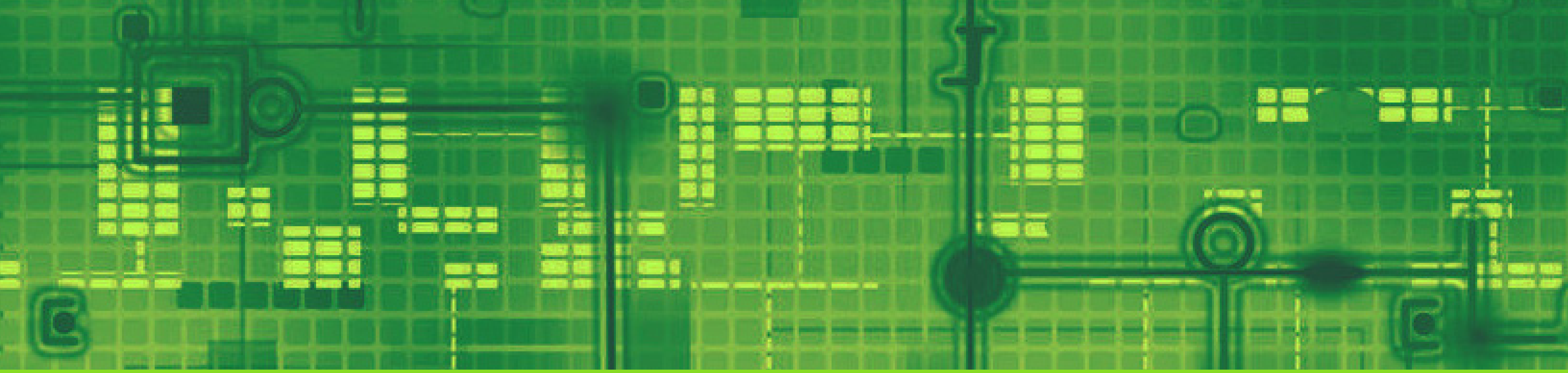


Passive Thermal Management Technology

For Fuel Cells - Part 1: Control Valve Tests

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]. Hydrogen is the most common fuel, but 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 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.

Fuel cells come in many varieties; however, they all work in the same general manner. They are made up of three adjacent segments: the anode, the electrolyte, and the cathode. Two chemical reactions occur at the interfaces of the three different segments. The net result of the two reactions is that fuel is consumed, water or carbon dioxide is created, and an electric current is initiated, which can be utilized to power electrical devices. Proton exchange membrane fuel cells (PEMFC) rely off a proton-conducting polymer membrane as electrolytes, use hydrogen and oxygen as fuel, and create water as waste by product. They operate at a temperature range of 50 to 100 °C and have broad applications in automobiles, backup power generation, space missions, etc.

Figure 1 illustrates how PEMFC operates. At the anode plate side, the hydrogen fuel diffuses to the anode catalyst, where it later dissociates into protons and electrons. The protons are conducted through the membrane to the cathode, but the electrons are forced to travel in an external circuit, because the membrane is electrically insulating. On the cathode plate side, oxygen molecules react with the electrons and protons to form water and generate waste heat.

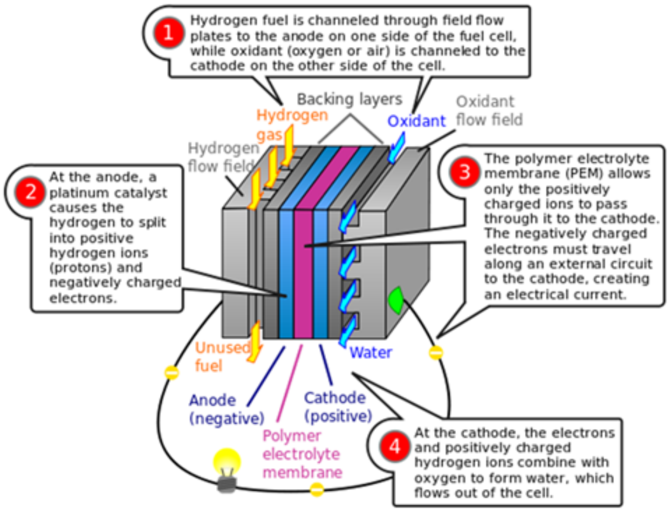


Figure 1. Proton Exchange Membrane Fuel Cell (PEMFC) [2]

