VII.H.4 Development of a Thermal and Water Management System for PEM Fuel Cells

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Contract Number: DE-FC36-03GO13109

Subcontractors:
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Emprise Corporation, Kennesaw, GA
Perma Pure LLC, Toms River, NJ

Start Date: October 2003
Projected End Date: April 2007

Objectives

The objective of this work is to assess and develop thermal and water management (TWM) technologies for polymer electrolyte membrane (PEM) fuel cells in transportation applications.

- Analyze and select the most efficient TWM system for a pressurized 80-kW fuel cell (FC) power system. Focus on:
  - Cathode humidification
  - FC stack waste heat rejection
  - Steady-state operation
- Design and develop the optimal TWM components and system:
  - Humidifiers
  - Radiators
- Demonstrate the performance of a breadboard TWM system with research hardware.

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- B. Cost
- D. Thermal, Air and Water Management

Technical Targets

This project consists of developing TWM systems and components. The main technical targets are the following.

- Cathode inlet humidity: 60% relative humidity (RH) at 80°C
- TWM system power consumption: 2.4 kW (3% of the net system power)

These components are part of the integrated fuel cell power system and affect the following DOE targets [Table 3.4.3 in the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan: 2010 80 kW (net) Integrated Transportation Fuel Cell Power Systems Targets]:

- Power density: 650 W/l
- Specific power: 650 W/kg
- Cost: $45/kW
- Durability: 5,000 hrs (typical w/drive cycle)

Approach

- Establish TWM system requirements with Argonne National Laboratory (ANL).
- Conduct trade study to evaluate cathode humidification options. Down-select best system(s) for further investigation.
- Conduct trade study to evaluate stack waste, heat rejection options. Down-select best heat exchanger technologies for further development.
- Perform detailed system designs and develop component specifications.
- Develop humidifier components.
- Develop heat exchanger components.
- Demonstrate the performance of a breadboard TWM system using a fuel cell simulator and a Honeywell turbocompressor.

Accomplishments

- Re-established TWM system requirements at new (80 kW) system power level.
- Conducted adsorbent wheel and vapor-vapor membrane humidifier sub-scale component performance tests.
- Completed adsorbent wheel and vapor-vapor membrane detailed system designs, and generated component specifications.
- Completed humidifier component hardware designs – fabrication is in process.
- Completed a radiator technology trade study. Identified aluminum foam radiators as being able to meet the project performance targets while achieving significant size and weight reductions.

Future Directions

- Validate adsorbent wheel and vapor-vapor membrane humidifier performance – FY 2006.
- Validate aluminum foam radiator performance – FY 2006.
- Design, build, and test a full-scale aluminum foam radiator – FY 2006.
- Demonstrate the performance of an integrated TWM system – FY 2007.

Introduction

The objective of this work is to assess and develop thermal and water management (TWM) technologies for PEM fuel cells in transportation applications. As stated in DOE's Multi-Year Research, Development and Demonstration Plan, a technical barrier to the successful implementation of fuel cells is thermal, air, and water management (technical barrier D). It states: "Water management techniques to address humidification requirements and maintain water balance are required." On the thermal management side, it states: "More efficient heat recovery systems, improved system designs, advanced heat exchangers… are needed to achieve the most efficient systems."

With this objective in mind, TWM system interface requirements were established prior to FY 2005. During that time, a systematic trade study was also conducted to identify the most efficient TWM systems. Two systems were chosen for further study as a result of this analysis. They were an adsorbent wheel humidification system and a vapor-vapor membrane humidification system.

During FY 2005, system and component specifications were generated for the two systems. Sub-scale humidifiers were tested to aid in this task. Full-scale humidifiers were then designed and hardware ordered, with the expectation of testing in FY 2006.

A systematic trade study was conducted to identify heat rejection technologies that show significant improvement over today's technology. Innovative heat transfer enhancement techniques such as microchannel, metallic foam and advanced platefin surfaces were considered. Results are presented in the following sections.

Approach

The approach used to successfully develop a TWM system and components and achieve the project goals consists of five steps. (1) Determine the TWM system requirements. (2) Conduct systematic trade studies to determine the optimal thermal and water management systems and components. (3) Detail the system designs and generate component specifications. (4) Develop the components and conduct full-scale performance validation testing, and (5) test the integrated breadboard TWM system using a fuel cell simulator and a Honeywell turbocompressor.

Results

Results obtained in the past year are detailed in the following paragraphs. First, the system power level was increased to 80 kW (from 50 kW) at the end of FY 2004. Due to this change, the various TWM system and component requirements were re-established. This effort was followed by (1) the adsorbent wheel humidification system development, (2) the vapor-vapor membrane humidification system development, and (3) the radiator trade study.

