High Thermal Conductivity Carbon Foams for Fuel Cell Radiators

by Dr. James Klett

Metals and Ceramics Division
P.O. Box 2008, Oak Ridge National Laboratory
Oak Ridge, Tennessee, 37831-6087
(423) 574-5220
klettjw@ornl.gov
www.ms.ornl.gov/cimtech/cimtech.html

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Objective

- To utilize high thermal conductivity foam to develop a heat exchanger/ heat exchanger system for fuel cell stacks which is significantly lighter and more efficient.

Approach

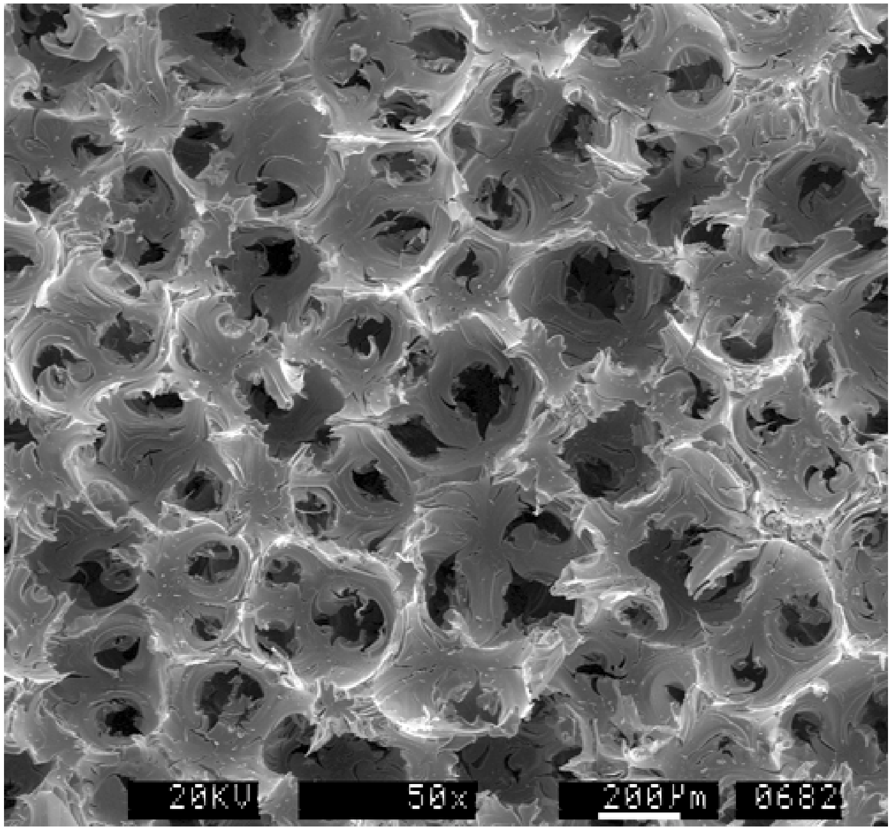
- To apply existing knowledge of foams as heat exchangers developed for power electronics and study potential systems for fuel cells with minimal pressure drop, minimum volume, and maximum efficiency.

Time Line

- Project Funded in October, 1999
- Initial work in contacting commercial partners and potential collaborations
- Work on gathering data on heat transfer coefficients and design opportunities
- Work is proceeding on developing initial radiator concepts, construction of prototypes, and testing.

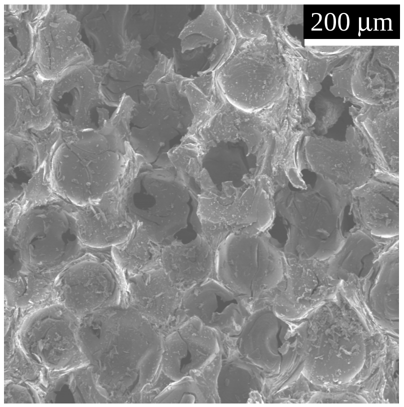
ORNL Mesophase-Derived Graphitic Foam

- Graphitic ligaments
  - Graphitic-like properties (high κ, E, σ)
- Dimensionally stable, low CTE
- No outgassing
- Open Porosity
- Excellent thermal management material

