2011 Fuel Cell Seminar and Exposition

October 31st- November 3rd 2011

Walt Disney World Swan and Dolphin Resort, Orlando, FL

Demonstration of Passive Fuel Cell Thermal Management Technology

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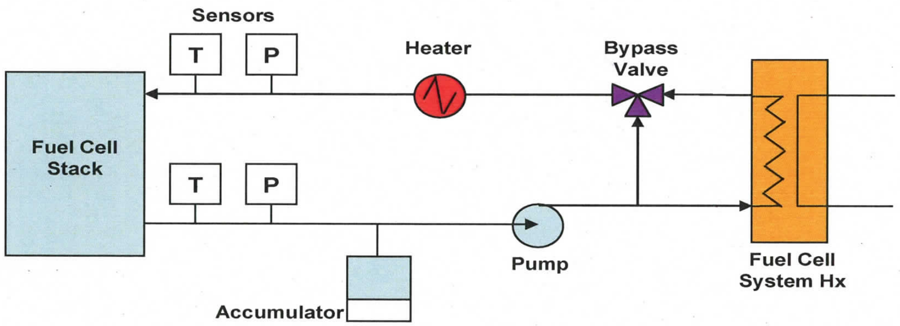
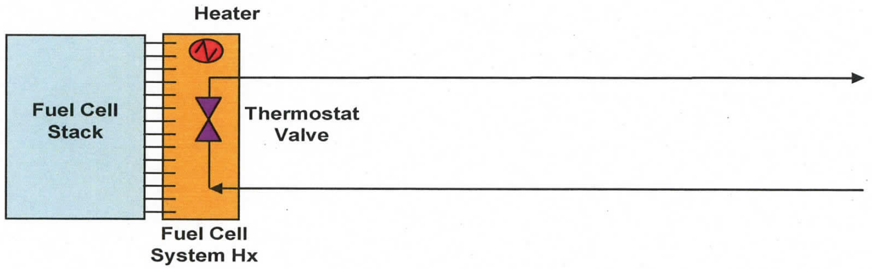
Demonstration of Passive Fuel Cell Thermal Management Technology

The objective of the advanced thermal management work is to develop a passive means of fuel cell thermal management that can eliminate system components within the conventional pumped loop cooling systems used presently. This will reduce mass and improve reliability.

Conventional Fuel Cell with Pumped Loop Thermal Management



Fuel Cell with Passive Thermal Management



Demonstration of Passive Fuel Cell Thermal Management Technology

The purpose of this work was to:

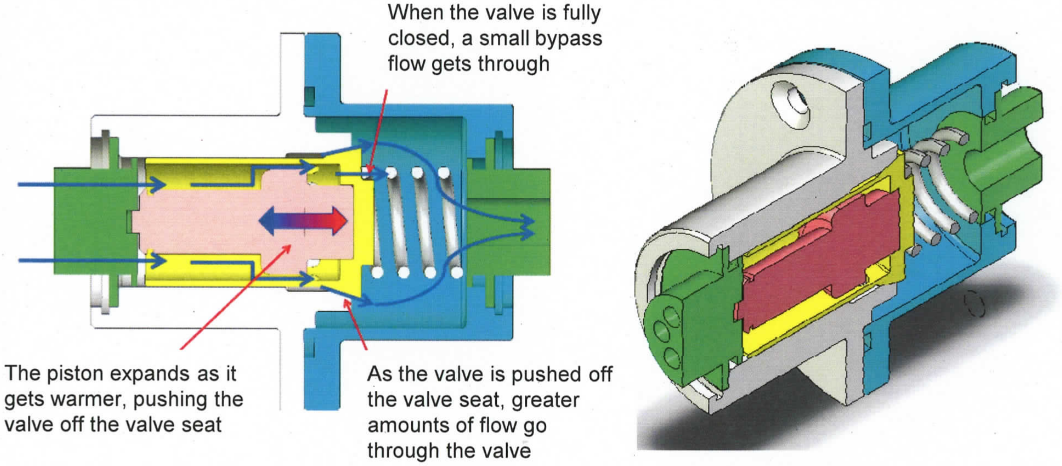
- Test two different control valve approaches to the control of the passive thermal management of fuel cell stacks.
    - **Electronically controlled proportional valve** to control the coolant flow through the heat exchanger which controlled the fuel cell temperature.
    - **Thermostatic valve** whose actuator opened and closed the valve through expansion and contraction in response to the temperature of the coolant flowing through the valve.

- Demonstrate previously developed cooling plate technologies in operational fuel cell stacks.
    - **Pyrolytic graphite** cooling plate fuel cell stack
    - **Titanium heat pipe** cooling plate fuel cell stack

Demonstration of Passive Fuel Cell Thermal Management Technology

Passive Thermal Management Control Valves

Electronically controlled proportional valve



Thermostatic valve

- The **Electronically controlled proportional valve** controls the coolant flow in response to a 0-5VDC control signal.
- The **Thermostatic valve** actuator opens or closes the valve in response to the temperature of the coolant flowing through the valve.

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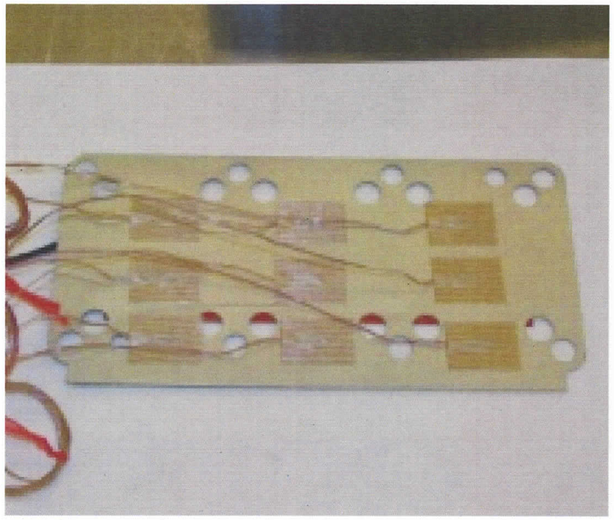
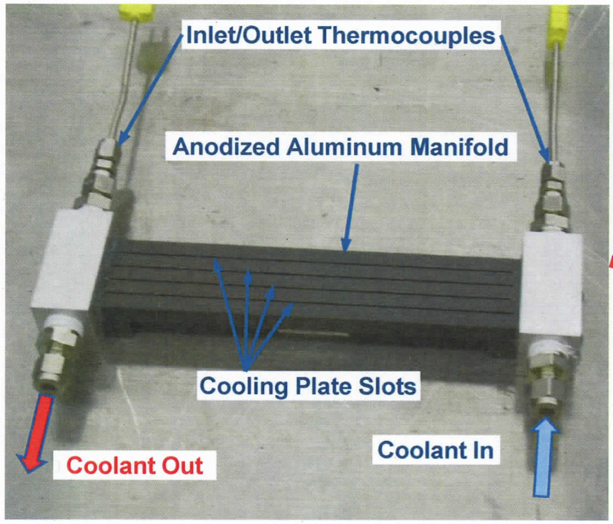
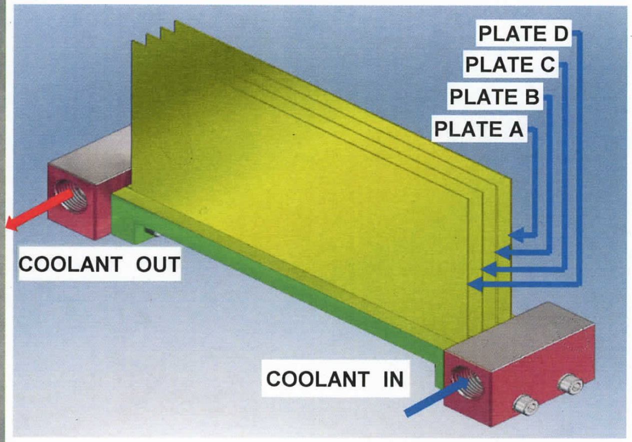
Simulated Fuel Cell Stack







Instrumented Cooling Plate

- 9 T/C's on one side
- Pad heater on other side

Interface Heat Exchanger

- T/C's on inlet/outlet
- Slots for 4 cooling plates
- Anodized aluminum

Simulated Fuel Cell Stack

- 4 Instrumented cooling plates

During the testing Plates A&D (the outer-most plates) tended to run cooler than the inner plates (Plates B&C).

