# Graphite-based Components for Thermal Management in Fuel Cell Systems

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This presentation does not contain any proprietary or confidential information

Project ID # FCP20

# Overview

## Timeline

- Project start: 11/03
- Project end: 9/06
- Percent complete: 50%

## Budget

- Total project funding
  - DOE share
  - Contractor share
- FY04 Funding: $129K
- FY05 Funding: $132K*

## Barriers

- Barriers addressed

  DOE Technical Barriers for Transportation System Fuel Cells
  - Thermal management and heat utilization (C. and F.).
  - Vehicle size, weight, cost and durability

## Partners

- 3-Tex Inc., University of Western Ontario

*Project activities are being leveraged with an DOE/DE-funded project. Progress in FY05 was slowed by delay in receiving funds.

# Objectives

To develop compact, low-weight, high-effectiveness thermal management system components for fuel cell power systems using carbon-based materials.

## For FY05

- To design, and evaluate 3-D woven graphite fiber structures for application as thermal management system components.
  - Assess the effect of pore size on heat transfer, permeability and mechanical strength of 3-D graphite fiber woven structures
  - Evaluate the effect of fiber architecture on the heat transfer and permeability of 3-D graphite fiber woven structures.
- To identify the fabric architecture that optimizes the physical and thermal performance of 3-D graphite fiber woven structures
- To construct a scaled prototype radiator for a fuel cell system.

# Objectives

| **Requirement** | **Specification*** |
|---|---|
| Heat Rejected from Coolant | 130 kW |
| Coolant Inlet Pressure | 1.7 to 2.0 bar |
| Coolant Flow Rate | 160 LPM |
| Coolant Inlet Temperature | 90$^{o}$C |
| Maximum Coolant Outlet Temperature | 73$^{o}$C |
| Maximum Coolant Pressure Drop | 0.7 bar |
| Maximum Vibration | 5 g @ 10-1500 Hz |

size:
550 x 350 x 25 mm

lifetime:
>10,000 hours

*Specifications developed by ORNL in collaboration with Ballard

# 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.
- Produce prototype thermal management devices to meet specifications given by industrial collaborators.

# Project Timeline

| 11/03-4/04 | 5/04-9/05 | 10/05-9/06 |
|---|---|---|
| Phase I | Phase II | Phase III |
| 1 2 | 3 4 5 6 | 7 8 |

## Phase I. Feasibility

1. Assess ability to weave high-stiffness fibers into 3-D architectures. (Go)
2. Fabricate woven fiber structure prototypes. (Go)

## Phase II. Development, Testing and Evaluation

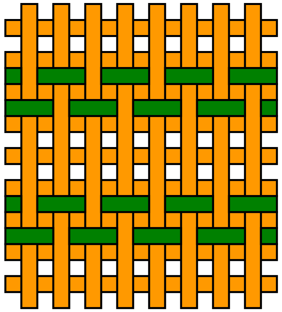
3. Evaluate effect of fiber architecture or microstructure on permeability and heat transfer of woven fiber structures. (In Progress)
4. Complete numerical models of effect of fiber architecture or microstructure on permeability and heat transfer characteristics of woven fiber structures. (In Progress)
5. Develop hybrid woven fiber structures to optimize cost, transport properties and mechanical durability. (In Progress)

## Phase III. System Design and Testing

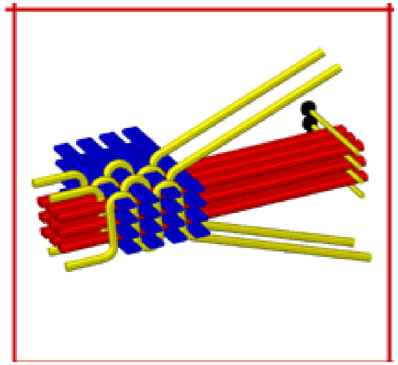
7. In collaboration with fuel cell developers and users, design and fabricate pilot versions of thermal management system components for testing and evaluation.
8. Transition technology to industry.