To ensure continuous operation, the fuel cell stack temperature needs to be maintained at a constant and uniform level in order to maximize the performance and efficiency of the fuel cell system. This is particularly challenging as the $2H_2 + O_2 \rightarrow 2H_2O$ reaction is highly exothermic and a large quantity of heat is generated within the fuel cell. The fuel cell can be air-cooled or liquid-cooled, depending on the power density and the application. Burke et al. [3] did an interesting study of 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 2 illustrates the difference between active and passive thermal management for fuel cells. In the 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.

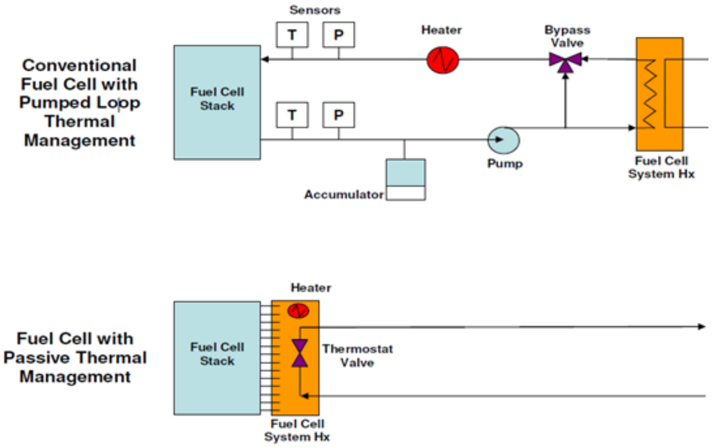


Figure 2. Active and Passive Thermal Management for Fuel Cell [3]

To validate the performance and function of their passive thermal management technology, Burke et al. [3] performed 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) Use a thermostatic valve

2. Demonstrate two passive cooling plate technologies in operational fuel cell stacks
   1) Pyrolytic graphite cooling plate
   2) Titanium heat pipe cooling plate

This article summarizes the test results of two different control valve approaches, by which Burke et al. [3] tested. The experimental results of two different passive cooling plates are discussed in the article "Passive Thermal Management Technology for Fuel Cell - Part 2: Passive Cooling Plates"
Burke et al. [3] built a simulated fuel stack to test the function of two different control valves, see Figures 3 and 4. They used a 4mm thin pyrolytic graphite plates coated with silver paint developed by NASA as conducting plates. On one side of the plate, 9 thermocouples were implemented to monitor the plate temperature. On the other side of the plate, a silicone pad heater was attached to simulate the fuel cell load. 4 conducting plates were plugged in a water-cooled heat exchanger, which is used to remove the heat from the conductive plates.

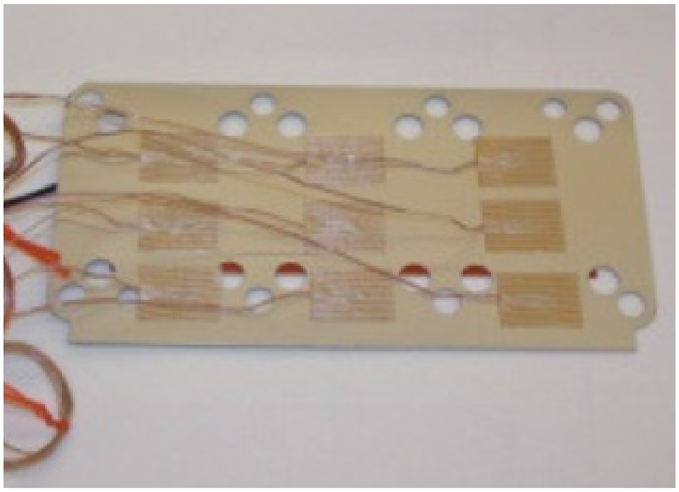
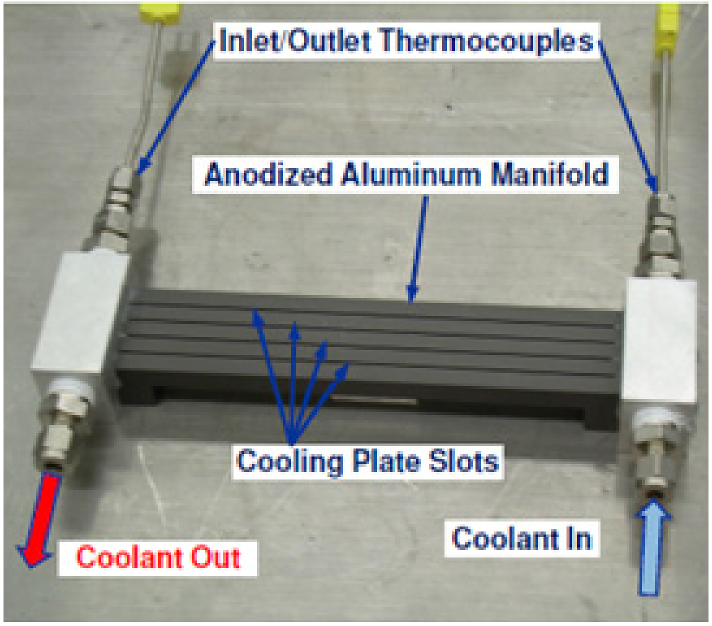