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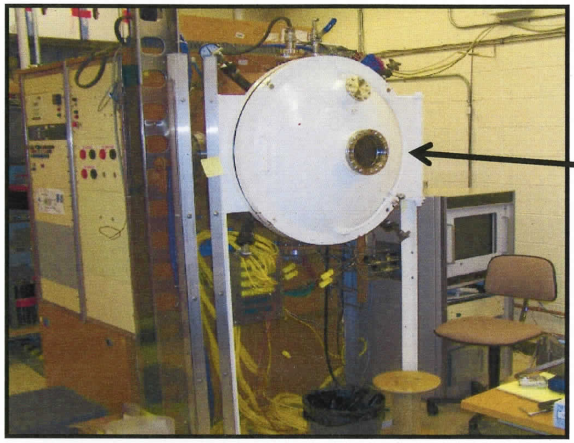
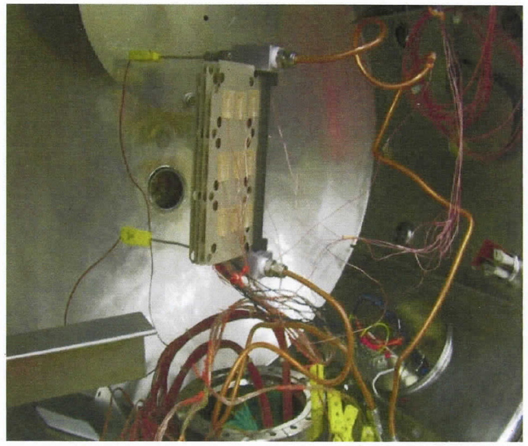
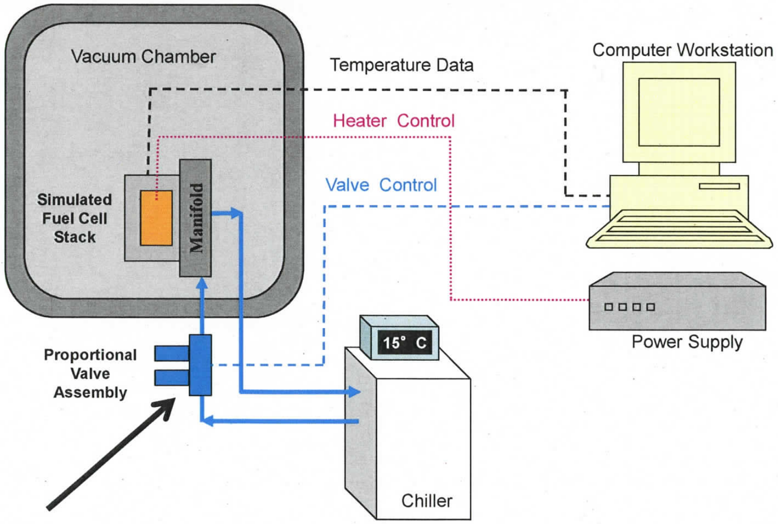
Passive Thermal Management Control Test Facilities

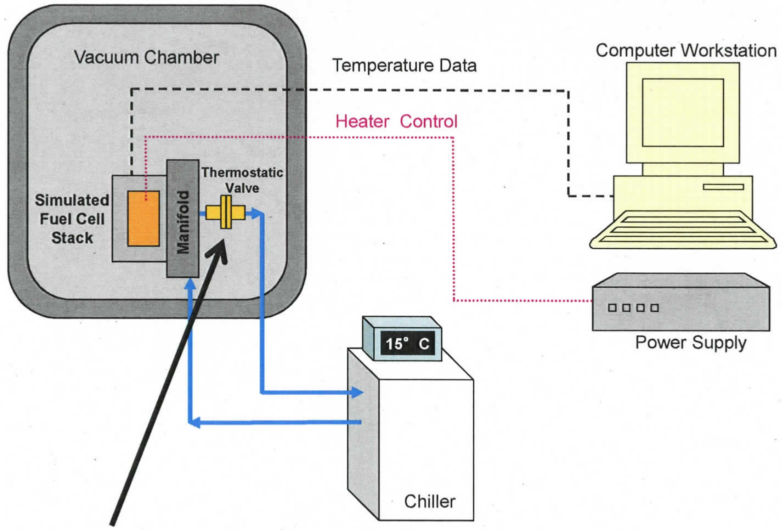


The testing was done in a vacuum chamber to eliminate convective heat transfer that would have complicated the results





The proportional valve is located outside the vacuum chamber because the valves were not compatible with vacuum conditions.



The thermostatic valve is located inside the vacuum chamber immediately downstream of the interface HX to more quickly respond to temperature changes.

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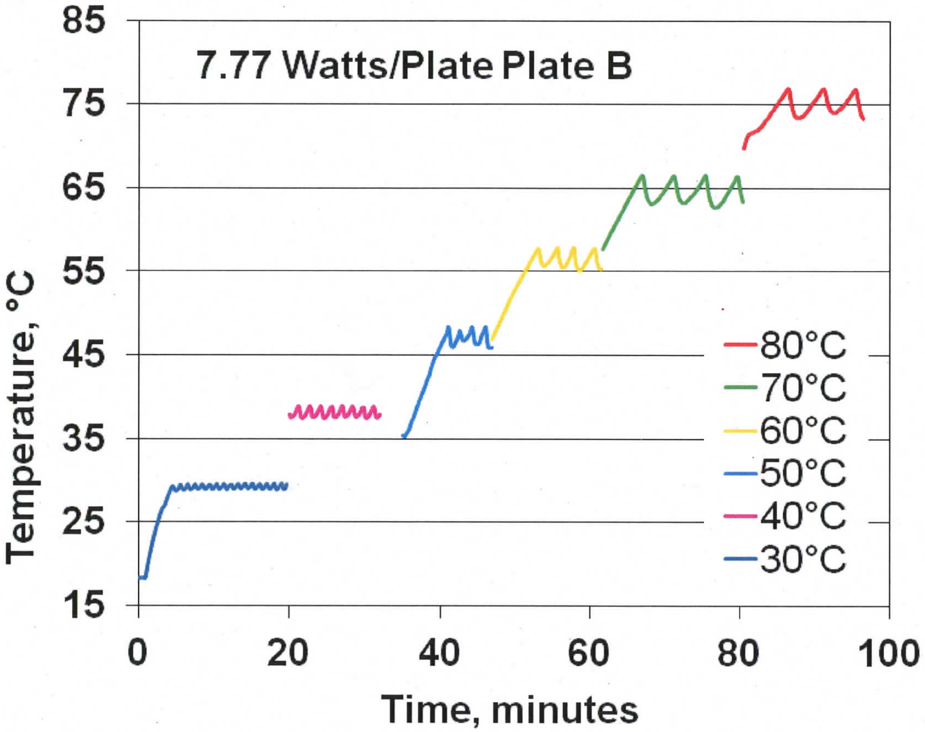
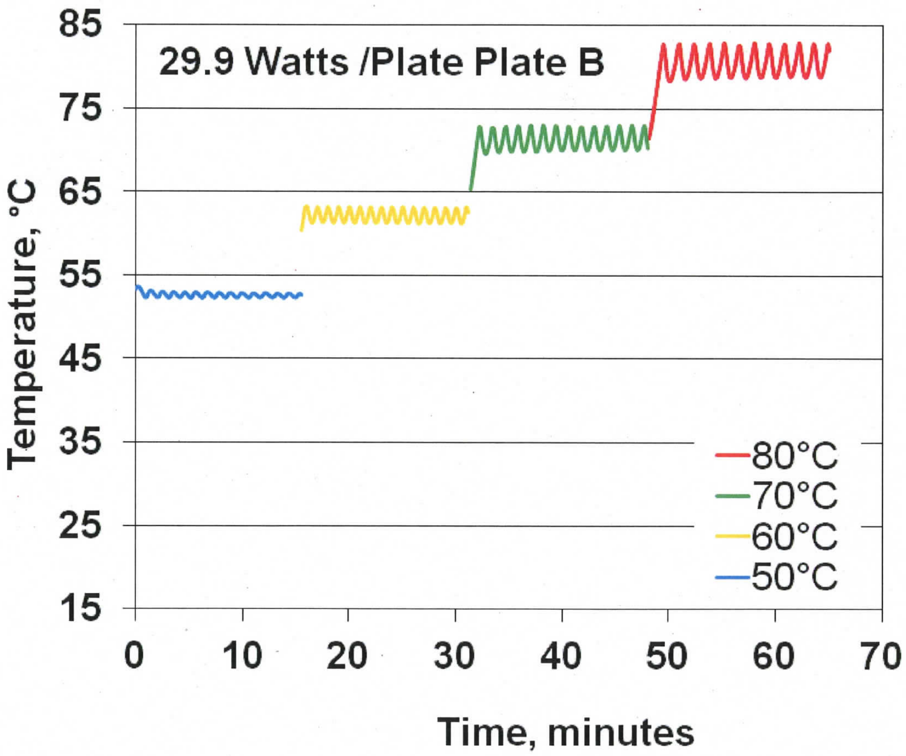
Passive Thermal Management Control Results – Proportional Valve





