II.E.5 Process Intensification of Hydrogen Unit Operations Using an Electrochemical Device

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Subcontractors:
- PBI Performance Products, Inc., Rock Hill, SC
- Plug Power, Inc., Latham, NY

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Project End Date: August 15, 2012

Fiscal Year (FY) 2011 Objective

Develop and demonstrate a multi-functional hydrogen production technology based on a polybenzimidazole (PBI) membrane which exhibits:

- High efficiency (70%)
- 100 scfh pumping capability
- CO_2 and CO tolerance
- 300 psig (differential) pressurization capability
- $3/kg operating costs

Technical Barriers

This project addresses the following technical barriers addressed in the Production section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan.

(K) Durability
(L) Impurities
(N) Hydrogen selectivity
(O) Operating temperature
(P) Flux
(R) Cost

Technical Target

This project is focused on fundamental chemical and mechanical engineering studies on PBI proton exchange membranes and electrochemical cell hardware, respectively. Learnings gained from these studies will be applied to the membrane fabrication process as well as toward the electrochemical cell architecture to meet the following key targets:

- 300 psid differential pressure operation at 160°C
- CO_2 tolerance
- High efficiency

FY 2011 Accomplishments

- 300 psig compression demonstrated at 160°C for over 600 hours on a PBI-based electrochemical pump.
- A process to increase the membrane durability and performance was developed.
- Advancements in the pump support and seal design (50 cm^2 format).
- Characterization of the gas diffusion layer (mechanical properties), enhanced pump architecture, and a 1st generation large format pump design completed to achieve the program target of 100 scfh.

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Introduction

One of the barriers to fuel cell acceptance is the lack of a simple, reliable, cost-effective and robust process to purify, pump, and pressurize hydrogen. This challenge is magnified by impurities and hydrogen generation occurring at near ambient pressure. Technical means of pressurizing the hydrogen is especially daunting for low to moderate flow rates. If the pressurization, purification, and recovery of the hydrogen can be developed into a single unit operation, the key goals relating to cost and reliability via process simplification could be an attractive and enabling option. Application of electrochemical methods is a potential solution. H2Pump has leveraged its extensive experience in electrochemical separation and pressurization systems to meet the project objectives with a high temperature membrane-based electrochemical hydrogen pump. The solutions have been based on developing a chemically and mechanically robust membrane in conjunction with advancements in cell hardware.

The significance of the success of the project to date is that multiple unit operations have been combined into a

single device and demonstrated to be capable of generating the targeted pressures and impurity tolerances.

Approach

H2Pump has shown that electrochemical methods to recover, purify, and pressurize hydrogen is a viable option for low to moderate volumes of hydrogen containing gases. The main challenge for this specific application is the lack of a proton conducting membrane which exhibits carbon dioxide and carbon monoxide tolerance and at the same time pressurize the hydrogen from atmospheric pressure to 300 psig. The approach has been to work closely with its partner, PBI Performance Products, to enhance the membrane properties relevant to this application while at the same time address cell hardware architecture so as to support the high temperature, CO_2 and CO tolerant membrane. The results (properties) of the membrane modifications were then used to guide the cell hardware program in which cell components have been assessed and characterized for the desired operating conditions. The combined efforts have led to the successful operation of 50 cm^2 cells which meet or exceed the program targets. Design guidelines developed with lab-scale pumps are then applied to a larger format to meet the volume requirements of the effort.

Results

The most significant result during this period is having achieved the targeted 300 psig compression using the high-temperature CO_2, CO tolerant membrane. Other accomplishments include membrane enhancement and characterization, gas diffusion layer characterization and selection, enhanced pump architecture, and completion of a 1st generation large format pump design. High pressure electrochemical hydrogen compression was achieved through rigorous material characterization and selection processes in conjunction with advancements in the pump support and seal design. Presented in Figure 1 are the data for a 300 psig 50 cm^2 pump operated at 160°C on humidified hydrogen for 300 hours. Membrane enhancement was accomplished via various treatments with the intent to improve material durability and performance over long lifetimes. Acid absorption, mechanical strength and electrochemical performance were studied after membrane treatments were performed. Polarization data for the pump operating with a 300 psig differential pressure are presented in Figure 2. Hardware design and material preparation methods were studied and improved to boost the maximum differential pressures within the hydrogen pump. This work was essential to address the failure modes which are unique to the high temperature and high pressure operation.

