50% RH and 100% RH, without statistics:
  - 5C and 8C best performers
  - 3C and 7C worst performers
  - 1C nominal rectangular cross-section made with exacting geometric precision NOT among the top performers.

- Varying back pressure doesn’t change performance differences between plates.

- Controlled dimensional “chaos” or very controlled complex geometry (whichever is your preference) seems to be more beneficial than simple straight geometric shaped channels made with dimensional perfection.

- Neutron imaging will hopefully produce insight with regards to how the water moves in the different cell configurations.
Conclusions

- Employed statistical analysis in an attempt to uncover what factors and two-factor interactions were most important.

  - Results of the statistical analysis are preliminary only, further review of the data is needed prior to making definitive conclusions with regards to factor sensitivity, beyond the obvious.

  - Due to the “fractional” factorial nature of the design of experiments the two factor interactions identified by this analysis come in pairs and are “confounded”; meaning that you don’t necessarily know without physics based interpretation which of the two interactions is most important.

  - Initial results using voltage data from each curve at 2 A/cm² from the 100% RH dataset we obtain a “strongly suggestive” but not “statistically significant” ranked order.

  - Initial results using voltage data from each curve at 2 A/cm² from the 50% RH yields a different ranked order, again suggestive but not statistically significant.

  - Common to both data set analyses is the significant importance of factor 1 (sidewall straightness)

  - Data needs to be investigated further at different current densities to evaluate consistency.

  - Analyses raises questions
    - Should the results from both datasets be consistent or different?
    - Is strongly suggestive versus statistically significant enough to make some conclusions?

  - Physics based insight is needed and an expert in the field of micro-fluidics and two-phase flow in fuel cells is currently reviewing the data.
P1 Cause-and-Effect: Flow Field Plate Manufacturing Variability and its Impact on Performance

Future Work

• Integrate physics based expertise
• Investigate statistical analysis further to understand potential inconsistencies
• Scrutinize data sets to ensure completeness
• Complete back-pressure sensitivity experiment with 5C testing
• Complete all fabrication and verification work in support of neutron imagining experiment
• Complete neutron imaging experiment
• Integrate what imagining reveals to better understand effects.
• Publish results by end of 2012
Technical Backup Slides
P1 Cause-and-Effect: Flow Field Plate Manufacturing Variability and its Impact on Performance

Technical Accomplishments and Progress

Design of Experiment Full Factorial $2^{4-1}$ (4 dimensional parameters, 2 levels each with center replica point)

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**P1 Cause-and-Effect: Flow Field Plate Manufacturing Variability and its Impact on Performance**

Anticipated Project Completion (Orig. Est. 9/2010)

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Los Alamos National Lab (LANL) – NIST/LANL Cooperative Agreement Approval & Funding for Fuel Cell Performance Study with NIST Experimental Plates

Los Alamos (POC: Tommy Rockward) Includes completion of explicit statement of work (SOW) with NIST/LANL collaboratively developed testing protocol.

LANL Initial Testing and Preliminary Report on Performance Experiments

LANL Testing and Final Report on Performance Experiments

(Initial CV data at 25 psig back pressure & back pressure sensitivity experiment 10 psig and ambient)

Neutron Imaging Experiment

Statistical Analysis of Experimental Results by NIST and Preparation for Publication by NIST & LANL

Report/Publication (Not Incl. Annual AMR & DOE Progress Report)

LANL Funding Received Delayed 10/1/2011