1. Adsorbent Wheel Humidification System Design and Development

After Honeywell and ANL established the 80-kW system technical targets, the adsorbent wheel system design was completed and component specifications generated. Figure 1 shows the adsorbent wheel system design. A sub-scale adsorbent wheel manufactured by Emprise Corporation was tested as part of the design process. Figure 2 shows wheel humidification performance versus face velocity and wheel speed. Results show that humidification performance is a strong function of face velocity and a weak function of wheel speed. Wheel leakage was also studied and was shown to be less than 1% of the process flow at the design point conditions. Based on the sub-scale results and component specifications, a full-scale adsorbent wheel has been designed by Emprise, and

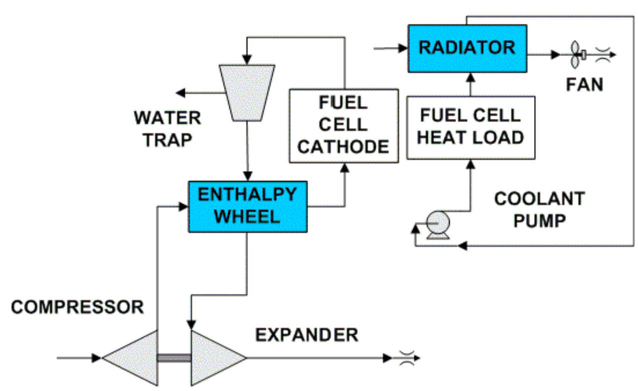

Figure 1. TWM Adsorbent Wheel System Design (80 kW)

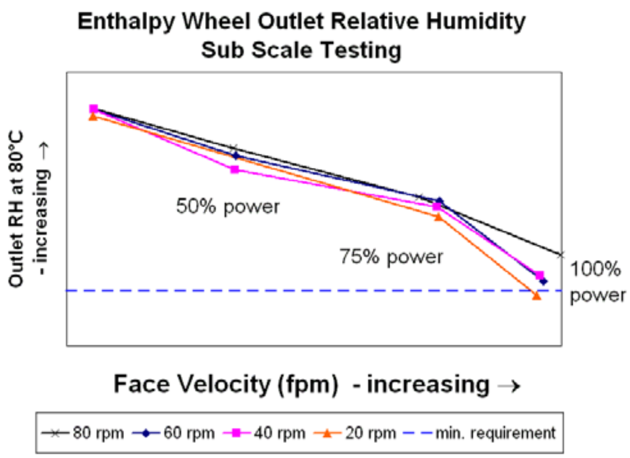

Figure 2. Adsorbent Wheel Sub-Scale Testing Results (80 kW)

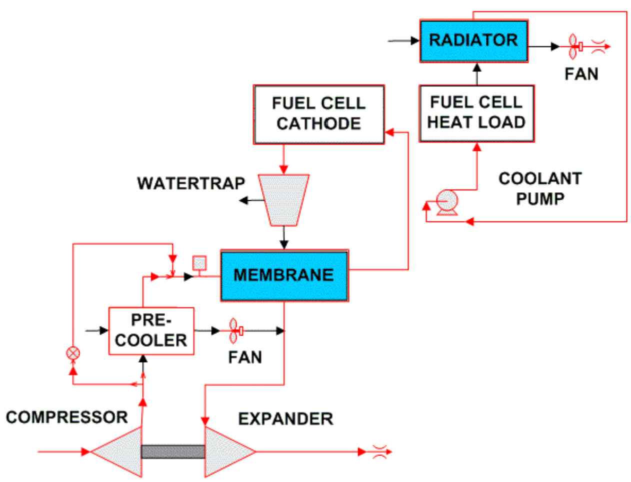

Figure 3. TWM Vapor-Vapor Membrane System Design (80 kW)

manufacturing is in process. Testing is expected to occur during FY 2006.

2. Vapor-Vapor Membrane Humidification System Design and Development

A vapor-vapor membrane system design was completed and component specifications generated. Figure 3 shows the vapor-vapor membrane system design. The system design used a Nafion®–based membrane. A Nafion sub-scale membrane from Perma Pure LLC was characterized as part of the design process. Figure 4 shows the sub-scale membrane humidification performance. Results show that the membrane performance is highly sensitive to membrane inlet temperature and power

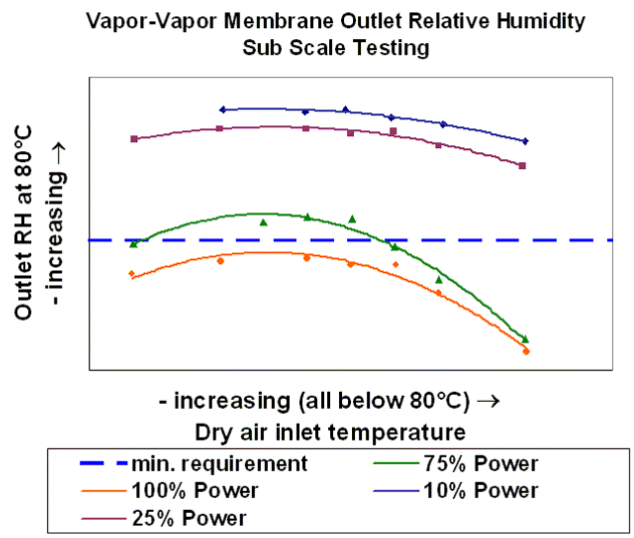

Figure 4. Vapor-Vapor Membrane Sub-Scale Testing Results (80 kW)

level. This temperature dependence demonstrates the necessity of a pre-cooler upstream of the membrane. Based on the sub-scale results and component specifications, a full-scale membrane has been designed by Perma Pure, and manufacturing is in process. Testing is expected to occur during FY 2006.