Figure 3. Instrumented Cooling Plate with Heaters [3]



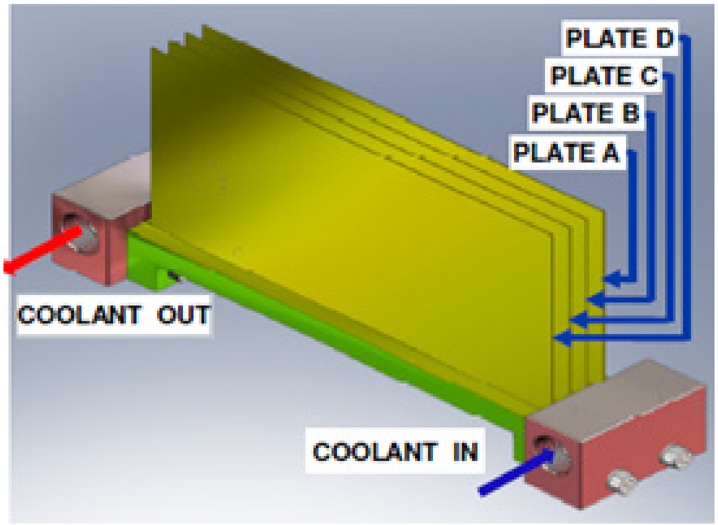


Figure 4. Heat Exchanger and Simulated Fuel Cell stack [3]

One of the control valves Burke et al. tested is an electronically-controlled valve produced by Kelly Pneumatics, Inc. (KPI), see Figure 5. The valve controls the coolant flow in response to a 0-5VDC control signal. The test rig for this valve and simulated fuel cell stack is shown in Figure 6. The simulated fuel cell stack was tested inside a vacuum chamber to reduce convective heat loss.

Figure 5. Electronically-Controlled Valve [3]

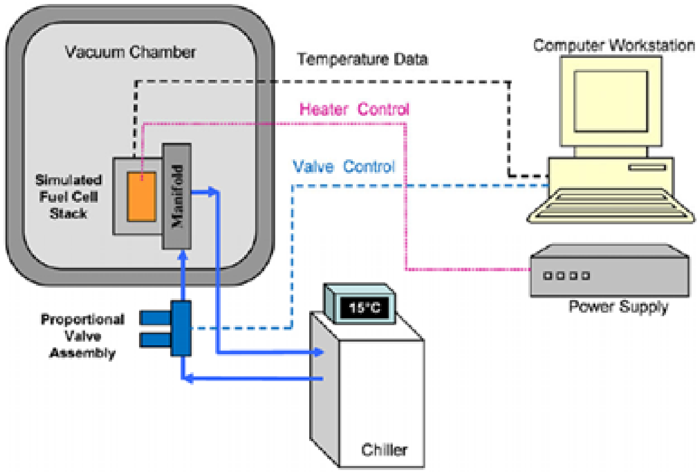


Figure 6. Test Rig for Electronically-Controlled Valve [3]

The electronically-controlled valve was placed outside the vacuum chamber to regulate the flow. Another control valve they tested is a thermostatic valve produced by Rostra Vernatherm, see Figure 7. The valve's actuator expanded or contracted in response to the temperature of the coolant flowing through the valve. The test rig for thermostatic valve and simulated fuel cell stack is shown in Figure 8. The thermostatic valve was placed close to the simulated load cell to reduce the temperature response time.