The proportional valve is able to control the plate temperature (with some small offset from the setpoint) independent of the power level on Plate B. Plates A,C & D were nearly identical in performance. The oscillation about the control value gets greater at greater temperature. No fine tuning of the control loop was done to improve the results because the simulated fuel cell stack had an unrealistically low mass. An actual fuel cell stack would respond slower and be even easier to control.

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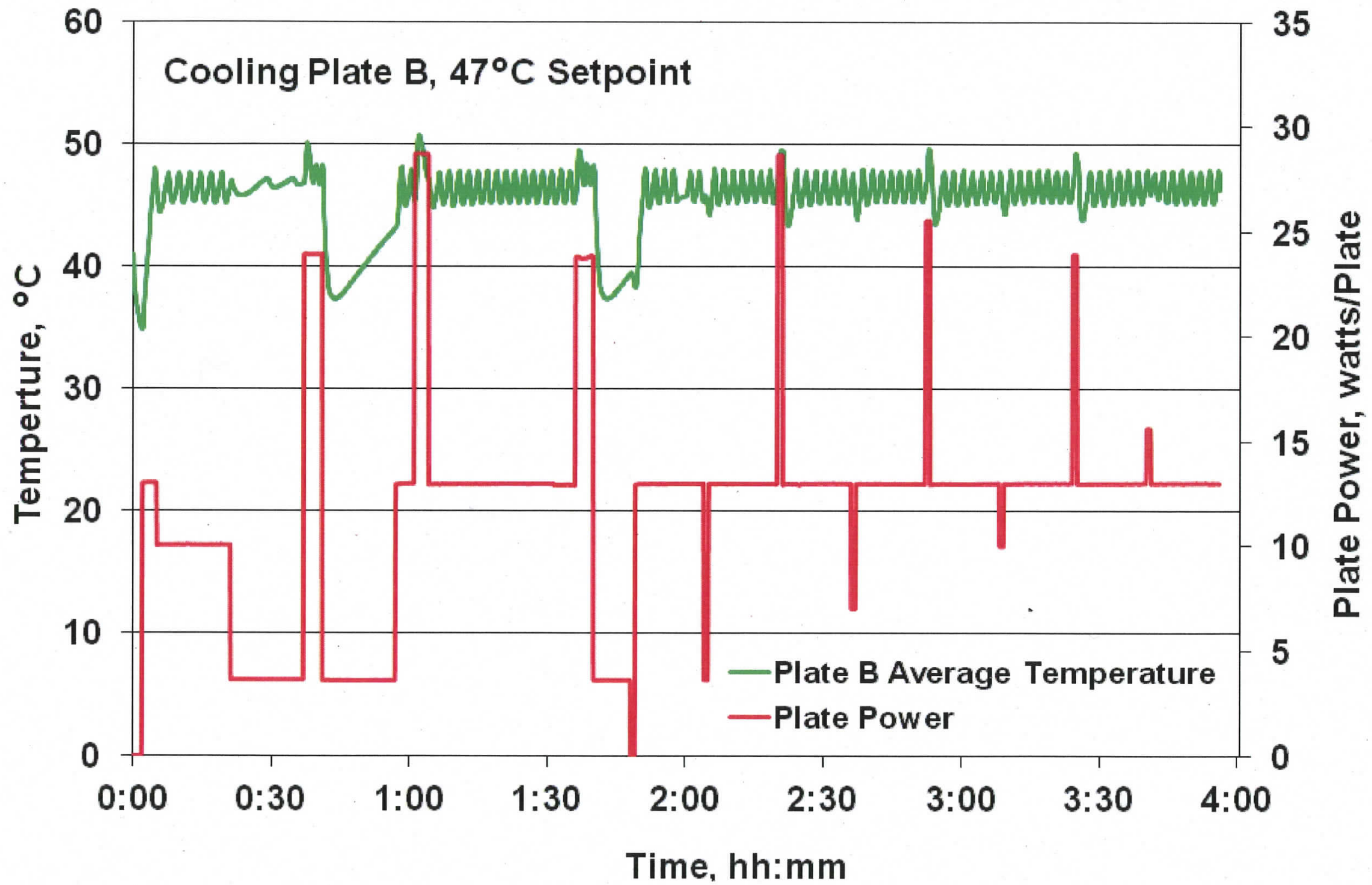
Passive Thermal Management Control Results – Proportional Valve



The proportional valve is able to control the plate temperature except when the plate power dropped drastically. Because the simulated fuel cell stack had such a low mass (compared to an actual stack) the temperature responded very quickly. Fine tuning the control loop could have improved this result, but was not done.