3. Radiator Thermal Performance Trade Study

A systematic trade study was conducted to identify radiator technologies that meet the established PEM fuel cell thermal requirements. Automotive-type "tube-fin" and aerospace-type "plate-fin" radiator designs were used as a backbone. Four fin technologies were evaluated: standard, advanced, microchannel, and aluminum foam. The evaluation was conducted using an equivalent system weight "value function (VF)" approach. This method includes the fan system weight and thermal system power consumption, and thus shows the overall system impact of the different radiators. Figures 5 and 6 show the face area, system weight, and parasitic power consumption for the different radiator technology/design combinations studied. All results meet the TWM system heat rejection criteria. Results show that:

- Standard automotive and aerospace radiators do not meet the power consumption technical target for a reasonable size.

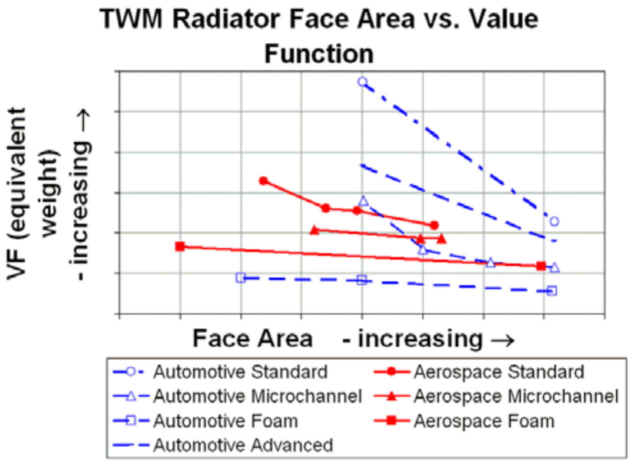

Figure 5. TWM Radiator Trade Study Results – Equivalent System Weight vs. Face Area

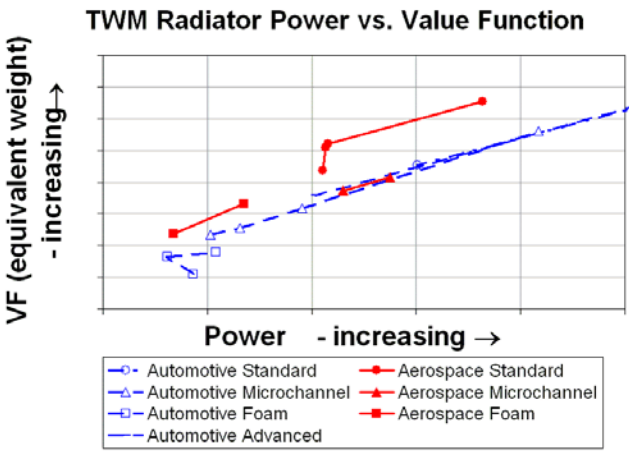

Figure 6. TWM Radiator Trade Study Results – Equivalent System Weight vs. Parasitic Power

- Microchannel automotive and aerospace radiators improve (reduce) the face area, power, and weight necessary to reject the required heat over their standard counterparts.
- Aluminum foam automotive and aerospace radiators show the best (smallest) face area, power, and weight performance of the technologies analyzed.
- Aluminum foam radiators can meet the power consumption technical target.

Validation of these promising results, and the manufacture and test of a full-scale radiator, will take place during FY 2006.

Summary

- TWM system and component specifications for an 80-kW PEM fuel cell power system have been generated.
- Two water management systems have been designed.
- Full-scale humidification components have been designed, and testing is scheduled for FY 2006.
- A systematic trade study has been conducted to identify radiator technologies that meet the established PEM fuel cell thermal technical targets.
- Aluminum foam technology has been shown to meet the program thermal technical targets while simultaneously achieving significant size and weight reductions.

FY 2005 Publications/Presentations

1. “Air, Water and Thermal Management for PEM Fuel Cell Systems”, 2004 Fuel Cell Seminar, November 2004. San Antonio, TX
2. “Advanced Thermal Management Solutions for Aerospace Applications”, Sixth Biennial SAE Power System Conference, November 2004. Reno, NV
3. “Development of a Thermal & Water Management (TWM) System for PEM Fuel Cells”, 2005 DOE Hydrogen Program Review Presentation, May 2005. Arlington, VA