V.J.1 Materials and Modules for Low-Cost, High-Performance Fuel Cell Humidifiers

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Subcontractor:
dPoint Technologies, Inc.
Vancouver, British Columbia, Canada

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Fiscal Year (FY) 2011 Objectives

- Demonstrate a durable, high-performance water transport membrane.
- Build and test a compact, low-cost, membrane-based module utilizing that membrane for use in an automotive stationary and/or portable fuel cell water transport exchangers.
- Model and show high-volume costs associated with membrane and module.

Technical Barriers

This project addresses the following technical barriers from section 3.3, Fuel Cells, of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan in Task 7, "Develop balance of plant components":

(B) Cost

(E) System Thermal and Water Management

(A) Durability and (C) Performance: by allowing the fuel cell to operate in less harsh, more humid environments they will perform better and be more durable.

FY 2011 Accomplishments

- Humidifier operating conditions for stationary, automotive and portable fuel cells have been established using input from manufacturers and other stakeholders.
- A range of humidifier membrane materials have been prepared and characterized.
- Permeance, air permeability and membrane durability testing for a range of humidifier membranes has been performed. One class of Gore prepared membranes has been identified as particularly promising.
- A room temperature static water vapor transport test protocol has been developed for rapid permeance testing and/or quality control of humidifier membranes.
- Humidifier cost modeling for the most promising candidate has been completed. The model shows acceptable high volume production costs for the most promising class of Gore prepared membranes.
- Initial module modeling and prototyping indicate that the composite Gore humidifier membrane will allow automotive module performance, size and durability targets to be met.

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Introduction

Today it is essential to humidify the gases supplied to the fuel cell inlets for automotive and many stationary fuel cell stack designs. In this work, we are providing a new, inexpensive, composite membrane capable of very high water vapor transport and low air cross-over. The composite structure has been designed to allow lower total cost while still meeting automotive and stationary humidifier water transport and durability targets.

Because the transport rates of these new materials are so high, current planar membrane humidifier designs are not capable of fully utilizing the high rates. Therefore, the project is using an innovative, low-cost humidifier module with customized channel geometries that can take advantage of the high water transport rates. By having a materials development effort integrated with a humidifier module-system design and build program, we will be able to effectively exploit the improved material properties in an actual device.

Approach

Perfluorosulfonic acid (PFSA) membranes fulfill most of the requirements for the water transport media at the heart of the planar membrane water exchanger. They fall short primarily on cost, and secondarily on durability, especially when they are made thin to increase performance and lower cost. W.L. Gore and Associates, Inc. (Gore) has developed a composite water vapor transport membrane that has overcome both of these limitations. The basic composite structure consists of a very thin ionomer layer sandwiched between two microporous polymer layers. The ionomer layer provides the active water transport and provides an impermeable layer to prevent gas cross-over. The water transport rate can be engineered to be very high either through the use of a material that has very high inherent water transport rates (e.g., PFSA polymers), or by making it extremely thin (e.g., <5 μm). The microporous layer provides three critical features: first it protects the thin ionomer layer from mechanical damage during handling; second, it confers strength to the thin layer allowing it to be more durable during use; and third, it offers a strong, protective support layer for placement of a macroporous gas diffusion layer.

Our subcontractor, dPoint Technologies, has developed an innovative pleated planar membrane humidifier that is able to achieve automotive manufacturer water transport and pressure drop requirements. The pleated design utilizes existing low-cost, high-volume pleating equipment that is used to manufacture air filters for automotive and heating, ventilation and air conditioning applications. The pleated humidifier is a proven technology that dPoint has been developing in cooperation with several major automotive manufacturers. Further improvement in humidifier size, cost and performance is possible through the use of the Gore membrane and optimizing the flow field channel design to take full advantage of this new membrane.