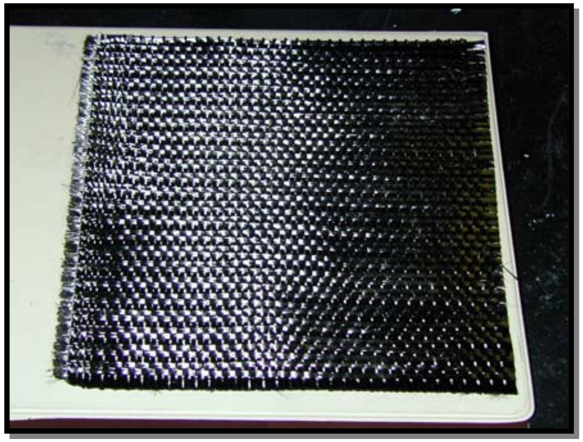
# Technical Accomplishments

## Graphite Fiber Weaving



- Technologies have been identified for weaving graphite fiber structures with complex three-dimensional architectures*.
- These technologies have be utilized to produce tailored structures with controlled pore structure, permeability and thermal properties.



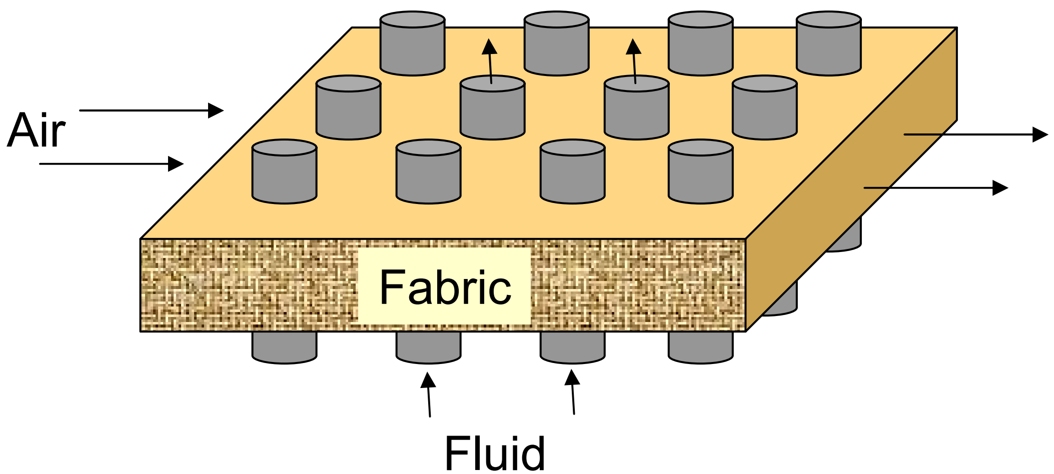


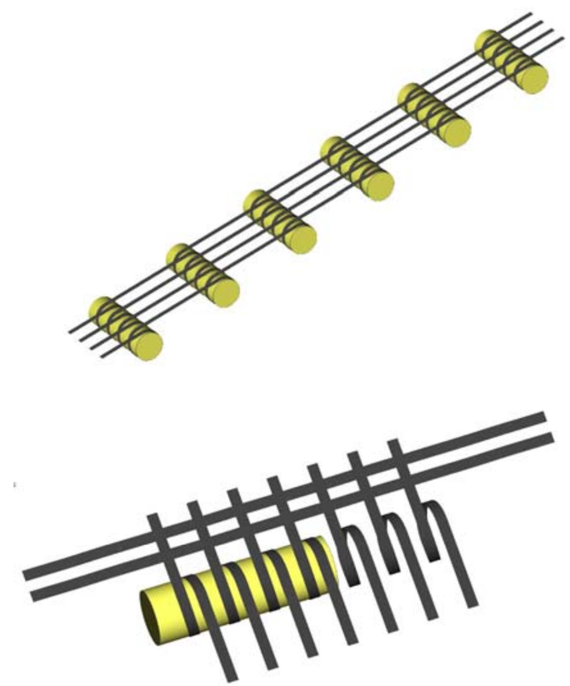
* 3-Tex 3Weave

# Technical Accomplishments

## Graphite Fiber Weaving

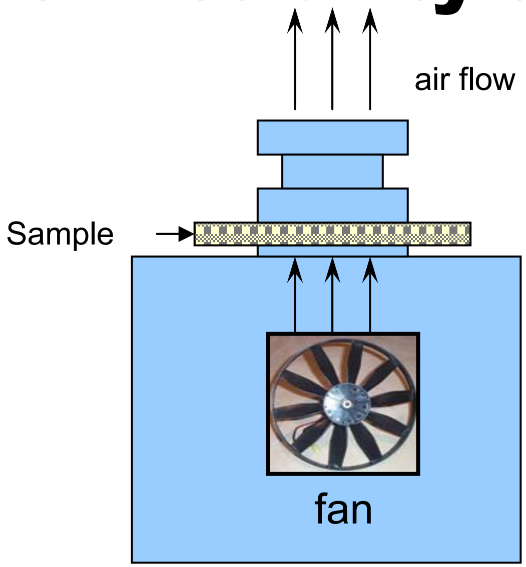
- Methods have been developed for weaving graphite fibers around tubular structures.
- Work is in progress to optimize fiber/fiber and fiber/tub interface.