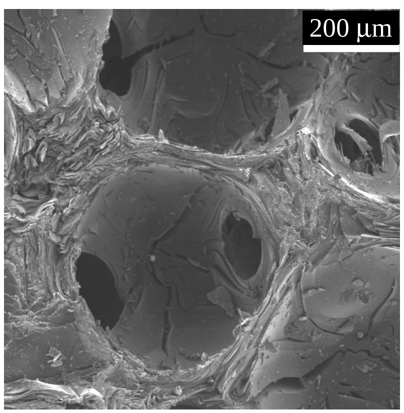


High Thermal Conductivity Graphite Foams

Domestic Precursor
Conoco Mesophase
FOAM A



Foreign Precursor
AR mesophase
FOAM B



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	ORNL Foam A	ORNL Foam B	Aluminum 6061	Copper	
Physical Properties					
Density	0.58	0.56	2.88	8.9	g/cm^3
Porosity	0.73	0.75	0	0	
Fraction Open Porosity	0.98	0.98	0	0	
Average Pore Diameter	60	325	0	0	microns
Coefficient of Thermal Expansion	--	4	24	16.5	ppm/°C
Max Operating Temperature in Air	500	500	600		°C
Mechanical Properties					
Tensile Strength	--	1.0	337	69	MPa
Tensile Modulus	--	1.0	69	130	GPa
Compressive Strength	5.0	3.45	330		MPa
Compressive Modulus	0.18	0.14	69		GPa
Thermal Properties					
Bulk Thermal Diffusivity	3.11	4.53	0.81	1.17	cm^2/s
Bulk Thermal Conductivity	127	175	180	400	W/m·K
Specific Heat Capacity	691	691	890	384	J/Kg·K
Bulk Specific Thermal Conductivity	218	313	63	45	$(W/m\cdot K)/(g/cm^3)$

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James Klett
865-574-5220
klettjw@ornl.gov