Results

A range of composite membranes have been produced by Gore, including ionomers coated on microporous membranes, shown schematically in cross-section in Figure 1a, and "sandwich" structures shown schematically in Figure 1b. The ability to prepare very thin layers of an ionomer allows very high permeances to be achieved with these materials. For example, using an ~5 micron PFSA layer (Figures 1c and 1d) in a sandwich structure, described as GORE™ M311.05, permeances of close to two times the next best alternative (Figure 2), i.e., a 25 micron homogeneous PFSA membrane, are achieved. A high-volume cost model for this class of composite membranes has also been completed, and it shows that these materials can be produced for ½ to ⅓ the cost of the next best alternative homogeneous membranes [4].

Initial studies of the durability of the sandwich composite microstructures, e.g., M311, show virtually no performance degradation with time at 65°C (Figure 3), a temperature consistent with stationary and/or backup power systems. Studies at 80°C and above, where most automotive systems operate, are underway. Initial results at these higher temperatures indicate there may be some limited reduction in performance after long times, but the magnitude of the loss will be manageable through appropriate module design and sizing.

The design and prototyping of humidifier modules by dPoint Technologies is well underway. Using a finite element model, the module flow field and other design parameters have been optimized (Figures 4a and 4b). Several subscale modules, (Figure 4c), have been built

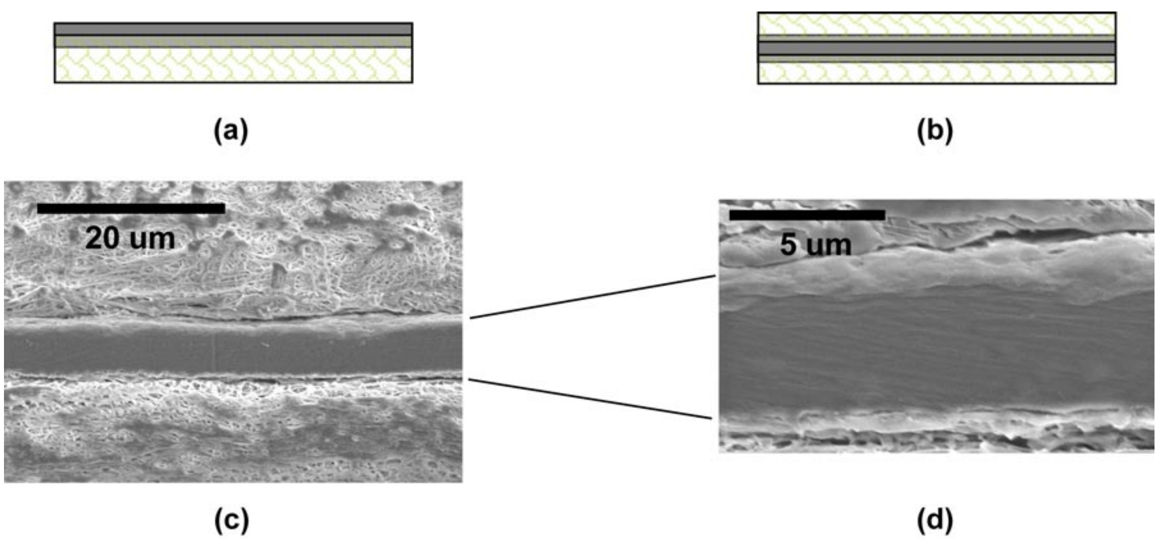

FIGURE 1. A range of composite membranes have been produced including ionomers coated on microporous membranes, shown schematically in cross-section in (a), and "sandwich" structures shown schematically in (b). One example of a "sandwich" composite structure is shown in a cross-sectional micrograph in (c). A higher magnification micrograph in (d) shows the ionomer layer is ~5 microns thick.