Tests are currently underway to assess lifetime of the multi-functional device at the targeted operating conditions. Additional cells have been tested with various sealing designs at pressures between ambient and 300 psig to assess the impact of the sealing method on high differential

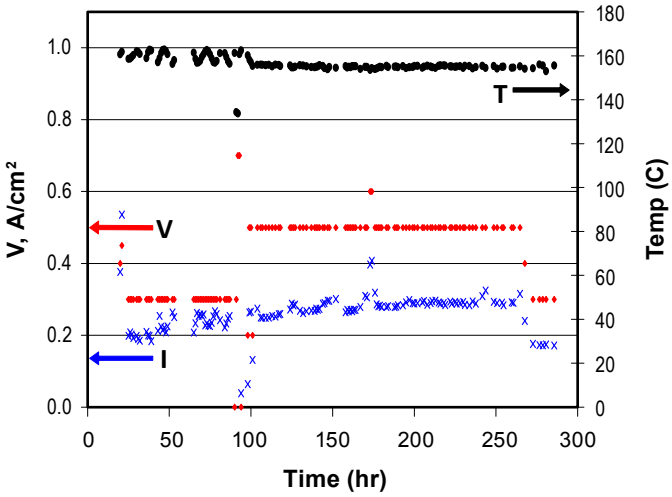

FIGURE 1. Cumulative Run Time: voltage, current, and temperature vs. time. 50 cm^2 PBI Performance Products enhanced membrane operating at 300 psi differential pressure in the H2Pump advanced cell hardware.

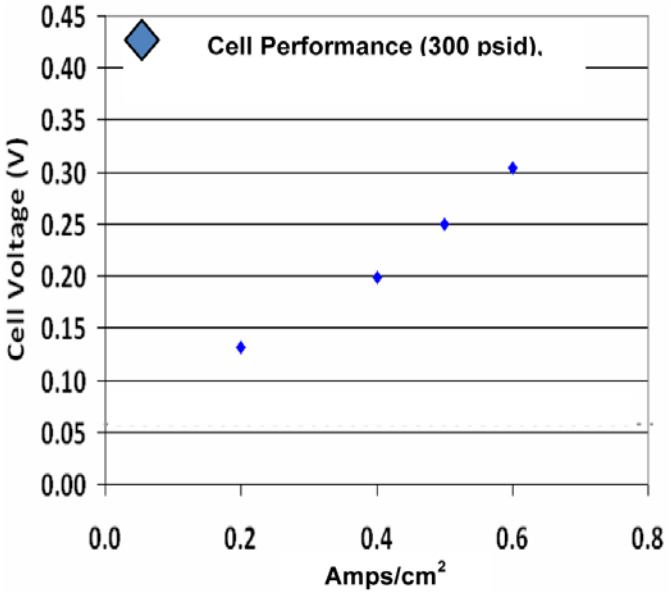

FIGURE 2. Voltage vs. current density: 50 cm^2 cell operating at 300 psi differential pressure with the PBI Performance Products enhanced membrane.

pressure operation. There are currently two approaches which have proven viable for the 300 psig pressurized operation, both relating a novel sealing and support design. In future activities one will be down-selected. Single cells operating at 300 psid have now exceeded 600 hours and remain on test.

Additional work is being carried out on enhancing the membrane properties via two approaches, thermal and chemical cross-linking of the polymer in the PBI membranes. Results of both methods (impact on stability and mechanical properties) have guided the effort to date.

Conclusions and Future Directions

- In collaboration with our partner, PBI Performance Products, PBI membrane has been successfully modified and is now stable in the targeted operating environment.
- Enhancement of the membrane – electrode interface successfully completed.
- Cell hardware has been modified and sub-components evaluated and down-selected.
- 300 psig differential pressure operation has been demonstrated for hundreds of hours.
- Life testing, impact of operating conditions, and durability will continue to be evaluated.
- Scale up of the membrane and electrode assemblies as well as the hardware is underway so as to achieve the 100 scfh target.
- Gas quality and analytical tests will be performed to further assess the performance of the 300 psig pump cells.
- Plans and preparation for an on-site demonstration of the technology will commence in the forthcoming months.

FY 2011 Publications/Presentations

1. Eisman, G., Ludlow, D., "Process Intensification of Hydrogen Unit Operations Using an Electrochemical Device, Proceedings of the DOE Hydrogen and Fuel Cell Annual Merit Review Meeting, Crystal City, VA., May, 2011.