VI.6 Cause-and-Effect: Flow Field Plate Manufacturing Variability and its Impact on Performance

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Fiscal Year (FY) 2011 Objectives

Develop a pre-competitive knowledge base of engineering data relating fuel cell performance variation to bipolar plate manufacturing process parameters and dimensional variability.

Technical Barriers

This project addresses the following technical barriers from the Manufacturing R&D section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

(B) Lack of High-Speed Bipolar Plate Manufacturing Processes

(F) Low Levels of Quality Control and Inflexible Processes

Contribution to Achievement of DOE Manufacturing R&D Milestones

This project will contribute to achievement of the following DOE milestones from the Manufacturing R&D section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

- **Milestone 13**: Complete development of standards for metrology of PEM fuel cells. (4Q, 2010)

FY 2011 Accomplishments

- Implemented performance testing protocol improvements to better highlight performance issues (1/2011).
- Quantified baseline repeatability of performance testing as a metric for determining what differences are statistically significant (1/2011).
- Completed initial round of performance testing on all experimental cathode plates at 25 psig back pressure which showed some significant performance differences (2/2011).
- Expanded protocol to include testing at ambient back pressure (as a result of a 2010 Annual Merit Review meeting reviewer comment) using the two worst performing experimental plates #3 and #7 (3/2011):
  - This testing showed that the performance differences still existed, regardless of back pressure.
  - The best performing experimental cathode plate #5 was to be tested under this extended protocol but broke during assembly (fabrication of replacement in process).

Introduction

Based on a workshop organized by the Center of Automobile Research and NIST in December 2004; industry bipolar plate manufacturers identified a need for engineering data that relates geometric bipolar plate tolerances to fuel cell performance. This need is in response to pressure from fuel cell designers to produce lower cost plates, as such, plate manufacturers are being forced to consider potential quality related trade-offs to achieve desired cost targets. To justify these trade-offs, manufacturers are questioning the relevance of stated tolerances on dimensional features of bipolar plates; they expressed a desire for published engineering data relating performance and dimensional quality of the plates that can be used as reference when making these decisions. In response to the identified need, this project was conceived in 2004 and partially funded through the NIST Advanced Technology Program (ATP) Intramural Competition for a period of three years (FY 2005-FY 2007). The ATP funding was also intended to aid NIST with the development and validation of a single-cell testing laboratory. In 2008, funding was provided through DOE in an attempt to bring this project to a successful completion by the end of FY 2008.

To date, the reference single-cell design has been selected, the fabrication and dimensional verification of all experimental plates has been completed according to a statistically based design-of-experiments. All that remains to be completed is the repeatability testing to verify the initial performance test results, the fabrication, dimensional verification, and performance testing of replacement cathode plate #5C at the various back pressures, and the analysis of the performance testing along with the derivation of conclusions based on the full-factorial design of experiments.

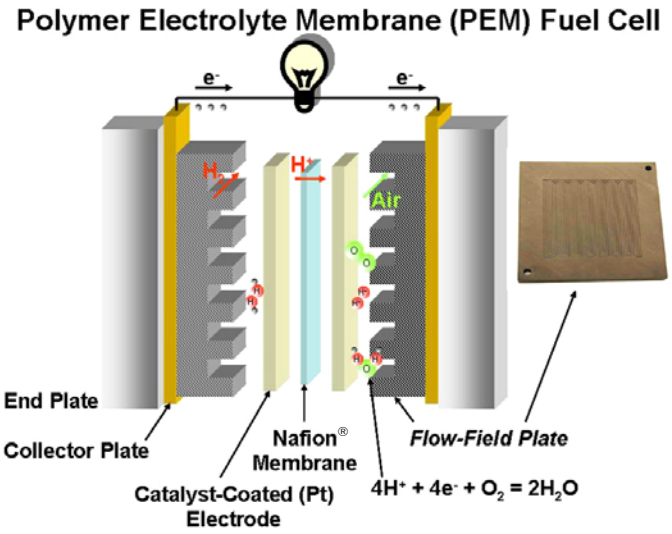

FIGURE 1. Concept - Reference Single-Cell and NIST Fabricated Cathode Flow Field Plates

Approach

Using a statistically based design-of-experiments (Figure 1), fabricate experimental "cathode" side flow field plates with various well defined combinations of flow field channel dimensional variations (Figure 2); then through single-cell fuel cell performance testing using a well defined protocol, quantify the performance effects, if any, and correlate these results into required dimensional fabrication tolerance levels.

Results

The initial performance testing last year, as reported, revealed some very necessary modifications to the protocol.