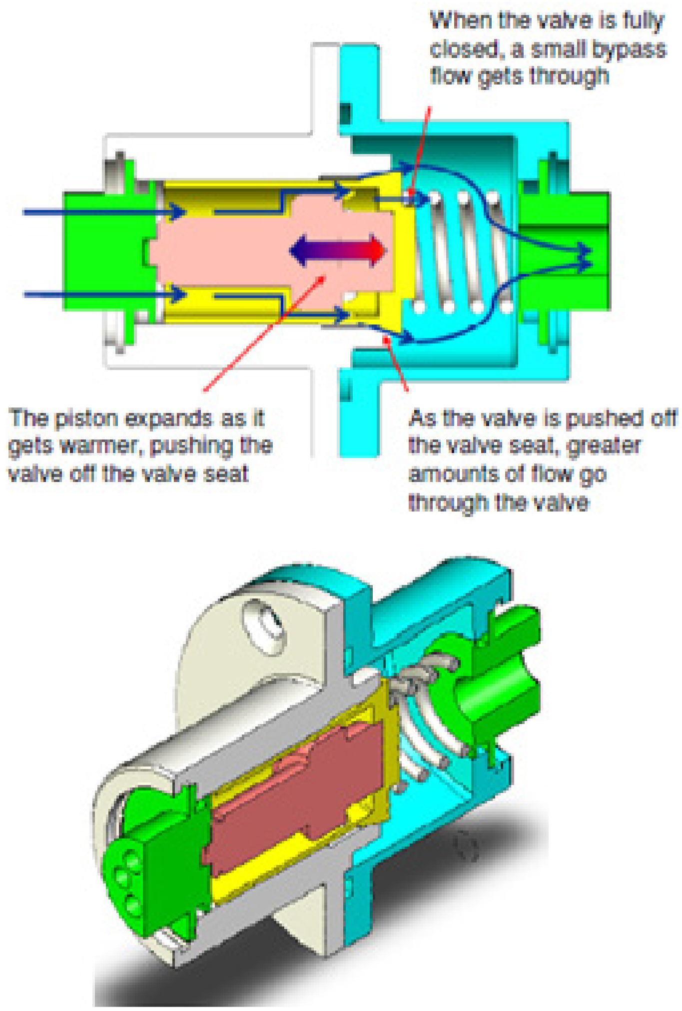


Figure 7. Thermostatic Valve [3]

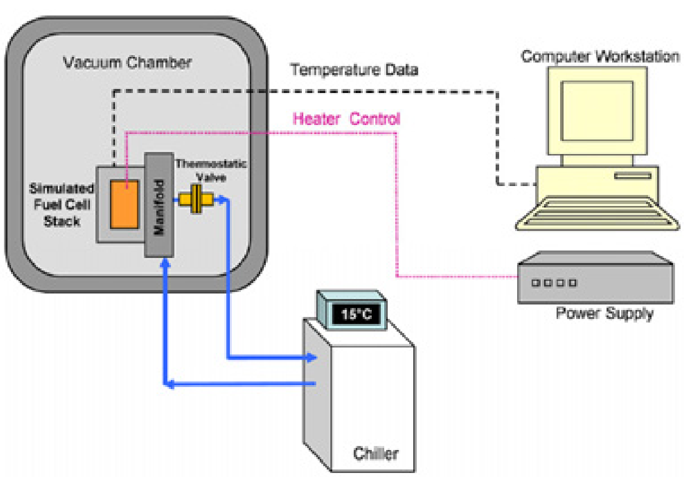


Figure 8. Test Rig for Thermostatic Valve [3]

For the electronically-controlled valve test, Burke et al. first applied a constant power level to each plate. Figures 9 and 10 show the average temperature of Plate B at different fuel cell operating temperature and two heat loads, 7.77 and 29.9 W/plate, respectively. They found that the thermal performance of Plates A, C, and D were very similar to Plate B and the uniformity of temperatures on each of the plates was very good. The proportional control maintained the plate temperature within a small temperature band at all power levels. At most, the observed temperature oscillated a few degrees above or below a nominal temperature at or near the set point.

