V.K.2 Materials and Modules for Low-Cost, High-Performance Fuel Cell Humidifiers

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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 the Fuel Cells section 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
(C) Performance

Accomplishments

- Contacts with various original equipment manufacturers (OEMs) have been initiated, and some preliminary feedback on humidifier operating conditions has been obtained for automotive and stationary conditions.
- Initial investigation of a number of membranes and processes has begun.
- A permeance testing system has been redesigned, and initial testing between 60º and 95ºC, 70% relative humidity (RH) for several GORE™ humidification membranes has commenced.
- An alternate room temperature water vapor transport test protocol has been developed for rapid screening of new materials.

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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 propose to provide 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 will use 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., PFSAs), or by making it extremely thin (e.g., <5 µm). Of course, both can be used for the highest possible rate. The ionomer composition can be either a PFSA, or any other ionomer, for example a hydrocarbon. 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. Third, it offers a strong, protective support layer for placement of a macroporous gas diffusion layer. The composition of the microporous layer is not restricted, although we believe that the high strength offered by expanded polytetrafluoroethylene is desirable. The initial tasks of the project are preparation and optimization of the various high performance water transport membrane, and characterization of the permeance and durability of the membranes. This will lead to a down selection to appropriate materials based on the performance criteria, coupled with cost modeling

Although the basic structure described above has already been developed by Gore [1], the material has not yet been optimized for automotive or stationary humidifier applications. In particular, there is a trade-off between using a relatively expensive ionomer (e.g., PFSAs) in a thicker ionomer layer, versus using a less expensive hydrocarbon ionomer in a thinner layer. Depending on thickness, each of these could have the same water vapor transport rate, yet may have very different durability at temperature, not to mention different costs. Furthermore, the microporous layer is expected to impact the durability and performance. A more open, weaker (and presumably less expensive) microporous layer would offer less resistance to water transport, but also offer less strength so could adversely impact durability. Finally, the effect of the macroporous gas diffusion layer has not been examined. Its composition, properties and attachment (loose-laid or laminated) have yet to be explored.

Our subcontractor, dPoint, has developed an innovative pleated planar membrane humidifier that is able to achieve automotive OEM water transport and pressure drop requirements. It has the advantages of low-cost materials and manufacturability, compact size, high pressure tolerance, a replaceable membrane cartridge and the flexibility to design for specific membrane characteristics. 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. A flat sheet permeable membrane is folded and separated with a plastic injection molded flow field insert. The flow field inserts have an open channel design that allows excellent flow distribution, maximum membrane active area and very low pressure drop. The membrane cartridge has a potted elastomeric seal around the perimeter to prevent leakage at high-pressure conditions. The membrane cartridge is placed in a clamshell housing that has been designed to withstand automotive pressures and temperatures. The pleated humidifier is a proven technology that dPoint has been developing in cooperation with several major automotive OEMs. 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

At the time of writing of this report, results are very limited because we have just completed the first quarter of a two-year project. To date, a high-temperature permeance measurement system has been designed, built and tested. The design is similar to those used previously for similar measurements [2,3]. Based upon input from automotive and stationary OEMs, appropriate test conditions for measurements have been chosen as 70% RH air on the membrane wet-side, dry air on the membrane dry-side, with test temperatures between 60 and 95ºC. Initial testing has commenced on various controls, as well as several variations of newly prepared materials. These initial results of various materials that have been prepared (Table 1) indicate very high permeance rates for some variants of the developed materials. One exciting material is shown in Figure 1, where the ionomer layer in the composite is ~1 micron

TABLE 1. Preliminary Water Permeance Results

Material	ΔC (kg/m^3) by ln mean	Equivalent RH at 80°C	Permeance (gpu)‡
18 um GORE-SELECT® Membrane*			
(18 μm nom)	0.176	60.7%	23,100 ± 1,000
18 um GORE-SELECT® Membrane* (REPEAT)			
(18 μm nom)	0.177	61.5%	28,400 ± 1,400
Cast 1100 Equivalent Weight PFSA			
(28 μm)	0.180	64.1%	22,600 ± 1,200
GORE™ Hydrocarbon Ionomer Composite Structure			
(30 μm nom)	0.182	62.6%	14,600 ± 800
Perfluorocarbon Ionomer Composite Structure (GORE™ M311)			
(25 μm nom)	0.164	56.6%	47,500 ± 4,000

† Test conditions: 80°C; Dry inlet = 0 kg/m^3 (0% RH);
Wet inlet = 0.263 kg/m^3 (70% RH); Ambient pressure both sides.
‡ Listed error bars are 99% confidence interval;
GPU = cm^3 @standard temperature and pressure/(cm^2-s-cm of Hg) x 10^6
* GORE-SELECT and Gore and design are trademarks of W. L. Gore & Associates, Inc.

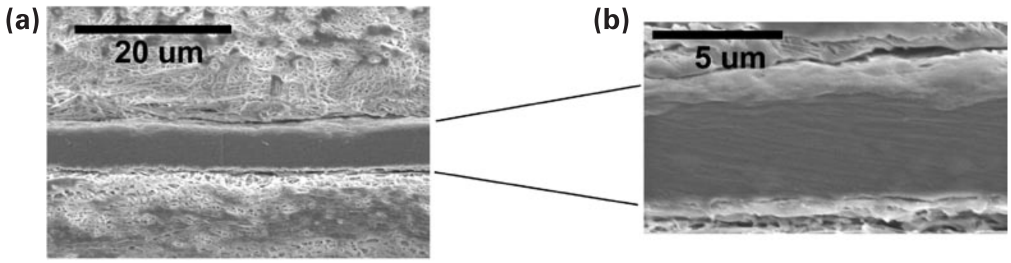

FIGURE 1. The composite membranes under development in this program offer very high permeance coupled with excellent durability, in part because of the composite microstructure shown in (a), as well as the ability to prepare very thin ionomer layers in the composite such as that shown in (b).

thick. This composite is air-impermeable, and should have high permeance because of the very thin ionomer layer. The permeance testing of this material is underway.

One issue related to testing is the time required to measure permeance, upwards of 4 days per sample. Therefore, an alternate room temperature water vapor transport test protocol is under development for rapid screening. This new test protocol is based upon a modified version of the International Organization for Standardization Standard 15496, Measurement of Water Vapor Permeability of Textiles for Purpose of Quality Control. The initial testing indicates reasonable correlation with higher temperature permeance test results. Further analysis and testing is required to establish whether this approach is truly viable, either as a quality control tool, or for new material screening.

Conclusions and Future Directions

- Water transport rates through GORE™ humidification membranes can be very high, especially for the fluorinated ionomer-based materials.
- Transport measurements of these high-rate materials are a challenge.
- A range of alternate materials have been prepared and water permeance and air-impermeability will be measured shortly.
- Cost modeling of potential membranes, coupled with air-impermeability and water permeance data, will be used as inputs to a Go/No-Go decision to occur within the next nine months.
- A new test protocol for quick room screening water permeance has been developed. Future work will establish whether this is a correlation with results this new test and higher temperature permeance measurements that more closely model actual use conditions.

References

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