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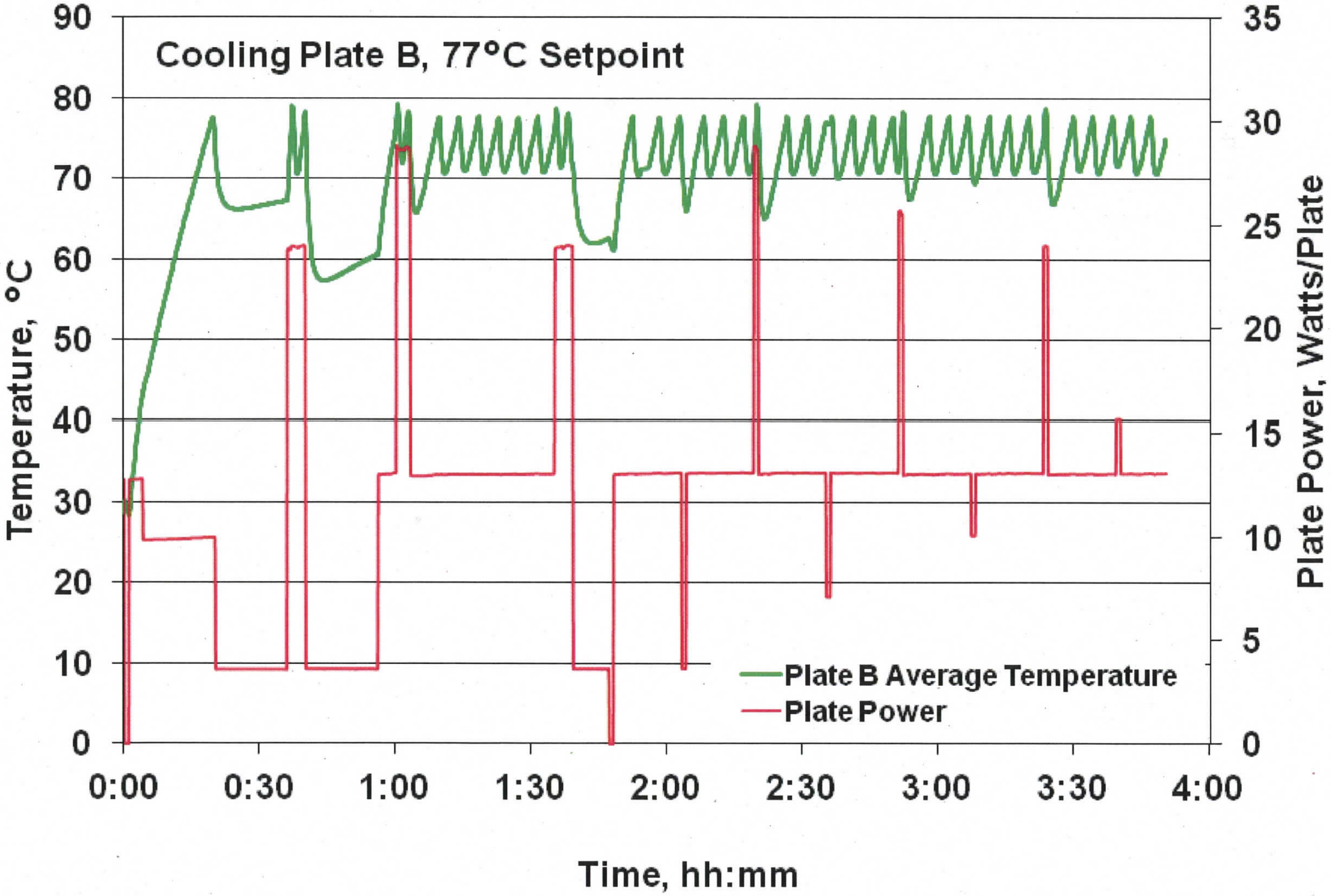
Passive Thermal Management Control Results – Proportional Valve



These are similar to the previous 47°C results except the oscillations are slightly bigger in amplitude.

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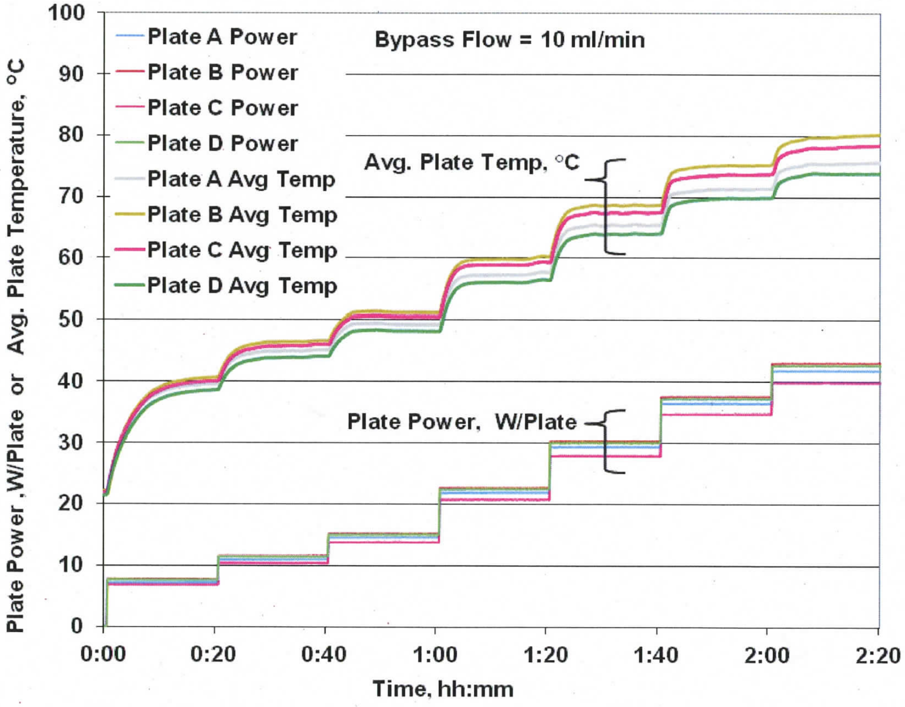
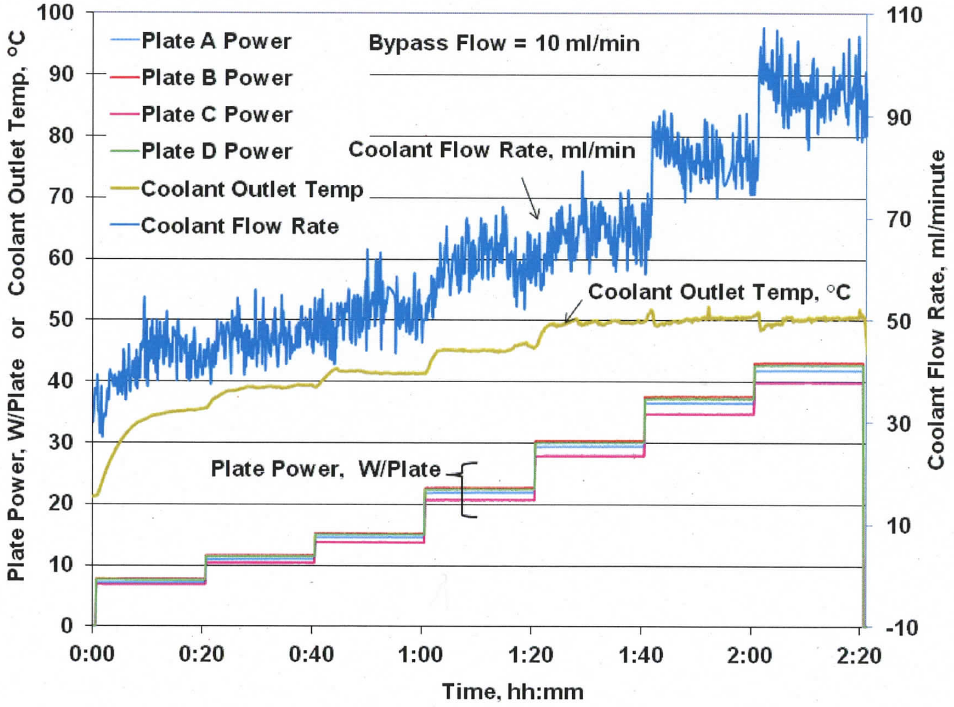
Passive Thermal Management Control Results – Thermostatic Valve





The Thermostatic Valve cannot control the plate temperature independent of the plate power., because the valve responds with greater coolant flow only after the coolant temperature has increased.