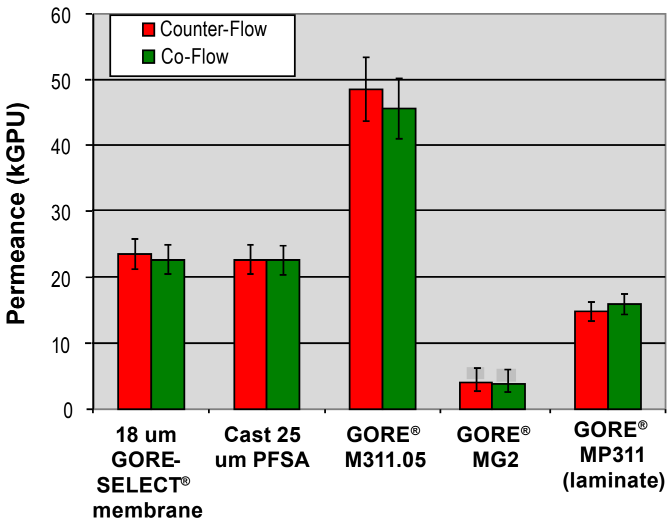

FIGURE 2. The permeance of a wide range of potential humidifier membrane materials has been measured using a dynamic permeance cell [1-3]. The results indicate the sandwich structures using PFSA ionomers, illustrated here by GORE™ M311.05, have permeances much higher than other potential alternatives. GORE™ MG2 is a hydrocarbon ionomer coated on a microporous substrate, while MP311 is an inexpensive hydrocarbon ionomer in a similar sandwich structure to M311.05.

using the designs identified by the modeling. The initial results from these subscale modules indicate that the high permeance Gore composite materials will allow modules to be built that have the requisite size and water transport characteristics required in demanding fuel cell automotive humidifier module applications.

Conclusions and Future Directions

- Water transport rates through GORE™ humidification membranes can be very high, especially for the fluorinated ionomer-based materials.
- A range of alternate materials have been prepared and water permeance and air-impermeability has been measured. Sandwich structures using thin PFSA layers offer the best combination of performance, durability and cost.
- A high-volume cost model has demonstrated that automotive cost targets can be met using the most promising Gore composite membranes.
- Initial module modeling and subscale prototypes show that using the high-performance Gore composite humidifier membrane will enable an automotive

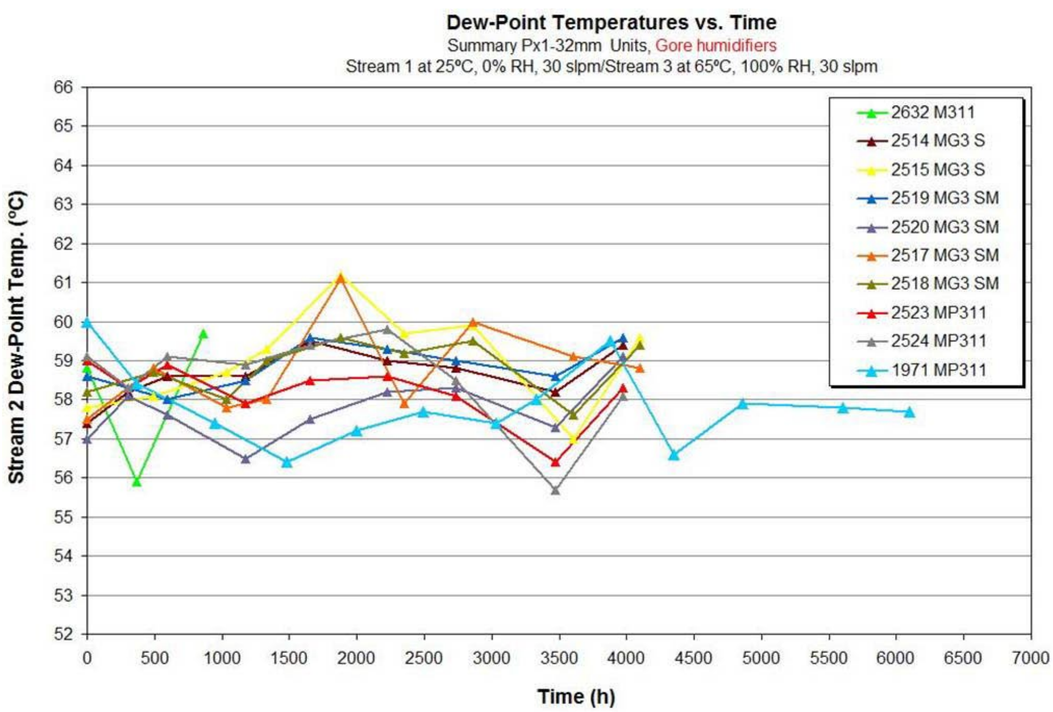

FIGURE 3. The performance of the composite humidifier membranes made in this program do not degrade with time under the conditions shown in this figure, where the stream 2 dew point temperature is the dew point of the dry outlet.