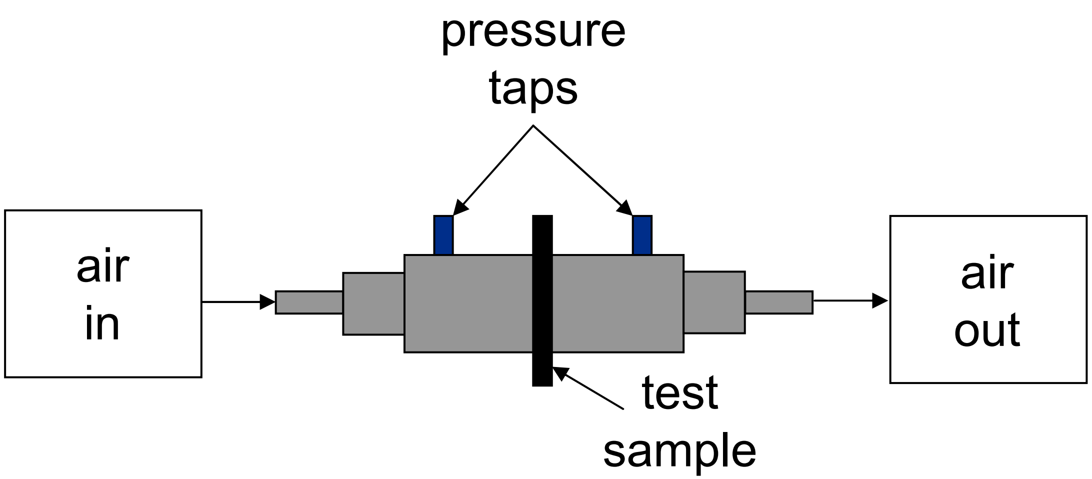


# Technical Accomplishments

## Permeability and Pressure Drop



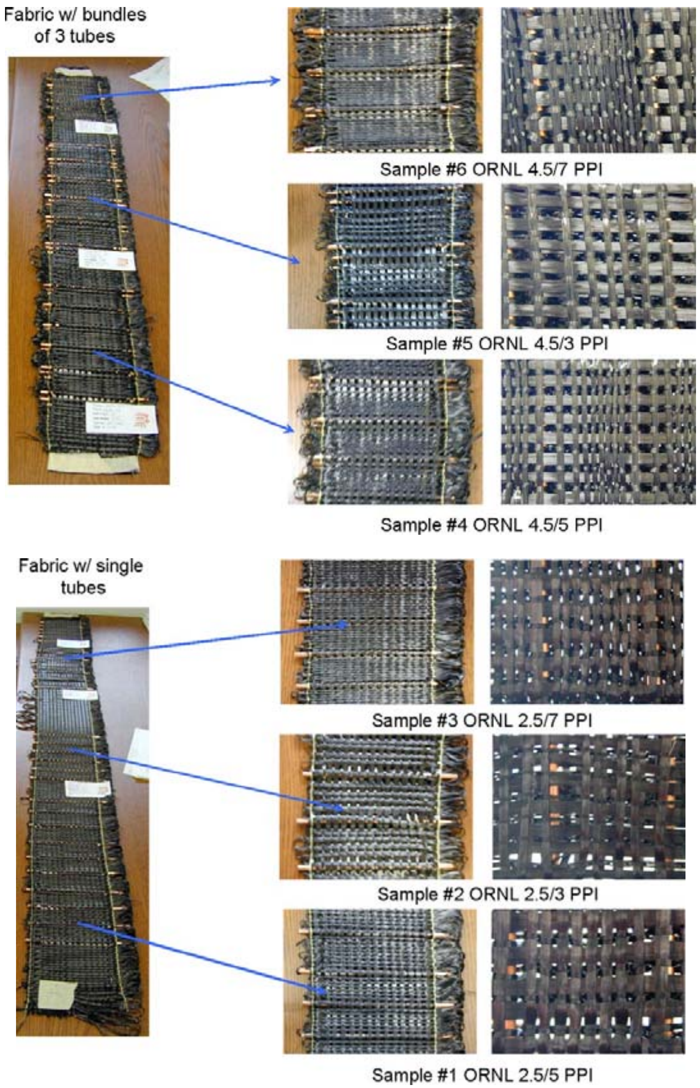



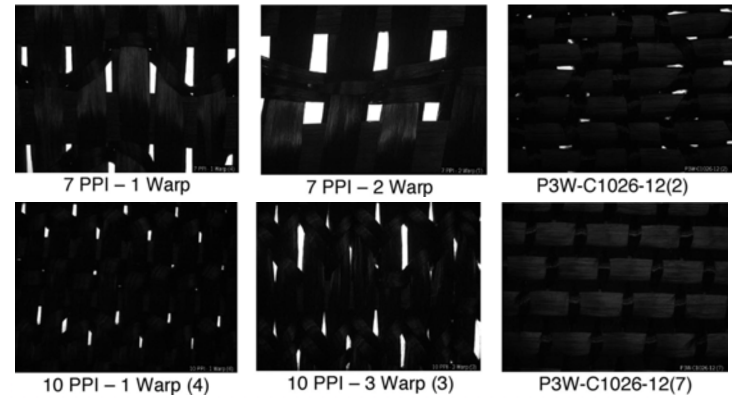

Permeability Test Set-Up

