VII.H.8 Graphite-based Thermal Management System Components for Fuel Cell Power Systems

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Projected End Date: Project continuation and direction determined annually by DOE

Objectives

- Develop compact, lightweight, highly effective thermal management system components for fuel cell power systems, using woven graphite fiber structures.
- Construct a prototype radiator for a fuel cell powered vehicle using woven graphite fiber structures, based on specifications determined in collaboration with fuel cell and heat exchanger manufacturers.

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:

- D. Thermal, Air and Water Management

Approach

- Use high-thermal-conductivity graphite fibers to develop lightweight, compact thermal management system components (heat exchangers, radiators, evaporators) with low density, high surface area, high permeability, high thermal effectiveness and high damage tolerance.
- Use commercially available graphite fibers and textile manufacturing processes to fabricate thermal management system components based on woven graphite fiber structures.
- Combine experimental and modeling work to optimize the design of compact, lightweight thermal management system components.
- Evaluate the thermal and hydraulic performance of a prototype radiator for a fuel cell powered vehicle fabricated with woven graphite fibers, and compare results with those obtained with commercial products.

Accomplishments

- In collaboration with 3-Tex, Inc. (Cary, NC), obtained a first generation of woven structures with controlled pore structure and distribution, permeability, and thermal properties using graphite fibers with intermediate elastic modulus (350 GPa) and thermal conductivity (250 W/mK). Subsequently, a second

generation of woven structures incorporating fluid-carrying metallic tubing was also obtained using graphite fibers with intermediate modulus and thermal conductivity values.
- Determined the permeability of woven graphite fiber structures (with and without metallic tubing) as a function of fiber architecture and number of metallic tubes.
- Using a test rig that was designed and built during FY 2004, determined the heat transfer characteristics and permeability of woven fiber structures.
- Undertook modeling efforts to aid the design, development, and optimization of woven graphite fiber structures for the manufacture of thermal management components.
- Established collaborations with fuel cell and heat exchanger manufacturers to guide the design and evaluation of thermal management system components based on the use of woven graphite fiber structures.

Future Directions

- With the aid of modeling tools, design and fabricate woven fiber structures using graphite fibers with high elastic modulus and thermal conductivity placed along directions in which heat transfer needs to be maximized. Graphite fiber of lower grade or glass fibers will be used in secondary directions. While the contribution of the latter to the thermal performance of the structure will be minimal, these fibers will be used to provide structural integrity. The resulting hybrid woven structures will be optimized for thermal and hydraulic performance and cost.
- Complete predictive numerical models that account for the effect of fiber architecture on the permeability and heat transfer performance of woven fiber structures.
- In collaboration with fuel cell developers and users, design and fabricate prototype versions of thermal management system components for testing and evaluation (e.g., radiators for fuel cell powered vehicles).
- Investigate the possibility of incorporating woven graphite fiber structures into body panels and other vehicle structures.
- Investigate cleaning, filtration, and maintenance requirements of woven graphite fiber structures.
- Continue to broaden industrial collaborations.

Introduction

The efficient operation of fuel cell powered vehicles will require systems capable of managing heat flow among exothermic components, which produce heat while in use and therefore require cooling (e.g., air compressor, water recovery condenser, fuel cell stack), and endothermic components that require heat to operate (e.g., water vaporizers). Furthermore, a fuel cell powered vehicle will incorporate a heating, ventilation, and cooling subsystem for passenger comfort, which will need to be an integral part of the overall thermal management system. The design of thermal management systems for fuel cell powered vehicles poses challenges because of the complexity and restrictions imposed by weight, volume, and cost. The outstanding thermal properties of graphite and its low density have prompted efforts to investigate the feasibility of using this material for the fabrication of thermal management system components, such as heat exchangers, condensers, and vaporizers.

Among the various forms of graphite, graphite fibers are ideal candidates for the fabrication of thermal management components because of their low density, high thermal conductivity, outstanding mechanical properties, and commercial availability. Furthermore, graphite fibers can be woven to produce lightweight 3-dimensional structures using textile technologies. The architecture of woven fiber structures, their geometrical features (e.g., weaving pattern), and their scale (e.g., spacing between fill and warp bundles) can be designed through a combination of experimental and modeling work to obtain thermal management components with optimum thermal and hydraulic characteristics. The types of fibers and their orientation in the woven structure can be selected to maximize heat transfer and minimize cost. Because the resulting woven structures are flexible, it could be possible to incorporate them into the body panels or chassis in a vehicle, contributing further toward weight savings.

