Passive Thermal Management Technology

for Fuel Cells - Part 2: Passive Cooling Plates

The importance of fuel cells cannot be overestimated. A fuel cell is a device that converts the chemical energy from a fuel into electricity through a chemical reaction with oxygen or another oxidizing agent [1]. While hydrogen is the most common fuel, hydrocarbons such as natural gas and alcohols like methanol are sometimes used. Individual fuel cells produce relatively small electrical potential, about 0.7 volts, so cells are stacked, or placed in a series, to increase the voltage and meet an application's requirements. In addition to electricity, fuel cells produce water, heat and, depending on the fuel source, very small amounts of nitrogen dioxide and other emissions. The energy efficiency of a fuel cell is generally between 40–60%, or up to 85% efficient in cogeneration if waste heat is captured for use.

To ensure continuous operation, the fuel cell stack temperature needs to be maintained at a constant and uniform level to maximize the performance and efficiency of the fuel cell system. The fuel cell can be air-cooled or liquid-cooled, depending on power density and application. Burke et al. [2] performed an interesting study using passive thermal management technology to regulate the PEMFC stack temperature. This article summarizes some of their finding and conclusions on their proposed passive thermal management technology.

Figure 1 illustrates the difference between active and passive thermal management for fuel cell. In passive thermal management method, waste heat is transferred directly from the fuel cell stack to the heat exchanger by conduction plates. A thermostat valve is used to regulate the cooling flow rate, which controls the fuel cell stack temperature. Potential benefits of the passive approach include reductions in mass, system complexity and parasitic power as well as improvements in system reliability.

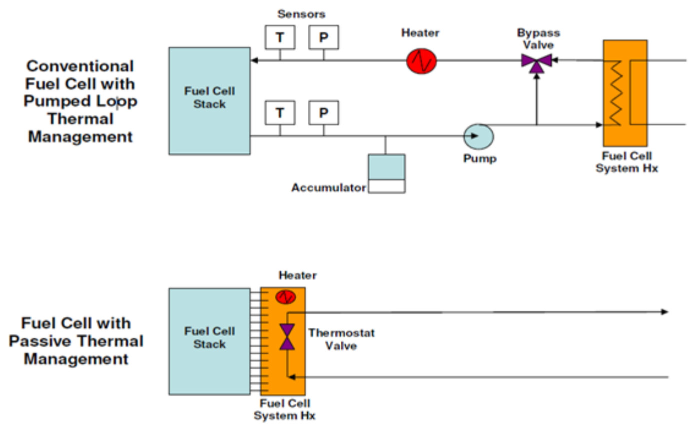

Figure 1. Active and Passive Thermal Management for Fuel Cell [2]

To validate the performance and function of their passive thermal management technology, Burke et al. [2] conducted the following two sets of tests on fuel cells.

1. Test two different control valve approaches to the regulation of cooling flow:
    1) Use an electronically controlled proportional valve
    2) Utilize a thermostatic control