	2^{4-1} Fractional Factorial Design with replicated center point (k=4,n=10)							
	Sidewall Straightness	Sidewall Straightness	Bottom Straightness	Sidewall Taper				
	Amplitude	Phase	Amplitude			Sequence		Drawing
Part	*X1*	*X2*	*X3*	*X4*	*Machining*	*Measuring*	*Perf. Testing*	*Cross-Section*
9	0(25µm)	0(90)	0(25µm)	0(5)	1	1	1	
3	-1(0)	+1(180)	-1(0)	+1(10)	2	2	2	
2	+1(50µm)	-1(0)	-1(0)	+1(10)	3	3	3	
4	+1(50µm)	+1(180)	-1(0)	-1(0)	4	4	4	
8	+1(50µm)	+1(180)	+1(50µm)	+1(10)	5	5	5	
5	-1(0)	-1(0)	+1(50µm)	+1(10)	6	6	6	
7	-1(0)	+1(180)	+1(50µm)	-1(0)	7	7	7	
10	0(25µm)	0(90)	0(25µm)	0(5)	8	8	8	
6	+1(50µm)	-1(0)	+1(50µm)	-1(0)	9	9	9	
1	-1(0)	-1(0)	-1(0)	-1(0)	10	10	10	

FIGURE 2. Design of Experiment 2^{4-1} Fractional Factorial Design…4 Parameters, 2 Levels, and Replicate Center Point

The most significant was that the same catalyst coated membrane (CCM) could not be reused from plate-to-plate thus a new CCM had to be used. To increase the likelihood of acceptable repeatability, we ensured that all the CCMs came from the same batch. As any particular level of repeatability cannot be assumed, we then performed multiple voltage-current (V-I) curves using the same plate configuration with a different CCM. The results as shown in Figure 3 demonstrate repeatability commensurate with previous high-level single cell testing round robins where multiple labs tested the same single cell assembly, thus we concluded we have attained the desired benchmark repeatability.

Two more recent modifications were identified to better highlight the impact of the intentional dimensional variabilities on performance in the mass transport region. To promote the onset of mass transport we: (1) reduced the anode and cathode platinum loadings from 0.2/0.4 mg/cm^2 respectively to 0.1/0.2 mg/cm^2 and (2) increased the cathode utilization from 50% to 71%. These modifications proved effective, thus we completed the initial V-I curves for all 10 experimental cathode plates as shown in Figure 4. These data were collected applying 25 psig backpressure at the outlets as originally defined in our protocol.

After receiving the reviewers' comments from the 2010 DOE Annual Merit Review meeting in June 2010 we added some additional testing to address a specific reviewer's concern that the backpressure chosen was not within realistic operating conditions. To address this concern, we selected cathode plates #3C, #5C, and #7C which represent the best and worst performers for repeated testing at an intermediate backpressure and ambient. The results for plates #3C and #7C are shown in Figure 5. Unfortunately plate #5C, the best performer, broke during assembly due to a misalignment of one of the sealing gaskets.