Approach

The objectives of this project will be achieved through a combination of modeling and experimental work. Woven fiber structures will be designed and fabricated using various grades of fibers and established textile techniques. Graphite fibers with high thermal conductivity will be placed in the structure along directions in which heat transfer needs to be maximized. Graphite fibers with lower thermal conductivity, or other types of fibers (e.g., glass fibers), will be placed in the structure along directions in which heat transfer is not critical but where the fibers contribute to the structural integrity of the woven structure. The combination of fibers with different thermal properties will yield hybrid woven structures with optimized thermal performance and cost. In collaboration with weaving manufacturers, cost projections will be obtained for the large-scale manufacture of thermal management components. The geometrical features of the woven structures (e.g., weaving pattern) and their scale (e.g., spacing between fill and warp bundles) will be determined by a combination of experimental and modeling work in order to minimize pressure drop.

The design, fabrication, and evaluation of woven graphite fiber prototype radiators for a fuel cell powered vehicle will be conducted in coordination with industrial collaborators (e.g., developers of thermal management systems, fuel cells, and fuel cell powered vehicles).

Results

In collaboration with 3-Tex, a first generation of woven graphite fiber structures was fabricated using graphite fibers with an elastic modulus of 350 GPa and a thermal conductivity of 250 W/mK. Woven structures with different fiber architectures and pore structures were obtained (Figure 1). A second generation of woven structures was fabricated using the same fibers but with fluid-carrying metallic tubing incorporated in the structure. Figure 2 shows these woven graphite fiber structures.

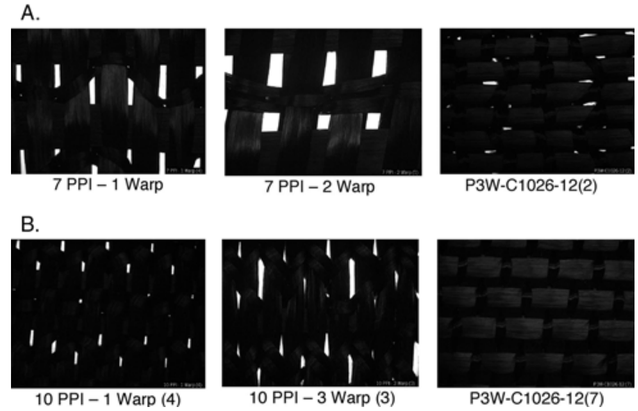

Figure 1. Generation-1 Woven Graphite Fiber Structures with Different Fiber Architectures

In collaboration with the Textile and Nonwovens Development Center at the University of Tennessee–Knoxville, air permeability measurements were made on generations 1 and 2 of the graphite fiber woven structures. A schematic of the test apparatus and a plot of permeability as a function of porosity are shown in Figure 3. It was found that the permeability of generations 1 and 2 of woven graphite fiber structures ranged from 225 to 6250 cfm/ft^2.

A test rig (Figure 4) was designed and constructed to evaluate the heat transfer characteristics, permeability, and pressure drop associated with woven graphite fiber structures. Results of pressure drop vs. flow rate are shown in Figure 5 for woven graphite fiber structures with different fiber architectures. They indicate that, as expected, pressure drop increases with increasing fabric density.

It is recognized that one of the highest levels of thermal resistance in these structures exists at the interface between the fibers and the fluid-carrying tubing. To minimize the magnitude of this thermal resistance, conductive epoxies have been applied to bond the copper tubing to the woven structure. It was found that conductive epoxies can increase heat transfer at these interfaces by as much as 25%.

To evaluate the performance of generation-2 woven graphite fiber structures under conditions similar to those that would exist in the radiator of a fuel cell powered vehicle, the test setup shown in Figure 4 was modified to flow hot water through the