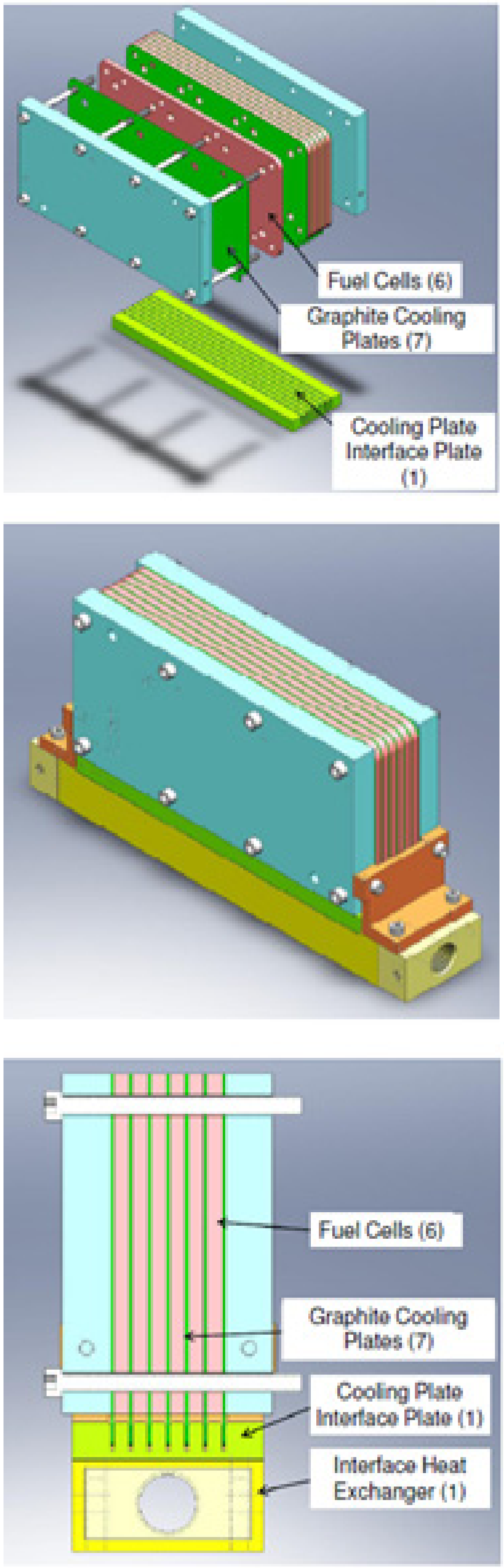

Figure 2. Pyrolytic Graphite Cooling Plate Technology Demonstration Stack [2]

2. Demonstrate two passive cooling plate technologies in operational fuel cell stacks:
   1) Employ a pyrolytic graphite cooling plate
   2)Use a titanium heat pipe cooling plate

The test results of two different control valve approaches for fuel cell stack were discussed in our previous article "Passive Thermal Management Technology for Fuel Cell - Part 1: Control Valve Tests". The experimental results of two different passive cooling plates are summarized in this article.

Burke et al. [2] tested two different passive cooling plates on two different PEMFC stacks. One is the pyrolytic graphite cooling plate developed by NASA, another is the titanium heat pipe cooling plate developed by Thermacore. Both plates have very high equivalent thermal conductivity. Figure 2 shows the pyrolytic graphite cooling plate technology demonstration stack. Teledyne Energy Systems, Inc. supplied the fuel cell hardware and NASA supplied the thermal management hardware. The thermal management hardware consisted of the pyrolytic graphite cooling plates, a cooling plate interface plate, an interface heat exchanger and associated brackets in the test. The PEMFC stack has 5 cells with an active area of 75 cm^2 for each fuel cell and 6 cooling plates.

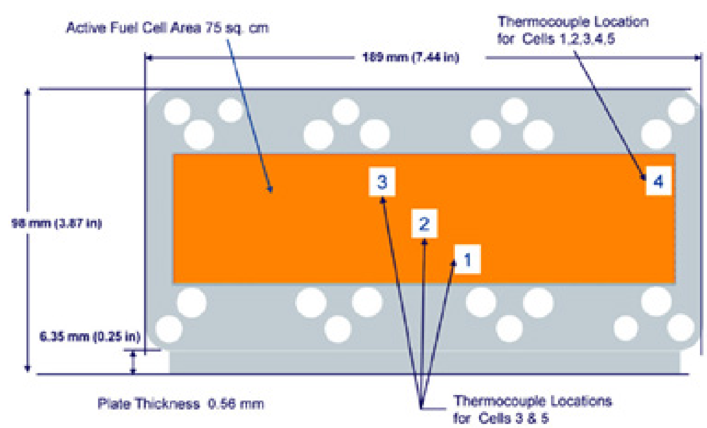

Figure 3. Pyrolytic Graphite Cooling Plate Geometry and Thermocouple Locations on Fuel Cells [2]

Figure 3 shows the geometry of the pyrolytic graphite cooling plates. Each of the cells was instrumented with thermocouples to measure the temperature distribution throughout the stack. The locations of the thermocouples on each cell in the fuel cell stack are shown in Figure 3.

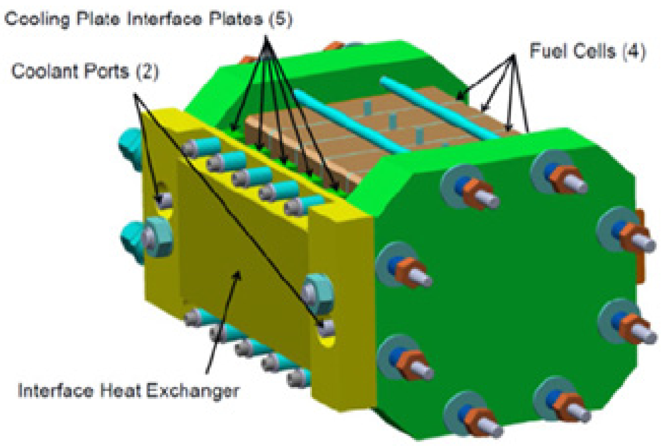

Figure 4. Titanium Planar Heat Pipe Cooling Plate Demonstration Fuel Cell Stack [2]

