Development of Thermal and Water Management System for PEM Fuel Cell

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Project ID FC066

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Overview

Timeline

- Project start: FY03
- Program stopped: FY05/FY06
- Project end date: Mar. 2011
- 90% complete

Barriers

- Develop efficient, cost-effective integrated thermal/water management system that effectively uses the fuel cell waste heat and water
- Develop advanced cooling/heat exchanger
- Reduce weight and cost of the components

Budget

- Total project funding
  - DOE share - $3,250K
  - Honeywell - $812K
- DOE funding in FY10
  - $340K
- DOE funding for FY11
  - $0K

Partners

- Argonne National Lab
- FreedomCAR Tech Team
Objectives

• Test two select full-size radiators to meet the 80 kW fuel cell cooling requirements
• Validate performance of humidification devices sized for 80 kW fuel cell
  – Test Emprise enthalpy wheel
  – Test Perma Pure sub and full-scale membrane modules
  – Test planar membrane module
• To improve PEM fuel cell performance and life, the humidity of inlet air stream should be maintained at a high level (currently 60%)
• Check select humidifier reliability for 5,000 cycles
• Thermal and Water Management program final report
Approach

• The approach is to provide humidity >60% (at 80 C) to the PEM fuel cell stack inlet air for increased performance and life
• Eliminate need for external water source by transferring water from stack exit air stream to inlet stream
• Test humidification systems which can efficiently transfer water from one air stream to the other
• Design, build and test high-performance full-size radiators to meet the 80 kW fuel cell stack cooling requirements
  • Increase performance required to dissipate low-quality heat
  • Optimize the weight, size, and cost
• Conduct reliability testing of two select humidifiers in FY11/12.
• Submit program final report

Thermal and Water Management System Program will end this year
Accomplishments for FY10/11

• Thermal Management part of the program was successfully completed and test report was submitted
• Last two humidifier were performance tested
  • Sub scale Perma Pure membrane module
  • Full scale planar membrane module
• Program plan for the FY2011/12 was developed and approved by DOE Program Office
• Two humidification systems were down-selected for reliability testing
  – Enthalpy Wheel
  – Planar membrane humidifier

*Testing of all humidification devices successfully completed*
PEM Fuel Cell Humidification Options

Diagram showing the flow of water and heat through various components such as a compressor, expander, radiator, fuel cell cathode heat load, and humidifiers.
Enthalpy Wheel

Supplied by Emprise, Kennesaw, GA
- Water adsorbed and de-sorbed in a rotating wheel
- Not sensitive to temperature
- Power: < 100W, Seal leakage < 1% of process air
- Volume 171 cu in, weight 17 Kg and size 8” Dia, 6” length wheel
Membrane Module

- Supplied by Perma Pure, Cincinnati, OH
- Membrane selectively allows water to pass through
- Performance sensitive to temperature
- Volume 6” Dia, 10” length cartridge
- 7,000 fibers, 0.045” OD and 11 in² Nafion®
Planar Membrane Humidifier

- Supplied by dpoint Technologies Inc., Vancouver Canada
- Gore membrane selectively allows water to pass through
- Performance sensitive to temperature
- Planar humidifier has advantage in manufacturing cost and installation over circular unit
- Max operating temp. 176°F (80°C), pressure of 35 psi & flow 12 lb/min
- Size 11.5” length, 9.3” width, and 5.4” height
Humidification Test Stand

- Test stand was used for performance testing of half and full-scale humidification system testing.
- The test stand is being modified for reliability testing of select humidification systems.

Humidity Sensors

Sub-scale membrane module under test
Humidity Systems Test Stand Schematics

Nomenclature

**Ppm**: Pounds/minute;  
**RPM**: Revolution per minute  
**Pri Out**: Air stream (2) from humidifier to fuel cell;  
**Sec In**: Air stream (3) to humidifier from fuel cell  
**UUT**: Unit under test
Planar membrane water transfer rate is between 20-37%
Planar membrane average water balance error is about 15%
Enthalpy Wheel Module

Water Transfer Rate vs. Enthalpy Wheel RPM

- Case 1: Dry Air Flow 12.0 ppm @157°F
- Case 2: Dry Air Flow 8.6 ppm @157°F
- Case 3: Dry Air Flow 2.5 ppm @157°F