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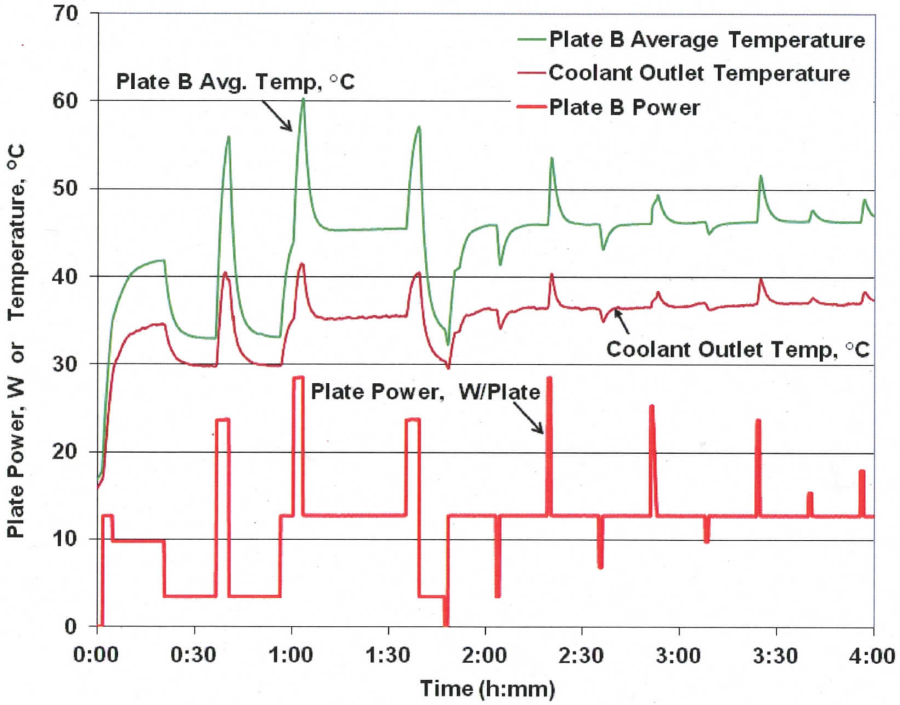
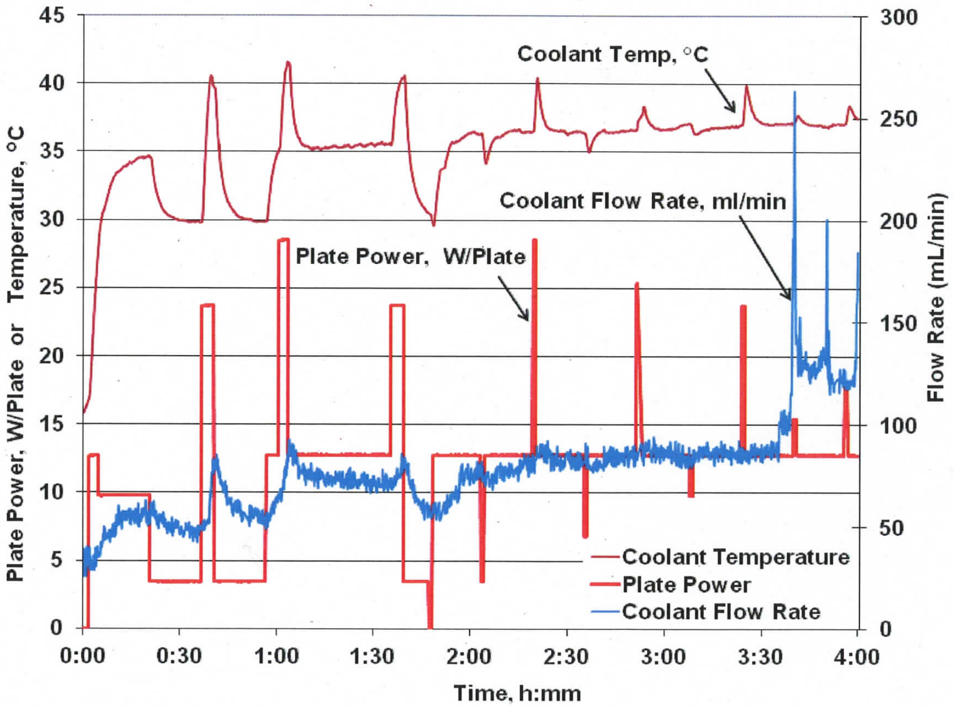
Passive Thermal Management Control Results – Thermostatic Valve





The Thermostatic Valve results show that the coolant flow does not respond as quickly as the power level (or plate temperature). When the power level returns to a "baseline" value the plate temperature and coolant temperature likewise return to their "baseline" values.

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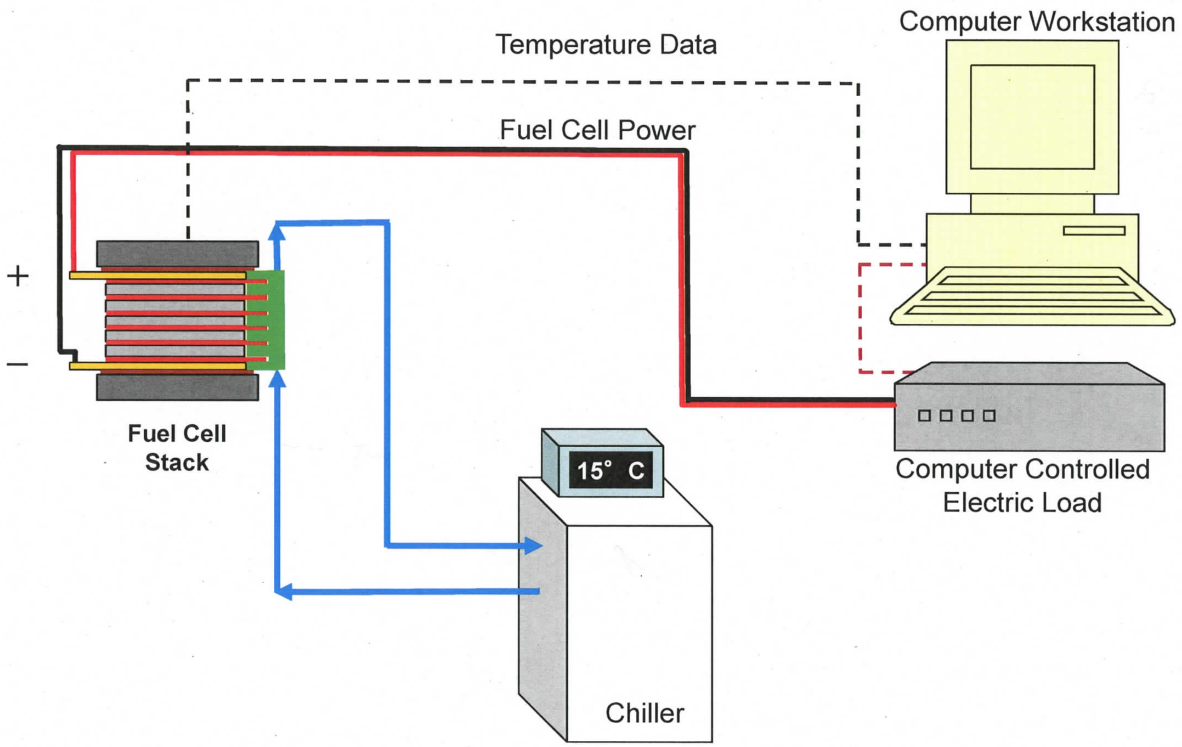
Passive Thermal Management Control Test Facilities



The coolant from the chiller flows through the interface heat exchanger at a high rate to ensure that the interface heat exchanger is essentially iso-thermal. The temperature of this interface is controlled by the chiller temperature control. This approach was followed to experimentally remove the interface heat exchanger as a contributor to plate temperature differences, and therefore any plate temperature differences would be attributable only to cooling plate performance.