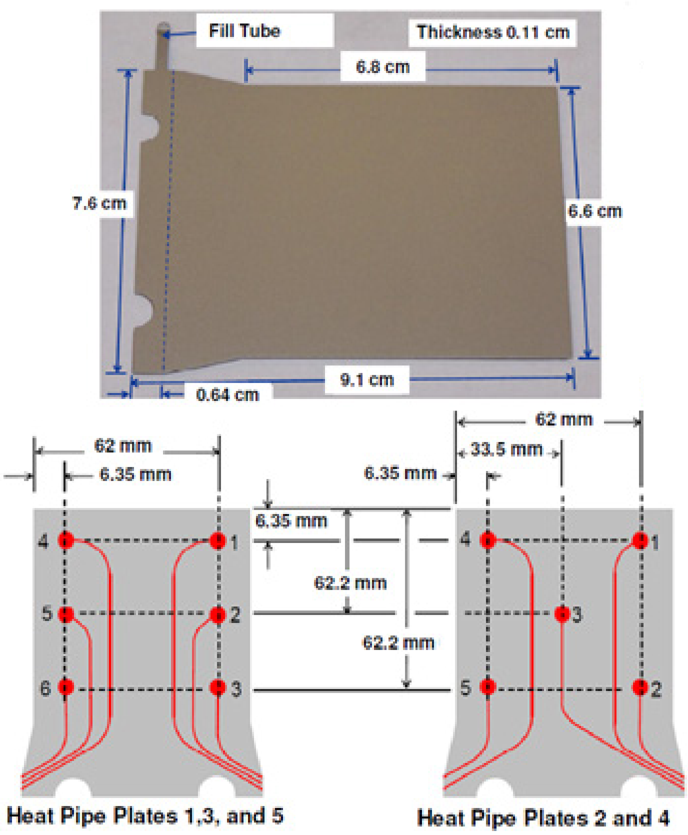

Figure 5. Titanium Heat Pipe Cooling Plate [2]

A titanium planar heat pipe cooling plate demonstration PEMFC stack was developed and manufactured by Infinity Fuel Cells and Hydrogen, LLC (see Figure 4). Figure 5 illustrates the titanium heat pipe cooling plate. Each of the heat pipe cooling plates was instrumented with multiple thermocouples. The evaporator area of each heat pipe plate was approx. 45 cm^2, which absorbed the heat from the fuel cell.

Figure 6 illustrates the test rig configuration for the PEMFC stacks. The fuel cell stacks were operated in a room-temperature laboratory environment. The coolant flow through the heat exchanger attached to the fuel cell stack was deliberately kept very high so that the coolant increased very little in temperature as it went through the heat exchanger. This kept the heat exchanger essentially isothermal. The temperature of the heat exchanger was adjusted manually using the controls on the heat exchanger.

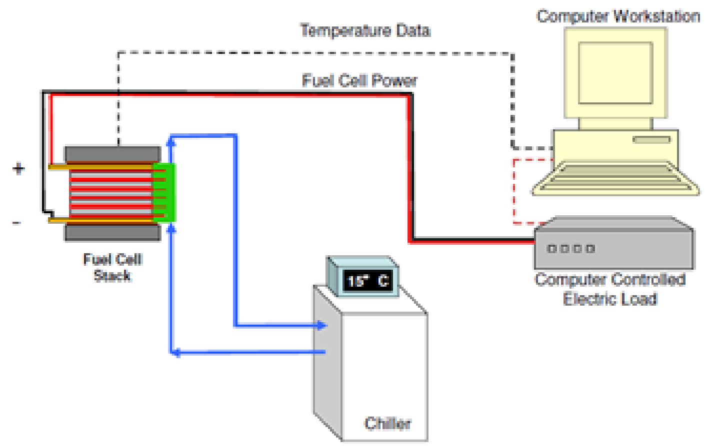

Figure 6. Fuel Cell Stack Test Rig Configuration [2]

Figure 7 shows the pyrolytic graphite cooling plate performance. At the start of the test, the cooling plates actually moved heat into the stack, allowing the cells of the stack to heat up uniformly. As the power was increased during the test, the cell temperatures reached their desired setting. As the power was increased further, the coolant temperature was reduced to maintain the cell temperatures at the desired level.

The difference between the highest temperature reading and the lowest temperature reading of the eleven thermocouples in the stack never exceeded 3°C. This is an excellent uniformity level throughout the stack.

Figure 8 shows the titanium heat pipe cooling plate performance. The coolant inlet and outlet temperatures were nearly identical because the flow rate of coolant through the fuel cell stack was very high. The difference in cooling plate temperatures was about 10°C. Figure 9 shows the distribution of temperatures on heat pipe plate #3.