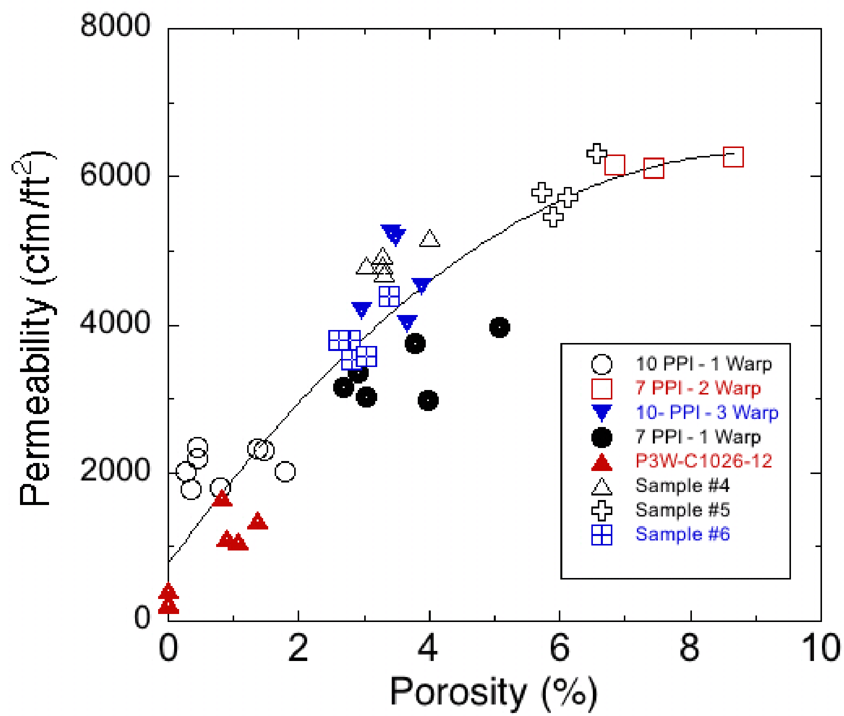
Pressure Drop Test Set-Up

- Methods have been identified or developed for evaluating permeability and pressure drop of woven graphite fabric structures.