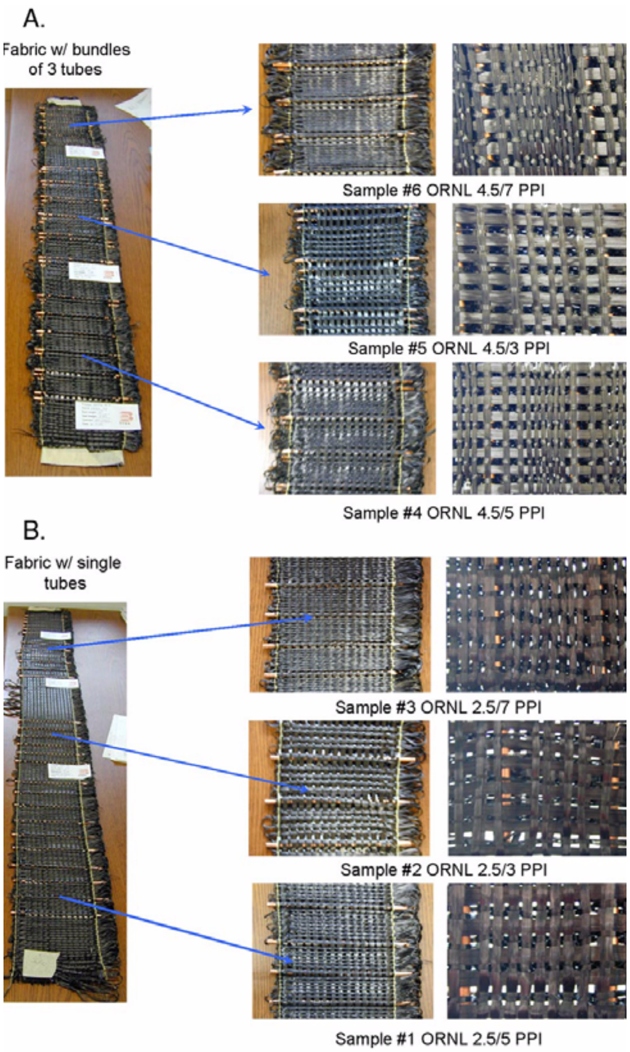

Figure 2. Generation-2 Woven Graphite Fiber Structures Incorporating Copper Tubing in Sets of (a) One or (b) Three Tubes

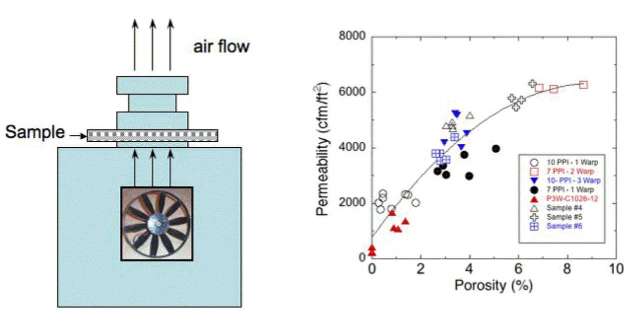

Figure 3. Permeability Testing Apparatus and Results for Generation-1 Woven Graphite Fiber Structures

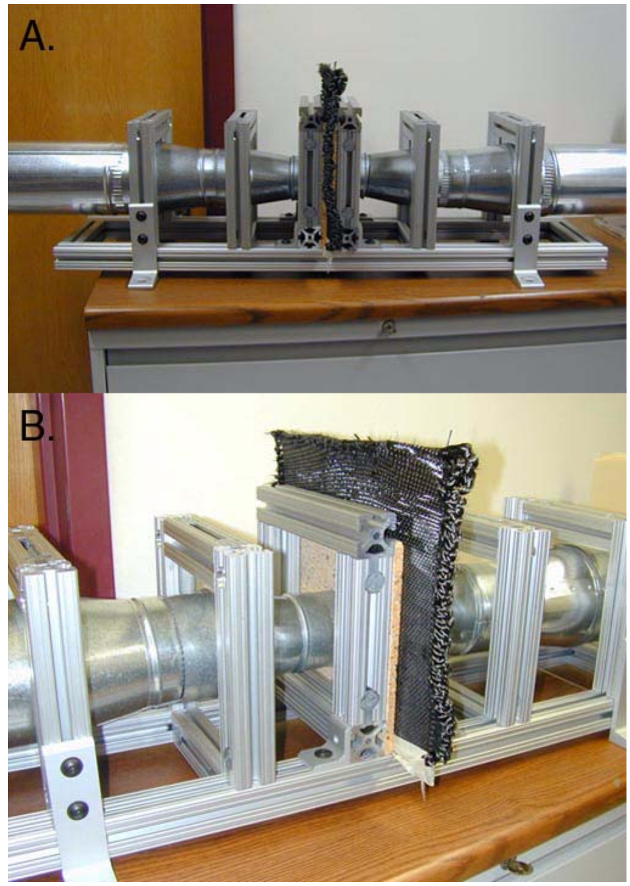

Figure 4. Oak Ridge National Laboratory's Heat Transfer and Pressure Drop Test Rig

copper tubing and to flow air through the woven structure using a variable-speed fan. The change in water temperature and the pressure drop across the woven structure were recorded as a function of the initial water temperature, the power supplied to the variable-speed fan, and whether conductive epoxy was used to bond the metallic tubing to the woven fibers. Typical results are presented in Figures 5 and 6 for woven graphite fiber structures with different fiber architectures. These results will be analyzed and used to benchmark and to compare the performance of woven graphite fiber radiators to that of commercial products.