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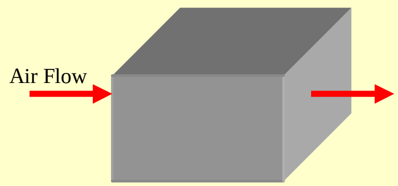
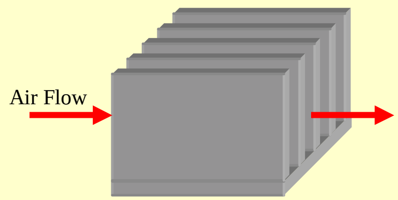
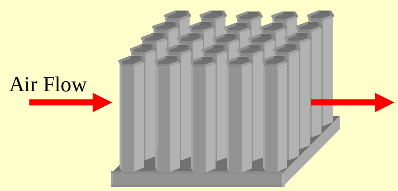
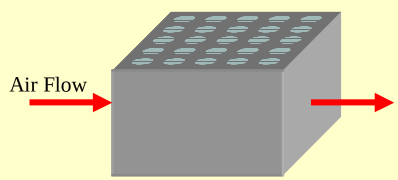
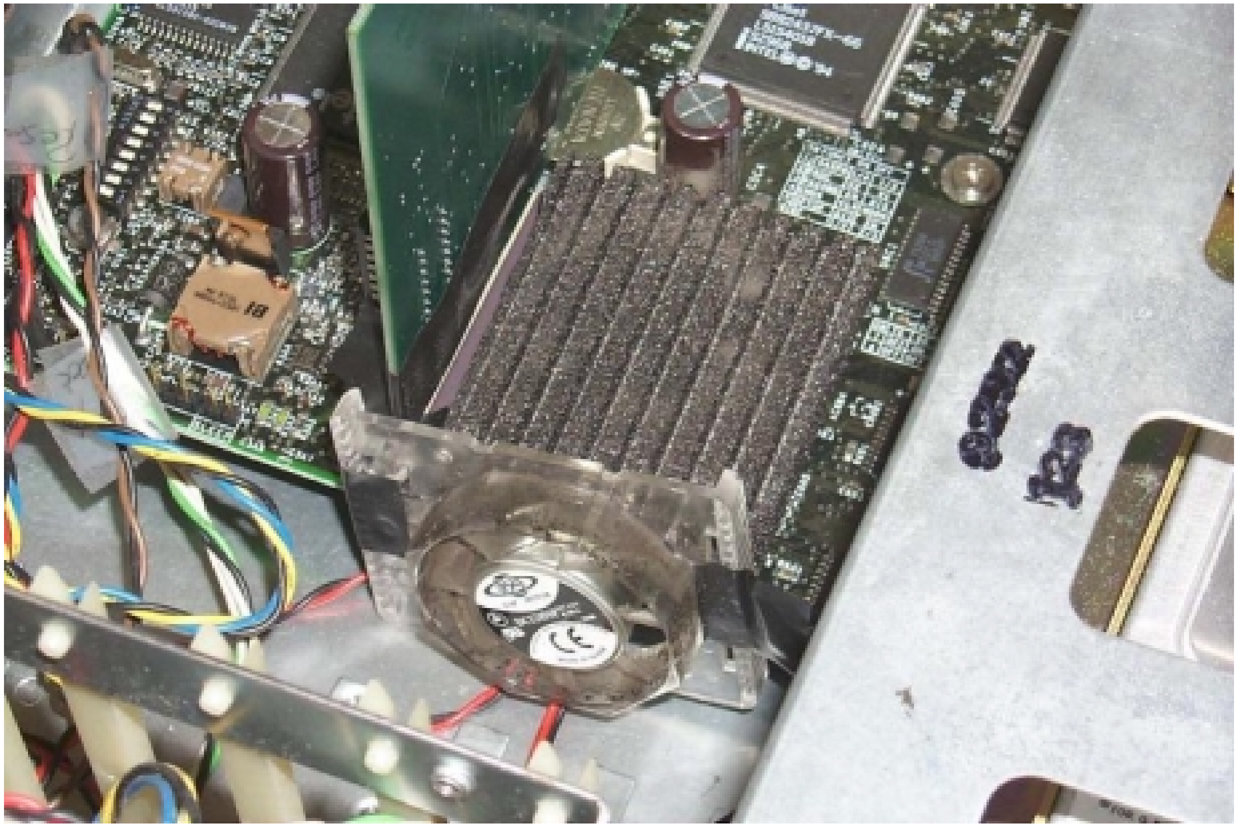
Heat Transfer as a Heat Sink with Air Cooling

	Heat Transfer Coefficient h, ($W/m^2 \cdot K$)	ΔP/L (psi/in)
Solid Foam 	3000*	2
Finned 	1000*	<0.05
Pin-Fin 	1500*	0.05
Blind-holes (pin fin negative) 	3500*	1
Copper Pin-Fin	500	0.05

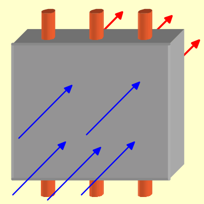
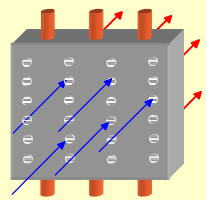
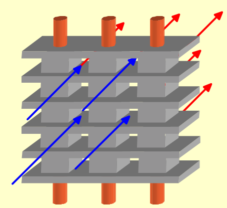
* Preliminary Data

Actual devices

- Finned foam heat sink running in Pentium 133 computer since December 12, 1998.