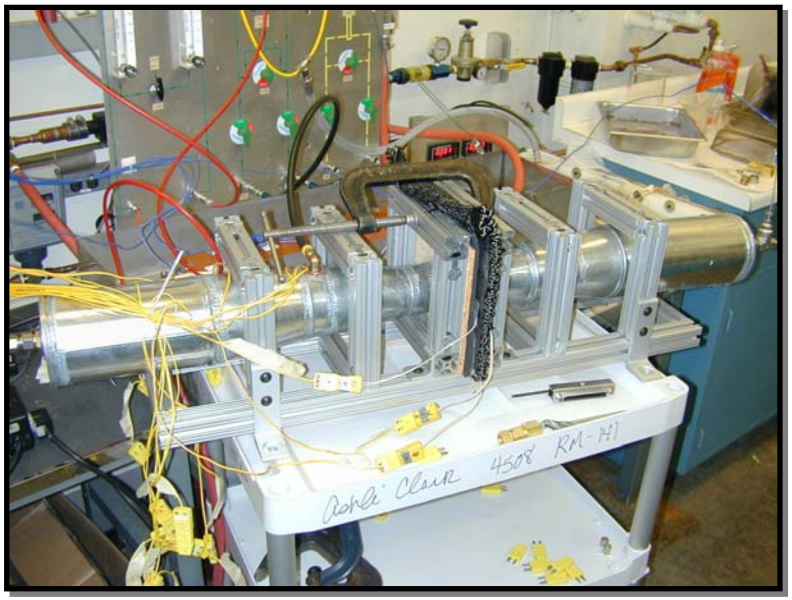
# Technical Accomplishments **Permeability**