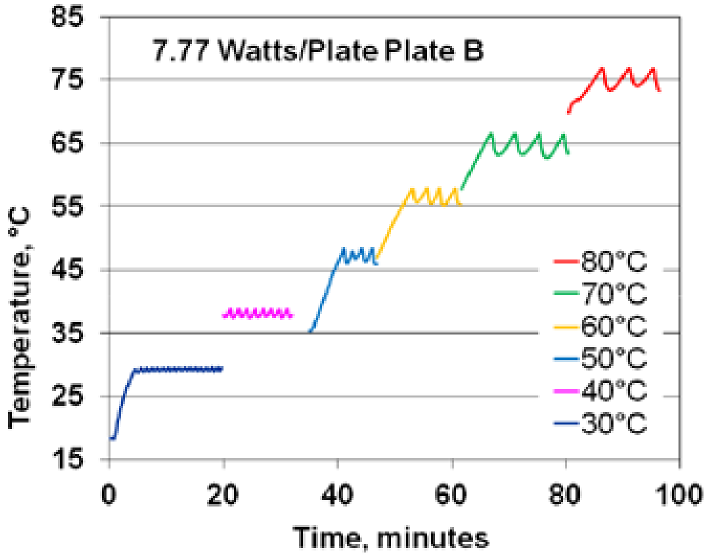


Figure 9. Electronically-Controlled Valve Performance at 7.7 W/plate [3]

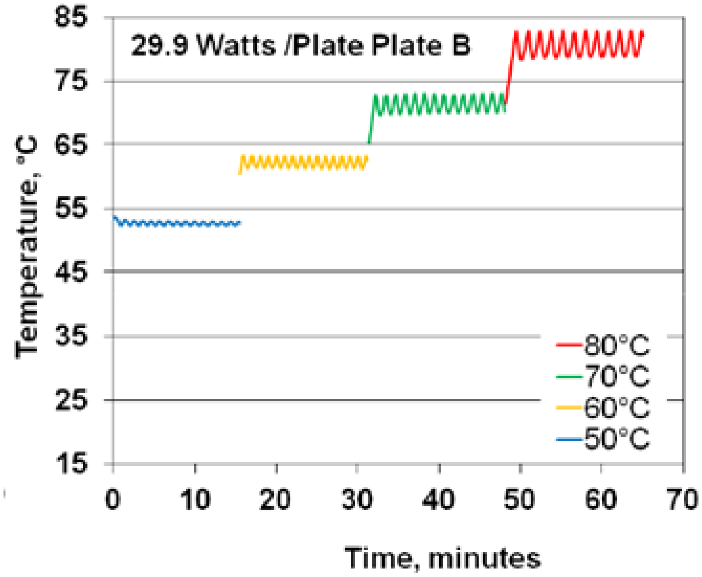


Figure 10. Electronically-Controlled Valve Performance at 29.9 W/plate [3]

Burke et al. then fixed the set point and varied the power level and duration at a given power according to a defined power profile. This type of test was designed to more realistically mimic the real operating conditions. Figures 11 and 12 show the test results at set points of 47 °C and 77 °C. They found for each of these tests the plate temperature quickly rose to the set point and then oscillated within a few degrees of that temperature despite the power level variation. Only when the power level dropped suddenly from high power to minimum power, the plate temperature dropped 10° to 15° before it stabilized and started to rise back to the set point.