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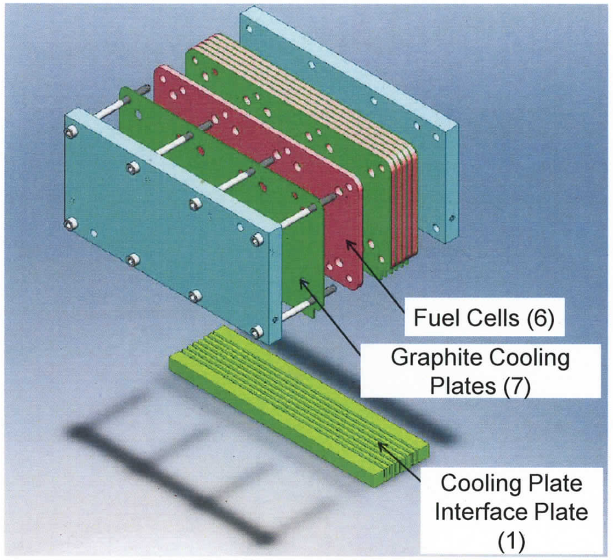
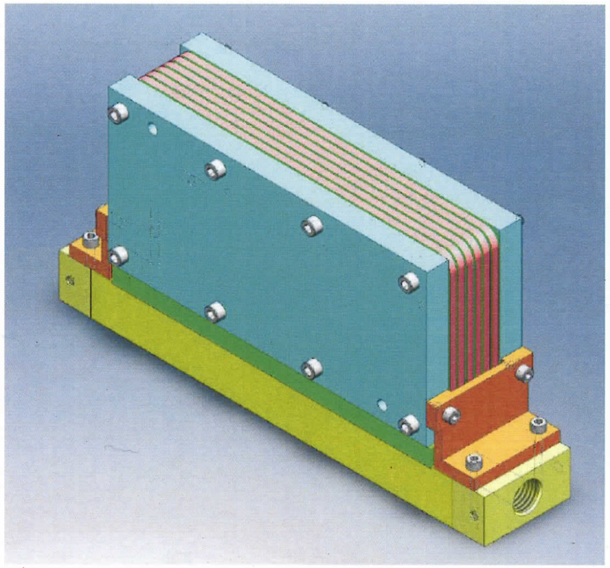
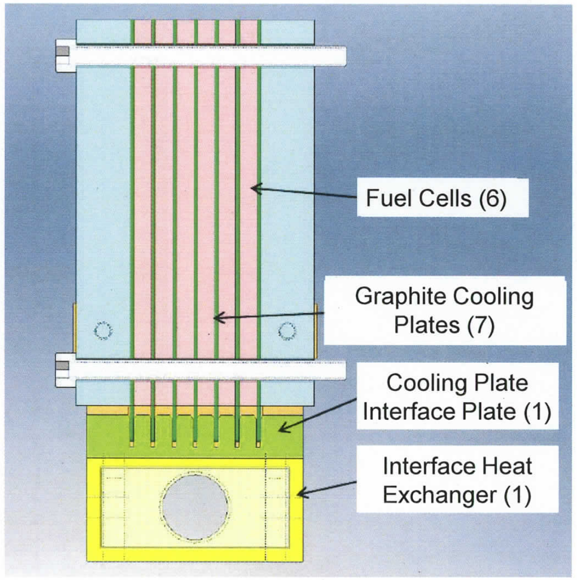
Pyrolytic Graphite Cooling Plate Fuel Cell Stack







- **1 to 4 T/C's on each cell**
- **Final fuel cell stack had 5 cells (not 6 as shown)**
- **Each fuel cell had an active area of 75 cm^2**
- **Each cooling plate had a slip fit into the interface plate groove**
- **Thermal grease filled the cooling plate/interface plate clearance**

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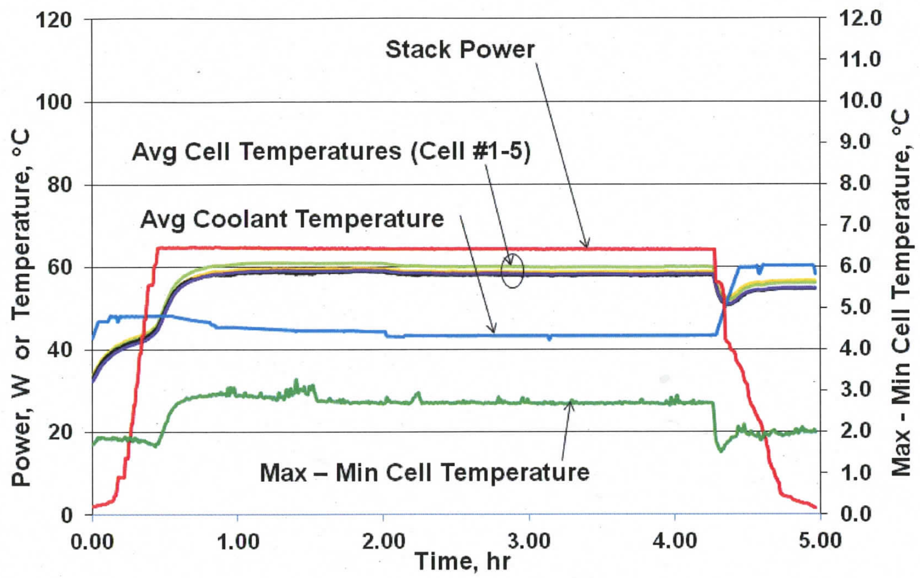
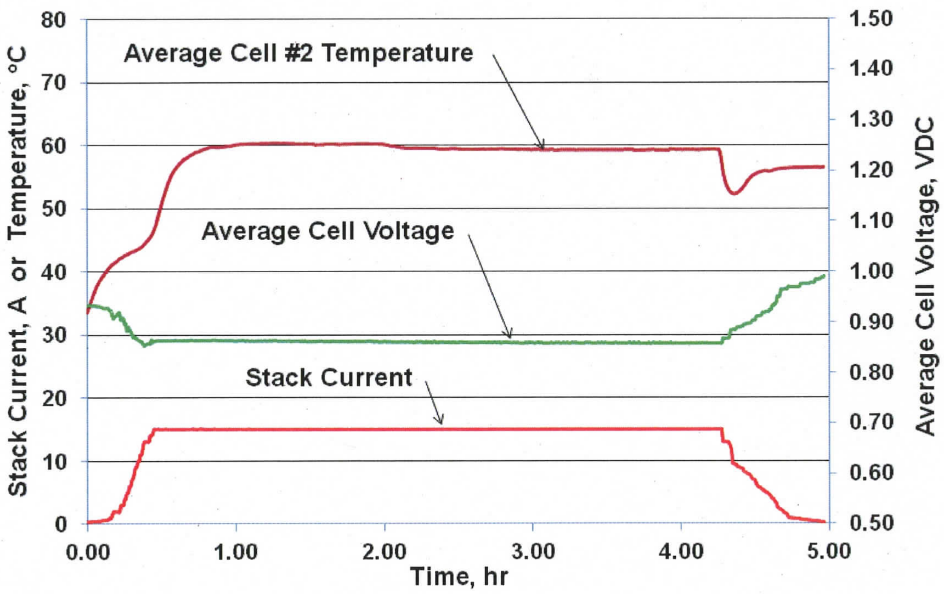
Pyrolytic Graphite Cooling Plate Fuel Cell Stack Results





All the thermocouples are at essentially the same temperature throughout the test , therefore the plates are highly effective at distributing the heat within a cell and that the cooling plates are very consistent from one cell to the next. Besides moving heat out of the stack, the cooling plates are also very effective in moving heat into the stack (see beginning and end of test).