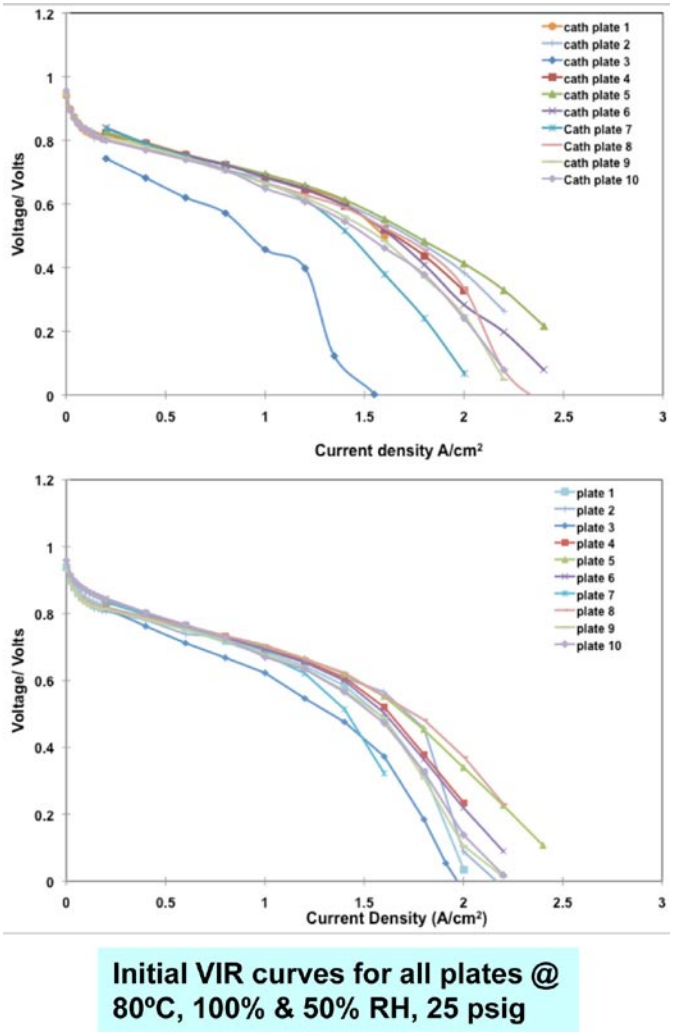

FIGURE 4. Initial Polarization Data for All 10 Experimental Cathode Plates

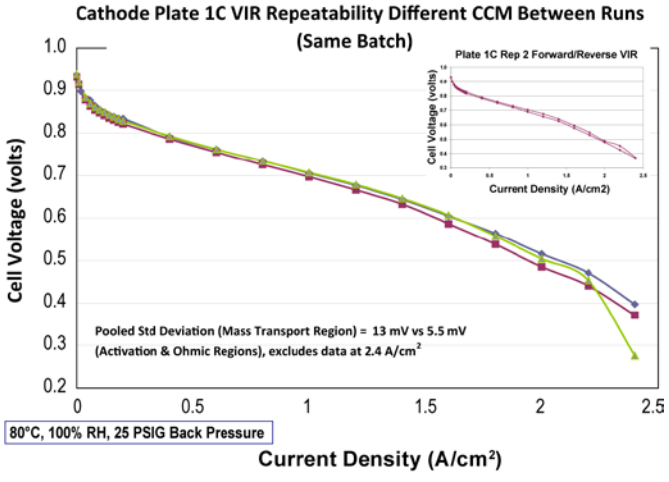

FIGURE 3. Polarization Curve Repeatability with CCM Change-Out between Runs

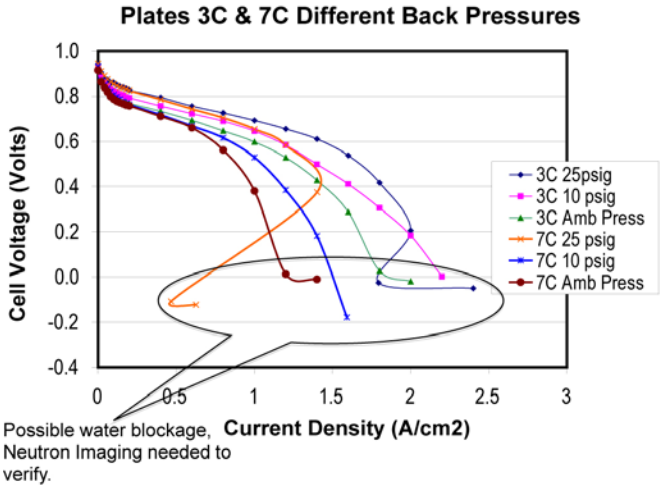

FIGURE 5. Polarization Testing of Select Plates at Different Back Pressures

As expected the polarization curves shifted lower with lower back pressures, however the plate-to-plate performance differences remained. A replacement for plate #5C is currently being fabricated.

Conclusions

- Protocol revisions were carefully derived and meticulously verified, thus the repeatability objectives were achieved and were better than expected.
- To this point testing shows that the intentional dimensional variability at the magnitudes chosen does affect the performance significantly.
- Additional testing, to this point, clearly demonstrates that these performance differences exist regardless of the outlet back pressure.

Future Direction

Project Deliverables

- NIST will fabricate and dimensionally verify a replacement experimental cathode plate #5C.
- Using the replacement #5C plate, LANL will repeat the initial polarization curve at 25 psig backpressure to ensure the results correlate with those of the original plate and complete the polarization curves at the intermediate and ambient backpressures.
- With the assistance of the NIST Statistical Engineering Division, correlate the polarization curve results with the design-of-experiments to elucidate which parameters or combination of parameters have the biggest impact on performance.
- Publish results.

Optional Deliverables (contingent on funding availability through either NIST or DOE)

The addition of the optional deliverables is to dispel the hypothesis that the water management issues are due to the serpentine flow field design or more specifically water being trapped in the turns rather than due to the dimensional perturbations. This concern was raised during a voluntary presentation we gave to the FreedomCAR Technical Team in March of 2011. All experimental plates use the same flow field design and perturbations do not exist in the turns therefore it is believed that repeatable performance differences are due to the perturbations.

- NIST will fabricate and dimensionally verify a subset of the experimental cathode flow field designs into a metallic flow field plate compatible with the LANL 50 cm^2 single cell designed for neutron imaging.
- LANL will perform the polarization protocol at the NIST Neutron Center for Neutron Imaging in order to identify where exactly within the flow field the mass transport issues are occurring.

Suggested Future Work

- Repeat experiments using a parallel flow field design in a metallic plate using the more critical parameters identified in this study along with other parameters, such as, surface finish not previously tested.

Disclaimer

Certain commercial equipment, instruments, or materials are identified in this paper in order to specify the experimental procedure adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the materials or equipment identified are necessarily the best available for the purpose.

Acknowledgements

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FY 2011 Publications/Presentations

1. E. Stanfield and M. Stocker, "Metrology for Fuel Cell Manufacturing," DOE Annual Merit Review Proceedings, MN006, May 12, 2011, http://www.hydrogen.energy.gov/pdfs/review11/mn006_stanfield_2011_o.pdf

2. E.Stanfield, M. Stocker, and B. Muralikrishnan, "Metrology for Fuel Cell Manufacturing," Invited Presentation Given to the FreedomCAR Tech Team, USCAR, Southfield, MI, March 16, 2011.

3. E. Stanfield, "Cause-and-Effect: Flow Field Plate Manufacturing Variability and its Impact on Performance," FY 2010 Annual Progress Report, DOE Hydrogen and Fuel Cells Program, February 2011, http://www.hydrogen.energy.gov/pdfs/progress10/vi_6_stanfield.pdf