Modeling efforts were initiated to evaluate the effect of design variables (e.g., fiber architecture, metallic tube size and spacing, number of layers in the woven structure) on the performance of radiators based on woven graphite fiber structures. Eventually, the models developed will be used to

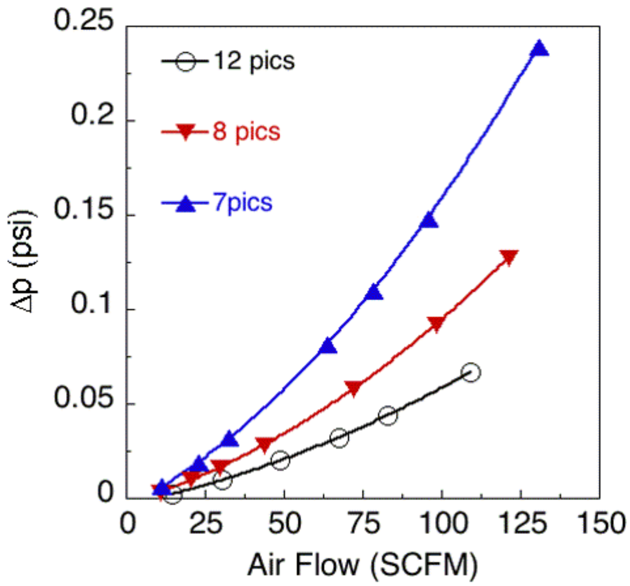

Figure 5. Pressure Drop vs. Volumetric Flow for Generation-2 Woven Graphite Fiber Structures

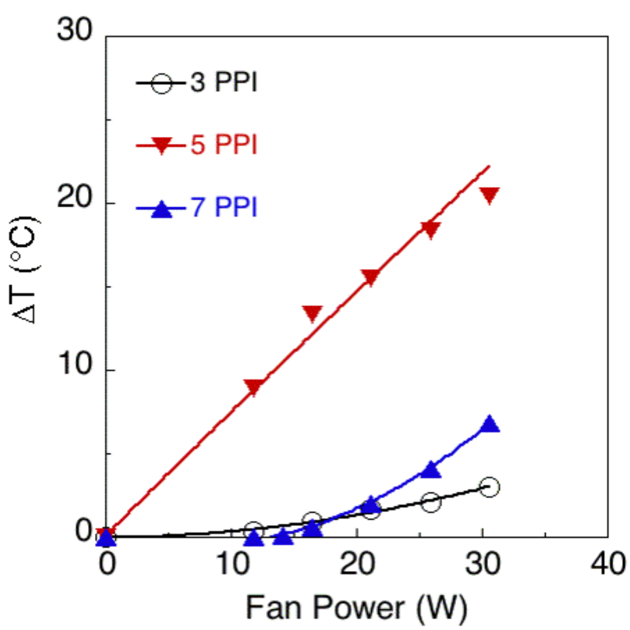

Figure 6. Temperature Drop Versus Fan Power for Generation-2 Woven Graphite Fiber Structures (Initial water temperature was 65°C.)

design the prototype of a radiator for a 130-kW fuel cell. This work will be carried out in collaboration with manufacturers of fuel cells and radiators.

Summary

Thermal management components are being developed using woven graphite fiber structures. In collaboration with 3-Tex, woven graphite fiber structures incorporating copper tubing were fabricated using graphite fibers with intermediate elastic modulus and thermal conductivity. The thermal and hydraulic performance of these woven structures was determined and correlated to their fiber architectures using a test rig designed and constructed at Oak Ridge National Laboratory. The ability of these structures to remove heat from water flowing through the copper tubing was demonstrated, and the results were correlated to the power required to operate a variable-speed fan used to blow air through the woven structure.

It was found that the heat transfer between the copper tubing and the fibers could be increased by 25% by using thermally conductive epoxies. Future work will be focused on developing hybrid structures incorporating different grades of graphite fibers that are aligned in order to optimize heat transfer and cost.

Collaborations have been established with fuel cell and heat exchanger manufacturers to guide the design and evaluation of thermal management system components, particularly radiators for fuel cell powered vehicles.

Special Recognitions and Awards/Patents Issued

1. One UT-Battelle, LLC, invention disclosure was submitted in June 2005 for thermal management components based on woven graphite fiber structures.

FY 2005 Presentations

1. A poster was presented at the 2005 DOE Hydrogen Program Review and Peer Evaluation, Arlington, VA, May 23-26, 2005.