IV.H.10 Graphite-based Thermal Management System Components for Fuel Cell Power Systems

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Objectives

- Develop compact, low-weight, high-effectiveness thermal management system components for fuel cell power systems using carbon-based materials.
- Design thermal management system components based on 3-D woven graphite fiber preforms.
  - Determine the feasibility of weaving high-stiffness graphite fibers into complex 3-D architectures.
  - Evaluate the effect of fiber architecture on the heat transfer and permeability of 3-D fiber preforms.
- Broaden industrial collaborations.

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:

- C. Thermal Management
- F. Heat Utilization

Approach

- Utilize woven preforms of high-thermal conductivity graphite fibers to develop compact thermal management system components (heat exchangers, radiators, evaporators) with low density, high surface area, high permeability, high thermal effectiveness and high damage tolerance.
- Utilize commercially-available graphite fibers and established manufacturing processes for fabrication of thermal management system components.
- Redefine geometry of thermal management system components.

Accomplishments

- Engineering model of thermal resistance and pressure drop has been developed. Primary resistance found to be at the air/preform or air/foam interface.
- Identified several commercial fibers with thermal conductivities greater than that of current heat exchanger materials such as aluminum (K of approximately 237 W/mK) and comparable to that of graphite foam ligaments. Thermal conductivities of fibers range from 320-1000 W/mK.
- Identified graphite fiber weaving technologies for preforms with complex three-dimensional architectures. These technologies will be utilized to produce tailored preforms with controlled pore structure,

permeability and thermal properties. Weaving of prototype preforms using mid-modulus/mid thermal conductivity fiber has been contracted to a commercial fiber weaving company (3-Tex Inc., Cary, NC).
- Designed and built test rig to evaluate heat transfer and permeability of graphite foams and woven fiber preforms.

Future Directions

- Evaluate the role of pore geometry and mechanical properties of individual graphite fiber preform fibers/ bundles on the macroscopic mechanical properties of the preforms and foams. This will be evaluated with the aid of models produced through X-ray tomography and rapid prototyping techniques.
- Incorporate cooling tubes into the weaving of fiber preform structures.
- Weave higher modulus/higher thermal conductivity fibers into three-dimensional architectures.
- Perform heat transfer and permeability testing on woven preform structures.
- Complete numerical models to determine the effect of fiber architecture (microstructure) on permeability and heat transfer characteristics of woven fiber structures.
- Develop hybrid woven fiber structures to optimize cost, thermal properties, permeability and mechanical durability.
- Broaden industrial collaborations.

Introduction

The outstanding thermal properties of graphite foam have prompted efforts to investigate the feasibility of using it in thermal management applications, such as cooling of power electronics and radiators for automobiles and trucks. The main advantage of using this material in such applications is its high specific conductivity and low density, which creates systems with high heat removal and low mass. Yet, the high costs and low mechanical strength associated with carbon foam may prove prohibitive to its use, despite its favorable thermal performance. Therefore, carbon fiber preforms, which may possess high thermal conductivities and greater mechanical performance in selected directions while offering possible lower costs, are under consideration for such applications.

Most previous fuel cell vehicle designs have been based on the use of several discrete heat transfer circuits, with each system having its own set of components (plumbing, pumps, valves, etc.). This will result in additional weight and cost for the vehicle. The use of graphite-based heat exchangers represents a unique opportunity for using advanced materials in the design of integrated thermal management systems for fuel cell vehicles. In these systems, endothermic and exothermic devices will be integrated by the thermal management system to distribute heat among the various components as needed.

Approach

Devices fashioned from woven graphite fiber preforms will be designed and evaluated. The planned approach, to be undertaken in coordination with modeling efforts, involves the design of graphite-based heat exchangers with microstructures that maximize heat transfer while minimizing pressure drop. The types of fibers and their orientations in the woven structure will be controlled to maximize heat transfer while minimizing cost. The geometrical features of the woven structure (e.g. weaving pattern) and their scale (e.g. spacing between fill and warp bundles) will be determined in order to minimize pressure drop, in accordance with transport model predictions.

Work will be supplemented with experiments to gain better understanding of the effect of heat exchanger material microstructure on gas flow penetration, pressure drop, and mechanical strength. The evaluation of graphite-based materials to be developed in this project will be conducted in coordination with industrial collaborators (e.g. developers of thermal management systems, fuel cells and fuel cell powered vehicles).