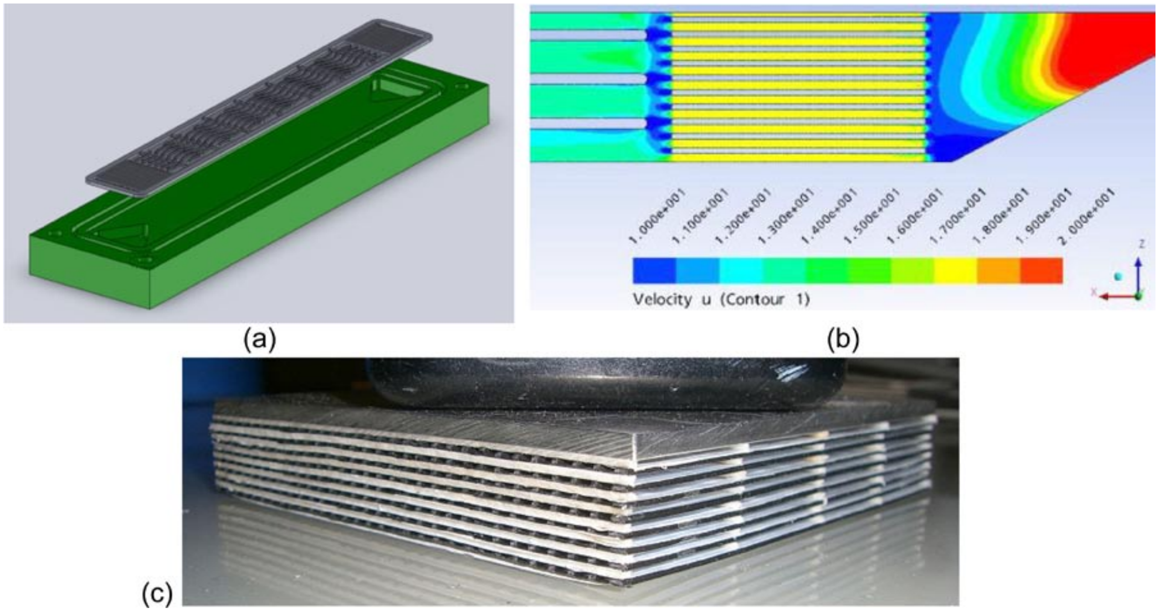

FIGURE 4. Using a finite element model of potential flow field geometries (a), the velocity contours, (b), have been used to optimize the module design. Several subscale modules, (c), have been built using several designs. The initial results indicate that the high permeance Gore composite materials will allow modules to be built that have the requisite size and water transport characteristics.

humidifier module that meets the demanding cost, durability and performance fuel cell automotive targets.

- In the final year of the project, the durability testing will be completed, the most promising membrane candidate and backer combination will be identified and scaled up, the best module design will be identified through further subscale tests, and a full-scale module will be built for DOE testing.

References

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4. William. B. Johnson, "Materials and Modules for Low-Cost, High Performance Fuel Cell Humidifiers", DOE Annual Review, Crystal City, VA, May 12, 2011, Oral Presentation fc067, available from www.doe.gov.

FY 2011 Publications/Presentations

1. Materials and Modules for Low-Cost, High Performance Fuel Cell Humidifiers, DOE Annual Review, May 12, 2011, Oral Presentation fc067.

2. Materials and Modules for Low-Cost, High Performance Fuel Cell Humidifiers, Freedom Car Technical Team Review, November 10, 2010.