Enthalpy wheel module water transfer rate reaches 70+% with 30+RPM at low flow rate
Enthalpy Wheel Module

Water Balance Error vs. Enthalpy Wheel RPM

Higher Flow and Speed (rpm), Less Water Balance Error

Case 1: Dry Air Flow 12.0 ppm @157°F
Case 2: Dry Air Flow 8.6 ppm @157°F
Case 3: Dry Air Flow 2.5 ppm @157°F
Full Scale Membrane Module

Water Transfer Rate vs Total Water In

Boiler Water In (lbs/min)

Water Transfer Ratio (Pri Out/Sec In)

Case 5: Dry Air Flow 12.0 ppm @177°F
Case 6: Dry Air Flow 8.6 ppm @177°F
Case 7: Dry Air Flow 2.5 ppm @177°F
Case 8: Dry Air Flow 0.93 ppm @177°F

_full scale membrane module water transfer rate is between 20-33%_
Full Scale Membrane Module

Water Balance Error vs. Total Water In

Dry air flow rate varied from 0.9 to 12 lbs/min

Higher Flow, Less Water Balance Error
Subscale Membrane Module

Water Transfer Rate vs. Total Water In

Subscale membrane module water transfer rate is between 20-37%
Subscale Membrane Module

Water Balance Error vs. Total Water In

For high flow cases (8-12ppm), water balance errors are 12-15%
Humidification Systems Test Results Summary

• Planar Membrane Module
  • Average water balance error for all the test points was 15%
  • Water transfer rate for the entire air flow range was between 20-37% vs. 60% requirement
• Enthalpy Wheel
  • Water balance errors for all test points were under 15% except at high flow rate with low speed
  • Water transfer rate at high air flow rate met the requirement of 60%
• Full Scale Membrane Module
  • Water balance error at high flow rate was 10-15%, however, at low flow rate the balance was poor
  • Water transfer was between 20-33% similar to other membrane modules
• Sub Scale Membrane Module
  • Average water balance error was 13%
  • Water transfer rate for the entire air flow range was between 20-37%

Enthalpy Wheel performance was better than membrane humidifiers
Thermal Management Program Summary

• Four sub-scale radiators with different fins configuration were built and tested
• Performance model validated, manufacturability lesson learned and documented
• Two down-select fin configurations; full-scale radiators built
• Test results validated the performance model
• Test results were used in PEM fuel cell system model by Argonne National Lab.
• Radiators estimated cost by Honeywell compared well with independent consultant estimates ($50 vs. $58)
• Submitted radiators final test report

Thermal Management program was successfully completed
Full-Scale Radiators

Size of the radiator: 27.6" width, 17.7" height, and 1.3" depth. Estimated weight of full-scale louver and microchannel radiator (with plastic tanks) will be 10 and 13 lbs respectively.

40 fins/in. Microchannel Fins  

18 fins/in. Louver Fins

*Full size microchannel radiators built successfully*
Radiator Test Set-up

Radiator Instrumented

Coolant Circulating Cart
Full-Scale Advance Louver Fin Radiator Performance

The water-glycol circulating rate 2.25 kg/sec (maximum allowable 2.5 kg/sec.)

Effectiveness and pressure drop test data in good agreement with model predictions
The water-glycol circulating rate was 2.25 kg/sec (maximum allowable 2.5 kg/sec.)

Effectiveness and pressure drop test data in good agreement with model predictions
Collaborators

• **Argonne National Laboratory**
  – Coordination of all technical activities including requirements definition, technical data interchange, and support to overall PEM Fuel Cell model development

• **FreedomCAR Tech Team**
  – Participate in program reviews

• **Emprise Corporation**
  – Designed and built humidification test stand and Enthalpy Wheel. Active participant in improvement of test stand and enthalpy wheel design

Federal Laboratory

US Council for Automotive Research

Industry
FY11/12 Schedule and Major Milestones

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Go-Forward Plan

FY 2011/12

• Test humidification systems for reliability
  • Modify the test stand for reliability testing
  • System will be tested for 5,000 cycles at full scale fuel cell operating conditions
  • The humidity will be cycled from 0 to 80% at 2 minutes intervals
• Submit program final report