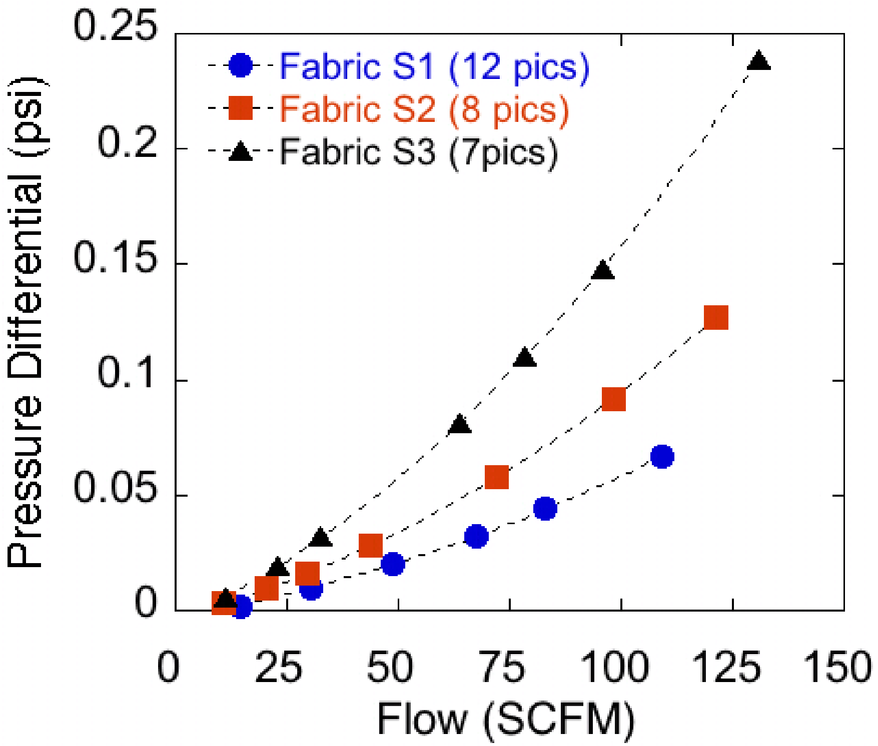


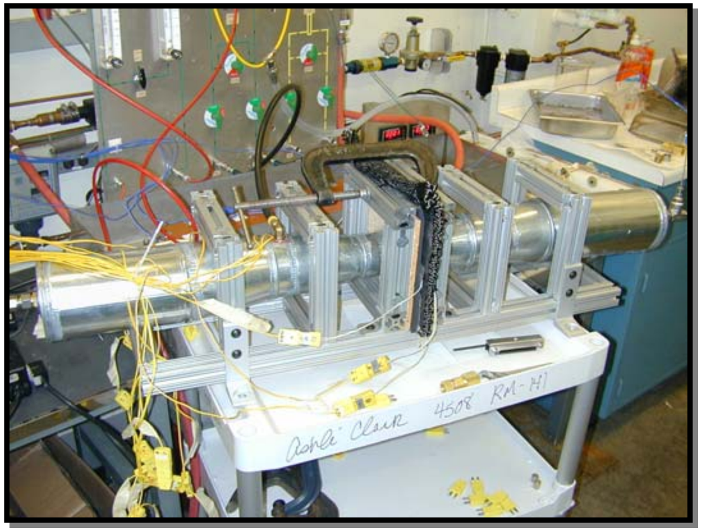



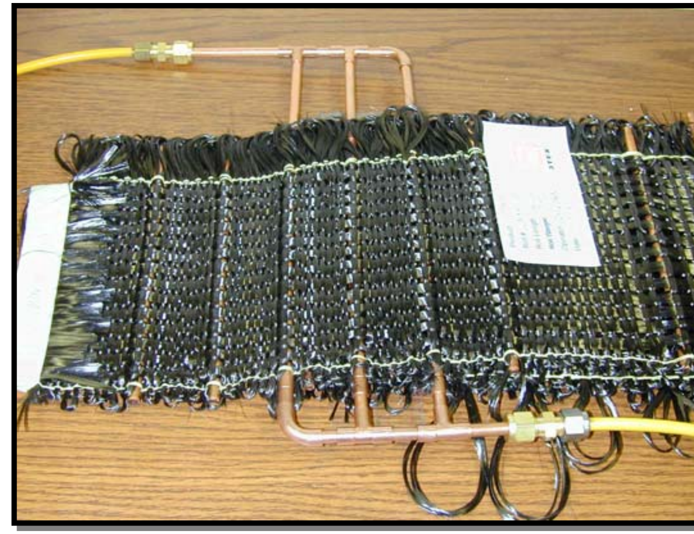
# Technical Accomplishments **Pressure Drop**



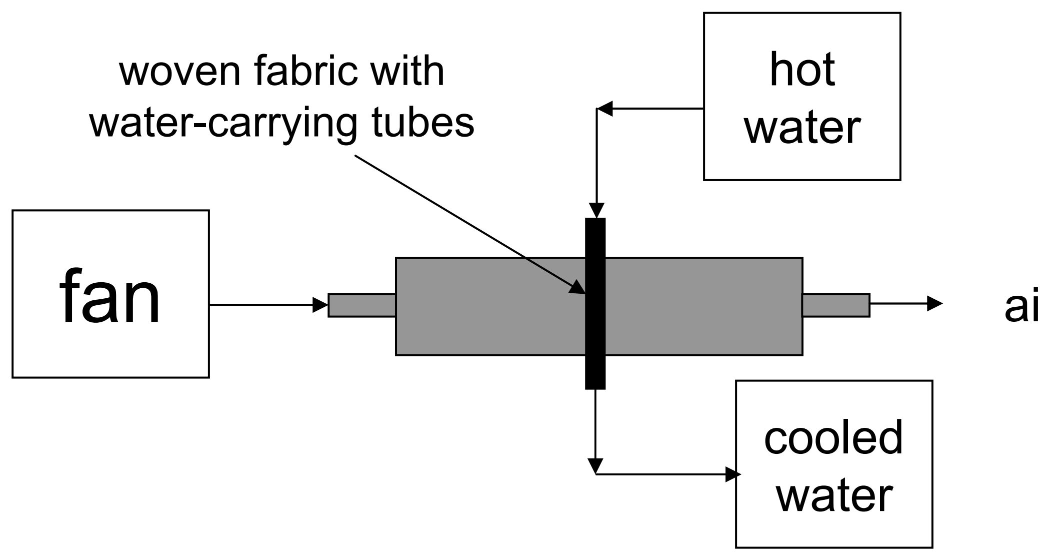



# Technical Accomplishments **Heat Transfer**



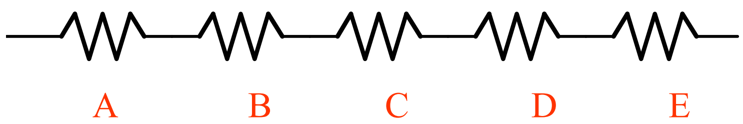


A method has been developed to evaluate the thermal performance of woven graphite fiber structures containing metallic tubing.