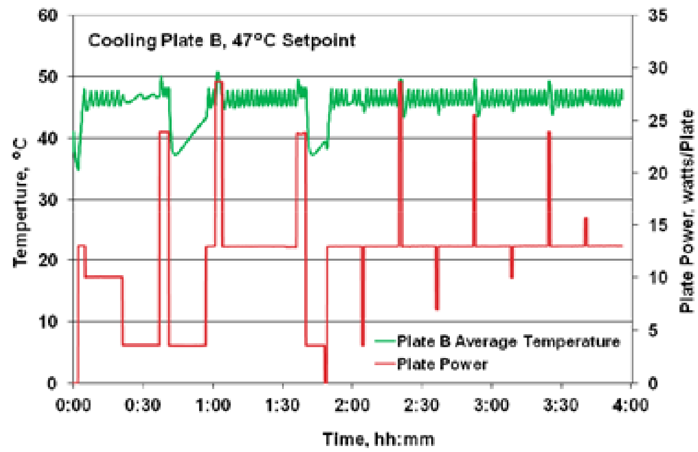


Figure 11. Electronically-Controlled Valve Performance at 47 °C. [3]

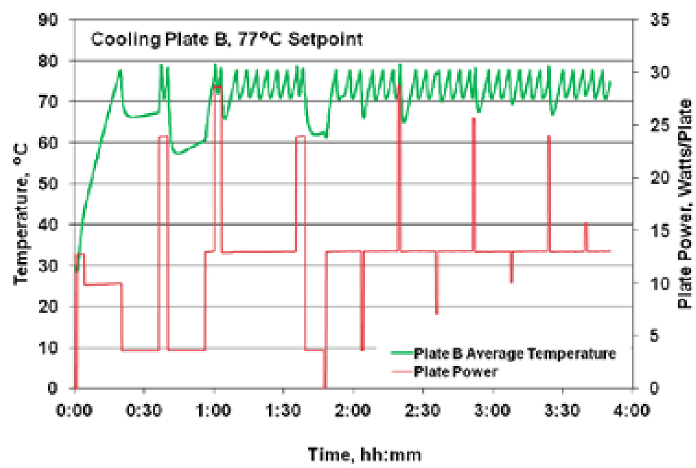


Figure 12. Electronically-Controlled Valve Performance at 77 °C [3]

Burke et al. did the same tests on a thermostatic valve. While this type of flow control is much simpler than the proportional valve control approach, it is less flexible. The thermostatic valve increases the flow as a result of an increase in coolant temperature. It is a passive control with a lag. The first test was to vary the heat load and observe the resultant increase in plate temperature, coolant flow rate, and the time to establish the new equilibrium. Figures 13 and 14 were run with the valve modified to make the bypass flow 10 cc/min. Figure 13 shows that as the power level was increased stepwise, the temperature of each plate likewise increased in discrete steps. Figure 14 shows the coolant flow and outlet temperature variation responding to power change. The coolant flow rate in particular shows a high frequency oscillation.

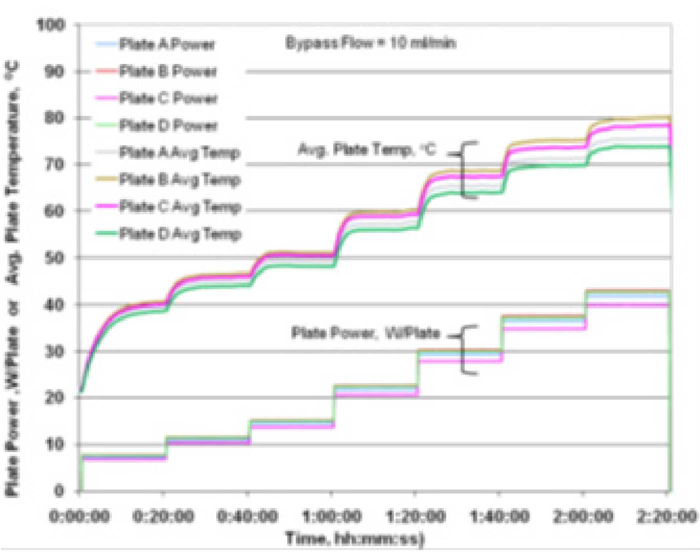


Figure 13. Thermostatic Valve Performance - Plate Temperature [3]