Results

An engineering model of thermal resistance and pressure drop has been developed in collaboration with researchers at the University of Western Ontario. The model provides thermal resistance and pressure drop in air-water heat exchangers. Results are based on a combination of the following: measurements of bulk conductivity of porous carbon foam; well-established correlations for convective heat transfer from tubes, plates and fins; measured thermal resistance at the interface between aluminum and porous carbon foam with a number of different joints; and an engineering approximation for the effects of porosity on convective heat transfer. The model will also be used to better design carbon foam materials and to evaluate fiber preform structures for the prediction of optimized pore structures and geometries.

High thermal conductivity graphite fiber samples have been obtained from commercial vendors. Lower thermal conductivity/lower modulus fiber materials have also been identified and samples have been obtained. A list of candidate fibers along with their corresponding thermal conductivities and elastic moduli are listed in Table 1. Additionally, a commercial company (3-Tex, Inc. of Cary, North Carolina) has been identified as a partner in the project to utilize their unique weaving process (3-Weave) which is capable of producing 3-dimensional fiber preforms as shown in Figure 1. A visit was made to 3-Tex, wherepossible preform weaving techniques and designs were discussed. It was decided that a series of preforms would be woven with and without metallic tubing incorporated in the structure. Initial weavings will use 50 Msi/lower thermal conductivity fibers. Subsequent weavings will be attempted with higher modulus/higher thermal conductivity fibers. Fiber has been ordered for the initial weavings and production time is being scheduled at the 3-Tex Rutherfordton, North Carolina facility. Several sample fabrics constructed from fiberglass and low modulus/low thermal conductivity carbon fibers (shown in Figure 2) have been provided for preliminary investigations.

Table 1. Candidate High Thermal Conductivity Carbon Fibers

Fiber (Manufacturer)	Thermal Conductivity (W/mK)	Elastic Modulus (GPa)
K-100 (Cytec)	1000	965
K-800X (Cytec)	900	896
P-120S (Cytec)	640	827
YS-95A (NGF)	600	920
P-100S (Cytec)	520	758
YS-90A (NGF)	500	880
CN-90 (NGF)	500	890
YS-80A (NGF)	320	785
CN-80 (NGF)	320	800

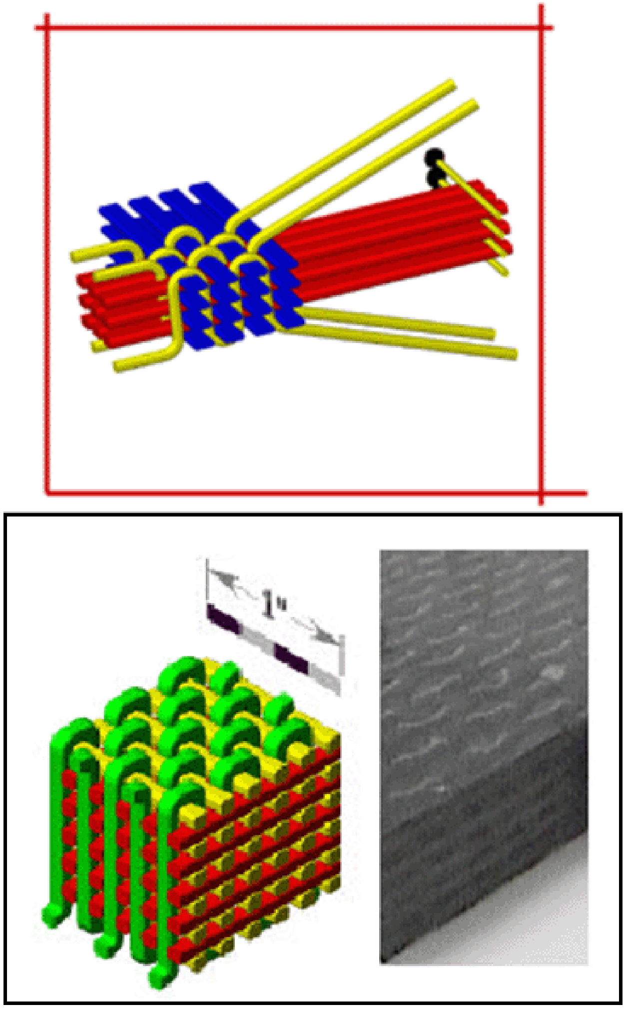

Figure 1. Schematics of 3-Tex (3-Weave) 3-Dimensional Preforms

A test rig (shown in Figure 3) was designed and constructed to evaluate heat transfer, permeability,