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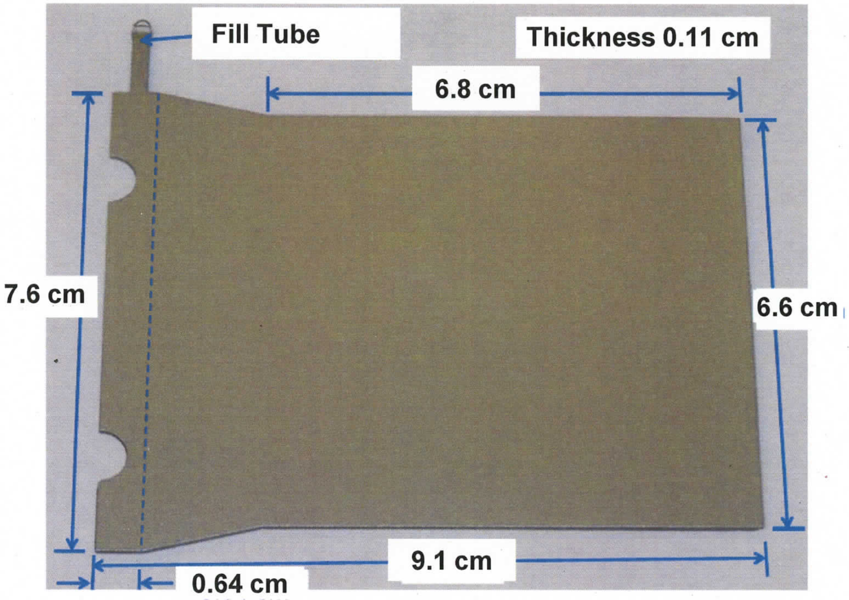
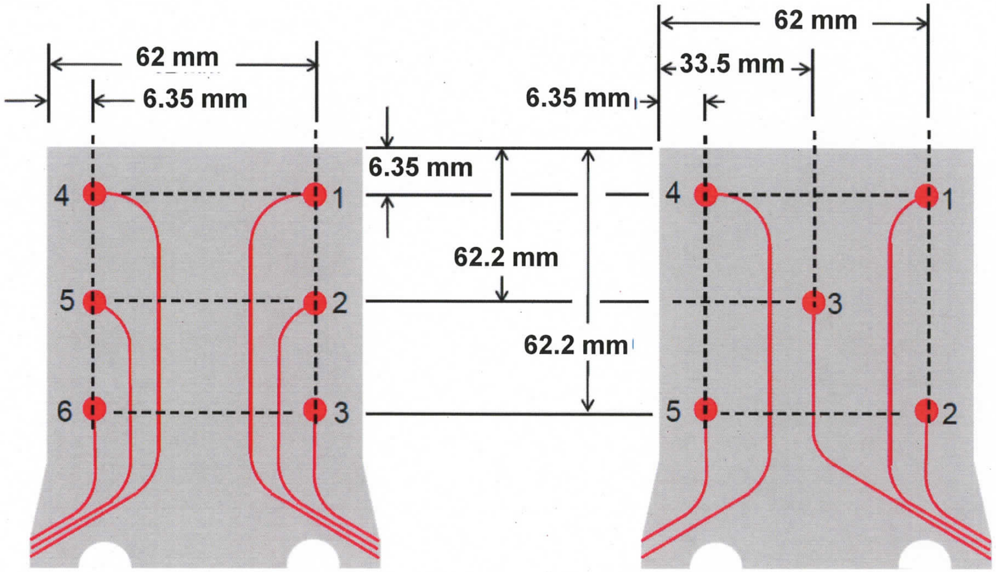
Titanium Heat Pipe Cooling Plate





Heat Pipe Plates 1,3, and 5

Heat Pipe Plates 2 and 4

Each of the five heat pipe cooling plates was instrumented with thermocouples. The evaporator area of each heat pipe was approx. 45 cm^2 which absorbed the heat from the active area of each fuel cell (which was 50 cm^2).

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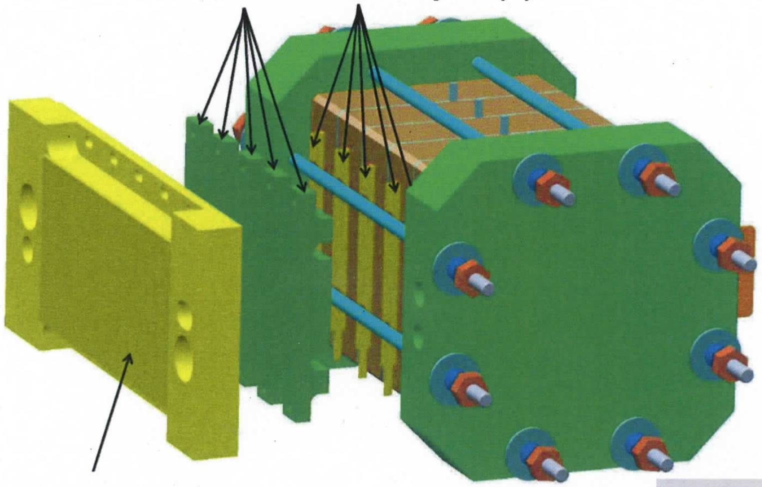
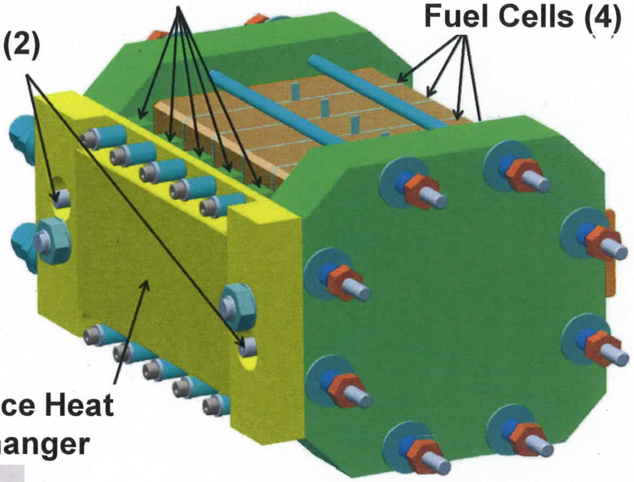
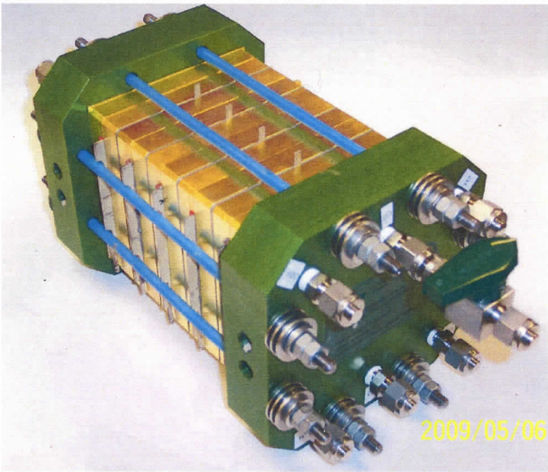
Ti Heat Pipe Cooling Plate Fuel Cell Stack