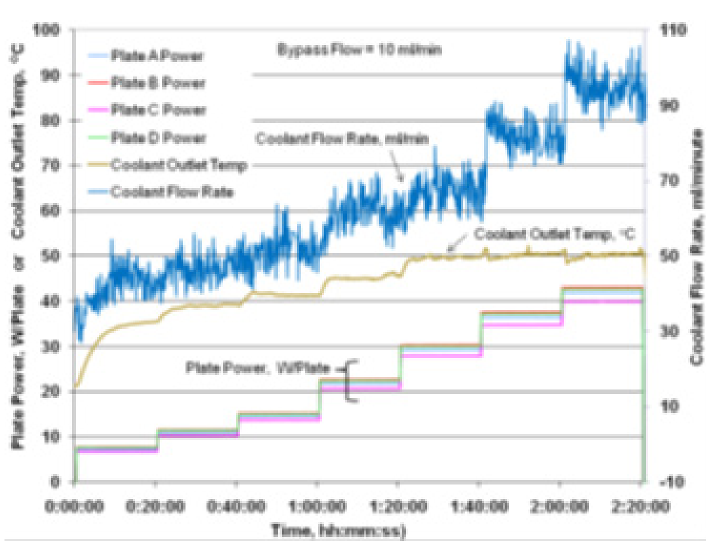


Figure 14. Thermostatic Valve Performance - Coolant Flow and Temperatures [3]

The other test performed with the thermostatic valve was the power profile test. Figures 15 and 16 show the results for the thermostatic valve. Figure 15 shows the average temperature of Plate B during the test. In general, the control observed with the thermostatic valve was not as good as with the proportional valve.

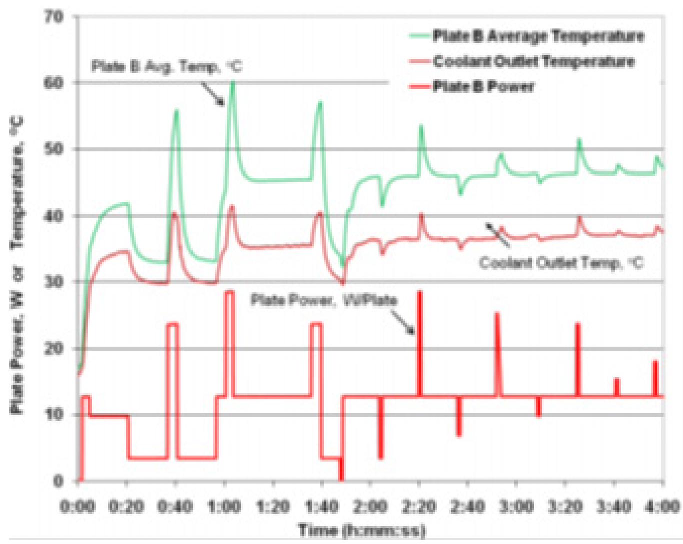


Figure 15. Thermostatic Valve Performance - Average Plate Temperature During Power Profile Test [3]

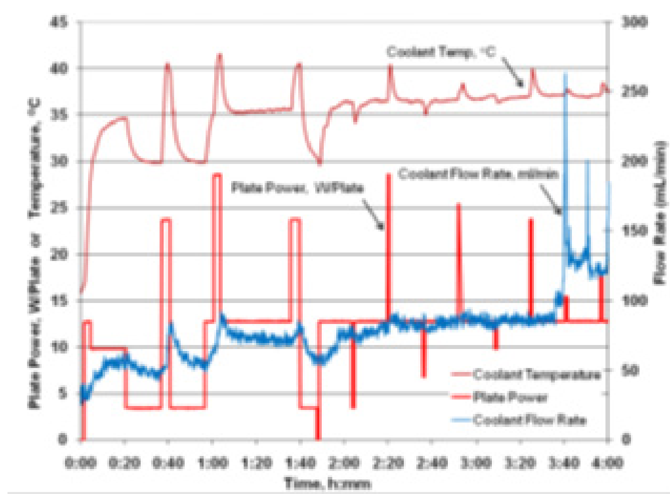


Figure 16. Thermostatic Valve Performance - Coolant Flow During Power Profile Test [3]

The tests conducted by Burke et al. [3] demonstrate that passive thermal control of fuel cell stacks is feasible. They found that using either the electronic proportional control valve or the thermostatic valve can effectively control the fuel cell stack temperature. The proportional valve controls the temperature independently of the fuel cell stack power and can maintain 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 they rise or fall together. Properly optimized for the fuel cell stack, it could provide an acceptable level of thermal control.

References:

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

2. **http://www.fueleconomy.gov/feg/fcv_PEM.shtml.**

3. **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.**