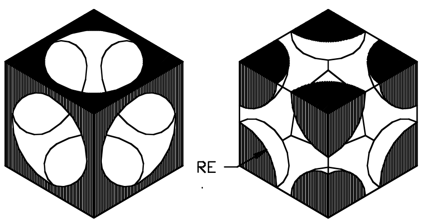


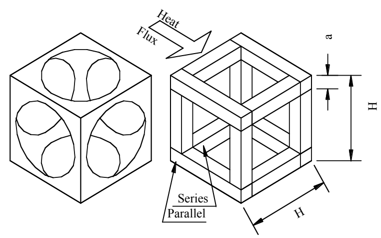
# Technical Accomplishments

## Modeling




| | |
|---|---|
| A | Convective resistance of water |
| B | Conductive resistance due to the metal tubing |
| C | Conductive resistance due to tube/HTM contact |
| D | Conductive resistance due to HTM |
| E | Convective resistance of air |




$$K = \frac{\varepsilon^3 D E^2}{147(1-\varepsilon)^2} \qquad K = \frac{36\varepsilon^3}{147\beta^2}$$

$$ke = \frac{\left(4a^2 + H^2(1-t)^2\right)\dfrac{\sigma + \left(\frac{1}{t}-1\right)^2 k_f}{1+\left(\frac{1}{t}-1\right)^2} + 4aH(1-t)\dfrac{k_s}{(1-t)\sigma + t}}{H^2(1+t)}$$

- Collaboration with Professor Brian Thompson of the University of Western Ontario (through a DOE-DER sponsored project).
- Engineering models are being developed to provide thermal resistance and pressure drop in air-water heat exchangers with periodic microstructures

# Response to Reviewer's Comments

- Project needs to identify a partner who will do real-world validation of component performance.
  - ❖ A collaboration was established with Ballard to test a prototype woven graphite fiber-based radiator in conjunction with a fuel cell.
- Work to improve thermal contact between fibers should be added.
  - ❖ Work was initiated in FY05 to identify and utilize materials (e.g.- conductive epoxies) that maximize heat transfer between the woven fibers and the metallic tubing.
- Project will need to address costs soon
  - ❖ One key to controlling cost of the woven components will be to optimize the properties of the fabric by utilizing high grade (more expensive) fibers only in select directions where maximum heat flow will be needed and utilizing lower grade (less expensive) fibers in other directions. Projections based on volume are being developed.

# Future Work

- Remainder of FY 2005
  - Further characterize the thermal and hydraulic properties of woven graphite fiber fabrics and optimize structure through modeling.
  - Initiate design and manufacture of a scaled prototype radiator for fuel cell according to specifications provided by industrial collaborator and the results of optimization models.
- FY 2006
  - In collaboration with fuel cell developers and end users, design and fabricate scaled prototype versions of thermal management system components for testing and evaluation and transition technology to industry

# Project Safety

- Project activities are covered by a formal, integrated work control process for each practice/facility.
  - Definition of task
  - Identification of hazards
  - Design of work controls
  - Conduct of work
  - Feedback
- Each work process is authorized on the basis of a Research Safety Summary (RSS) reviewed by ESH subject matter experts and approved by PI's and cognizant managers.
- RSS is reviewed/revised yearly, or sooner if a change in the work is needed.
- Staff with approved training and experience are authorized through the RSS.
- Activities involve the use of gases (< 100 psi), hot-surfaces (< 300°C), small-diameter fiber and low-voltage instrumentation.

# Hydrogen Safety

The most significant hydrogen hazard associated with this project is:

N/A

# Hydrogen Safety

Our approach to deal with this hazard is:

N/A