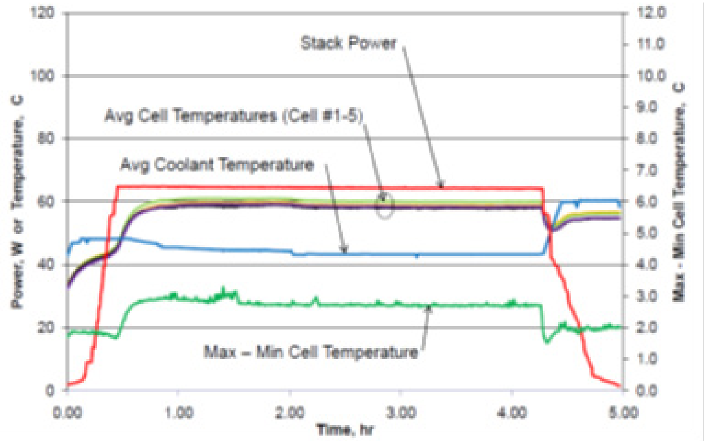

Figure 7. Pyrolytic Graphite Cooling Plate Performance [2]

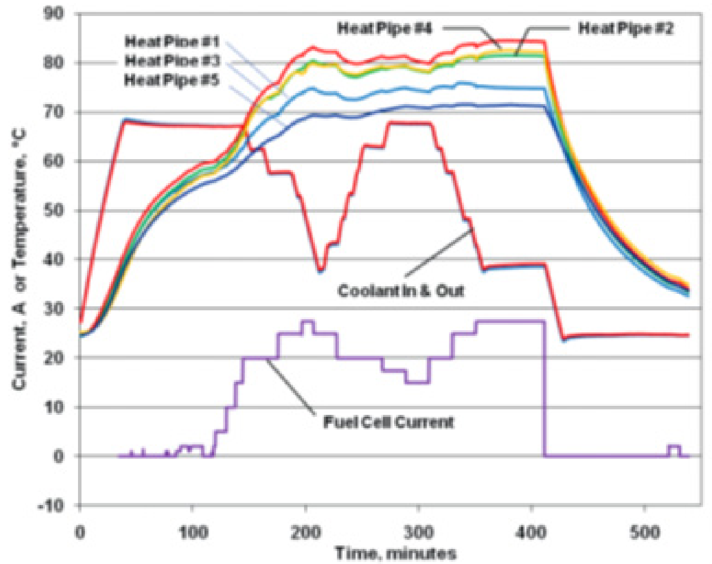

Figure 8. Titanium Planar Heat Pipe Cooling Plate Performance [2]

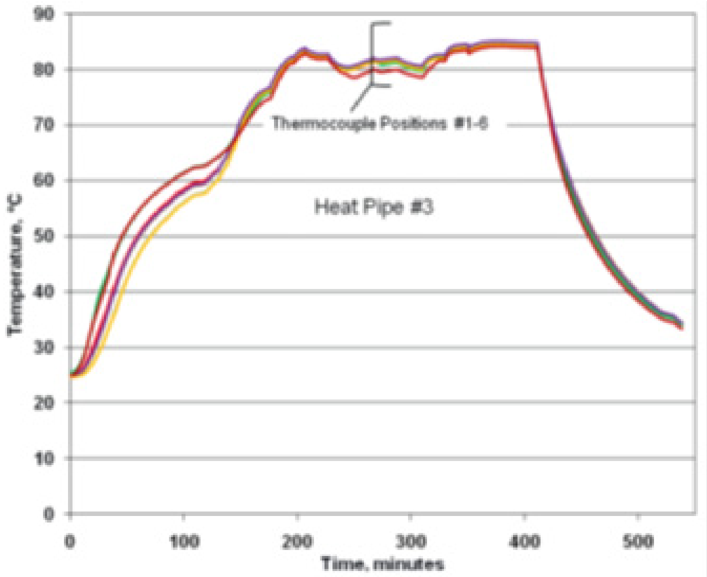

Figure 9. Heat Pipe Cooling Plate #3 Temperature Uniformity [2]

The results show a high degree of thermal uniformity on a given heat pipe plate in the test. The uniformity generally got better after the cells reached their nominal operating temperature.

The tests conducted by Burke et al. [2] demonstrated that passive thermal control of fuel cell stacks is feasible, and that passive removal of heat is controllable and provides the highly uniform thermal environment desired for fuel cell operation. This revolutionary thermal control approach can reduce the components and parasitic power compared to the traditional pumped loop thermal control approach. In their tests, Burke et al. [2] found that the performance of both pyrolytic graphite and titanium heat pipe cooling plate technologies are good and well suited for fuel cell cooling applications.

References:

1. Khurmi, R. S. Material Science, S. Chand & Company Ltd., 2013.

2. Burke, A, K., Jakupca, I., Colozza, A., Wynne, R., Miller, M., Meyer, A., and Smith, W., Demonstration of Passive Fuel Cell Thermal Management Technology, NASA/TM—2012-217421.