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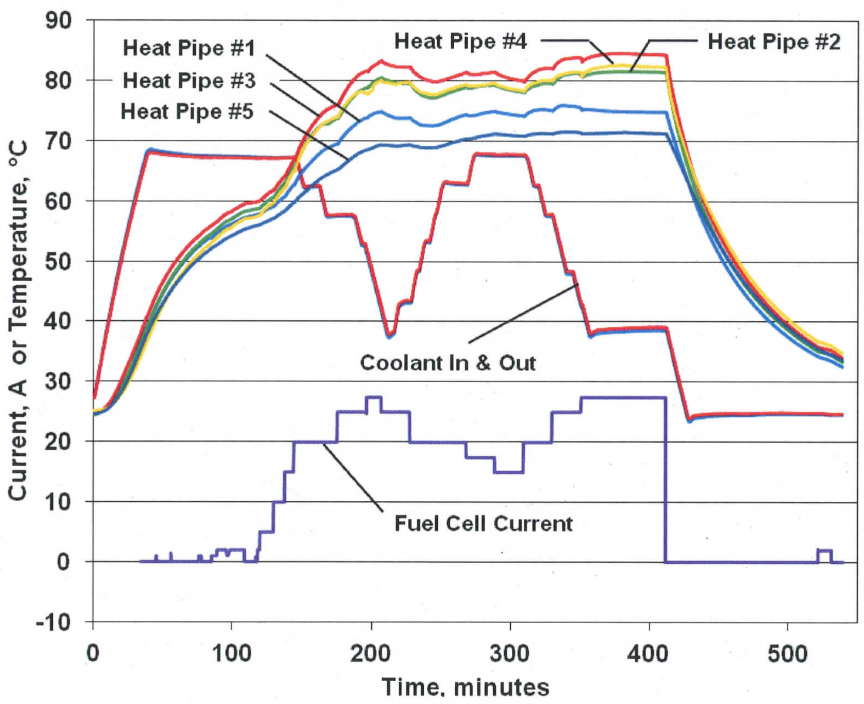
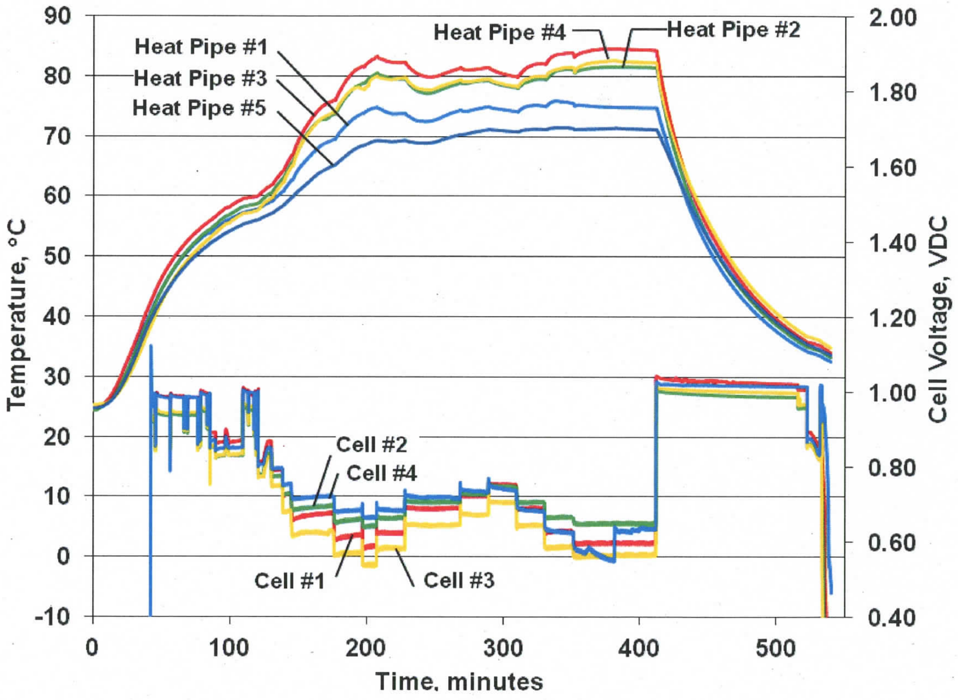
Ti Heat Pipe Cooling Plate Fuel Cell Stack Results





T he heat pipes were generally within a few degrees of each other except for heat pipes 1 & 5 which were the outer-most heat pipes (closest to the stack endplates). At the start of the test the heat pipes actually transferred heat from the coolant into the cell stack. Once the fuel cell current was increased to 20A the heat pipes got hotter than the coolant. At this point the heat pipes were transferring heat from the cell stack to the coolant. Further increases in the current required the coolant temperature to be lowered to maintain the stack at 80°C

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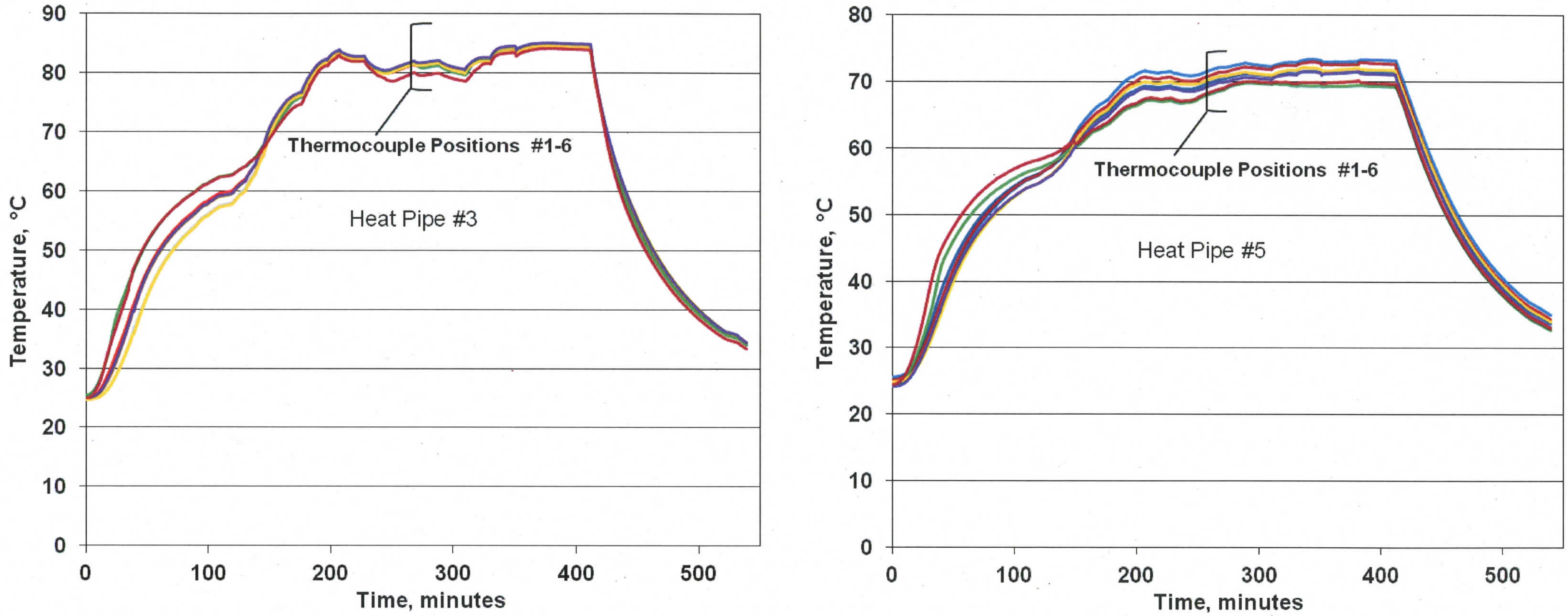
Ti Heat Pipe Cooling Plate Fuel Cell Stack Results



The temperatures on heat pipes #3 (the center-most heat pipe in the stack) and heat pipe #5 (one of the outer-most heat pipes) are shown above. The data shows that even though the plates differ by about 10°C, the heat pipes themselves are nearly isothermal.

Demonstration of Passive Fuel Cell Thermal Management Technology

Conclusions

The results demonstrate that passive thermal control of fuel cell stacks is feasible. It is controllable and provides the highly uniform thermal environment desired for fuel cell operation. This revolutionary thermal control approach reduces the components and parasitic power compared to the traditional pumped loop thermal control approach.

- Coolant flow control using either the electronic proportional control valve or the thermostatic valve effectively controls the stack temperature .

- The proportional valve controls the temperature independently of the fuel cell stack power, and maintains the stack temperature within a small control band.

- The thermostatic valve is an extremely simple though less flexible approach. The power level and the operating temperature are not independent, but rise or fall together. Properly optimized for the fuel cell stack, it could provide an acceptable level of thermal control.

- The performance of both pyrolytic graphite and titanium heat pipe cooling plate technologies proved the feasibility of either style cooling plate. Both technologies can be adapted for integration in fuel cell stacks and both produce uniform thermal environments for fuel cell operation, both cell-to-cell and within any one cell.

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