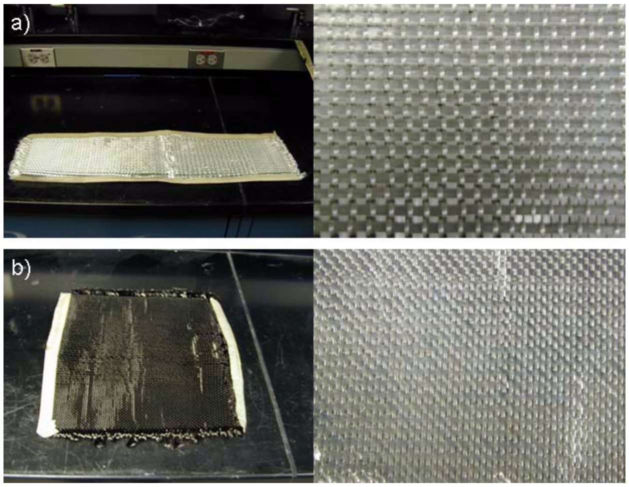

Figure 2. Samples of (a) Fiber Glass and (b) Low Modulus/Low Thermal Conductivity Carbon Fiber (3-Weave) Fabrics

and pressure drops associated with experimental graphite foams and woven preform structures. Results will be used to optimize the pore structures of foams and fiber preforms to maximum performance and to verify model predictions.

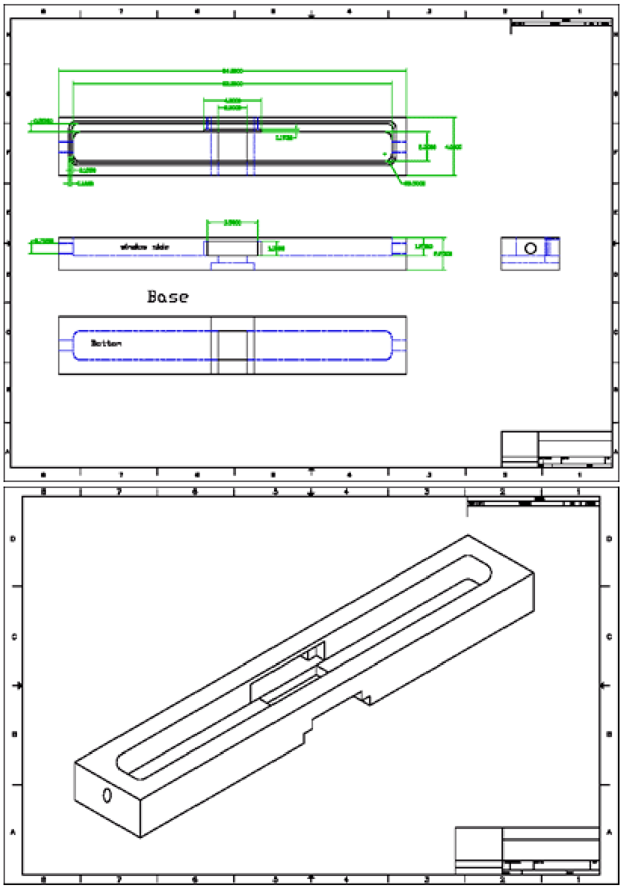

Figure 3. Oak Ridge National Laboratory Heat Transfer and Pressure Drop Test Rig

Conclusions

The outstanding thermal properties of graphite foam have prompted efforts to investigate the feasibility of using carbon fiber preforms in thermal management applications. These materials are expected to have high specific conductivity and low density creating systems with high heat removal and low mass with lower costs and higher mechanical strength than carbon foam systems. Devices fashioned using woven graphite fiber preforms are currently being designed and evaluated in coordination with modeling efforts and testing to gain a better understanding of the effect of heat exchanger material microstructure on gas flow penetration, pressure drop, and mechanical strength. A commercial weaving company has been identified as a partner in the project to utilize its unique weaving process (3-Weave) which is capable of producing 3-dimensional fiber preforms. Currently, a series of preforms are being woven using 50 Msi/lower thermal conductivity fibers with and without metallic tubing incorporated in the structure. These materials will be evaluated, with subsequent weavings being attempted with higher modulus/higher thermal conductivity fibers.

Future work will focus on:

- the synthesis of structures with larger pore structures and higher mechanical strengths to minimize pressure drops and increase durability,
- testing of heat transfer and permeability of preform structures and modified graphite foams,
- numerical modeling of the effect of fiber architecture or microstructure on permeability and heat transfer characteristics of woven fiber structures and graphite foams, and
- development of hybrid woven fiber structures to optimize cost, thermal properties, permeability and mechanical durability.

FY 2004 Publications/Presentations

1. B. E. Thompson and A. G. Straatman, "Modeling of Porous-Carbon-Foam Heat Exchangers", AGS Scientific Inc. (2003).

Special Recognitions & Awards/Patents Issued

1. Graphite Fiber-based Thermal Management System Components: Report of Invention, Oak Ridge National Laboratory. April 2004.