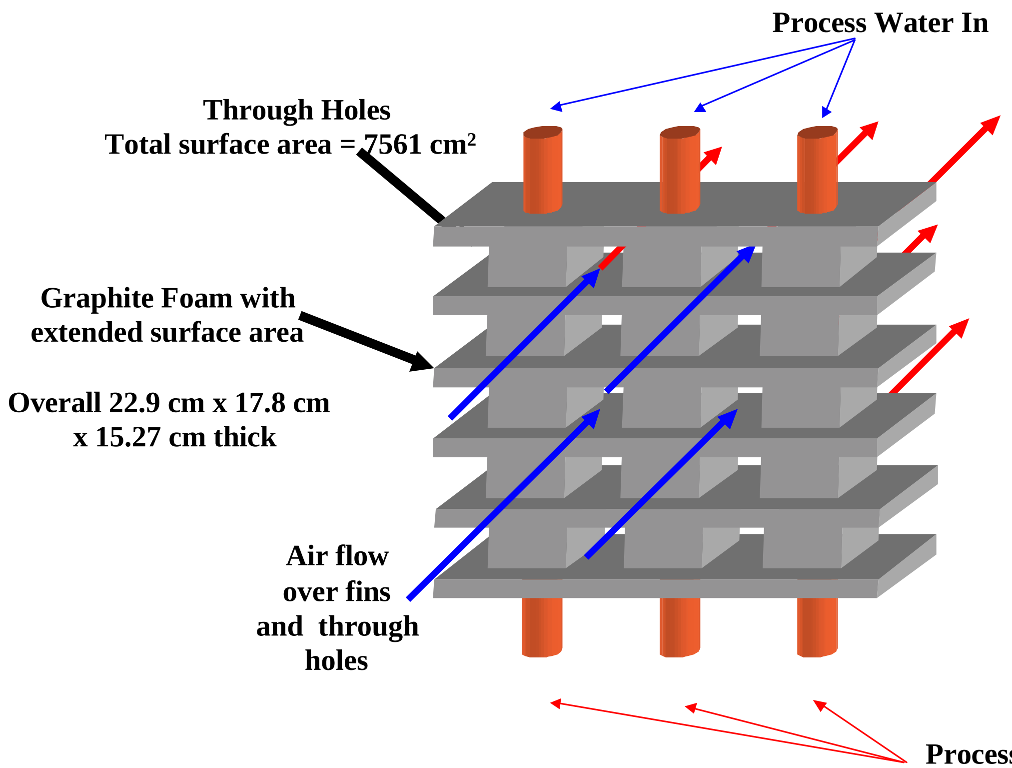


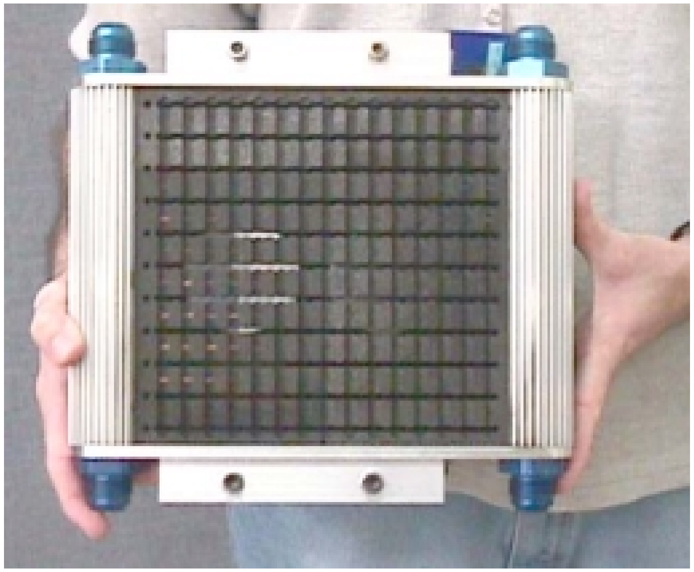
Heat Transfer as a Radiator Design

	Heat Transfer Coefficient h, ($W/m^2 \cdot K$)	$\Delta P/L$ (psi/in)
Solid Foam 	10,000*	2
Through-holes 	1,000*	1
Finned 	1,000*	0.05
Current Radiator	30	<0.05

* Preliminary Data

Prototype Radiator Demonstrated





Measured U_o **= 1000 W/m^2 ·K depending on air humidity**

Similar design built for 800 hp racing engine

Next Generation Radiators

- Several more radiators will be tested in the near future
- These tests will be designed to gather important data about finned surface area, joining techniques, air flows, heat transfer coefficients, etc.
- From these tests, research will begin on integrating the foam into a radiator for fuel cell applications.
  - Better manufacturing methods
    - Don't limit heat transfer
    - Reduced pressure drop
    - Reduced volume and increased efficiency
  - Vibration analysis
  - Corrosion/erosion analysis
- Alternative uses/designs
  - Combine humidification of inlet air with cooling of radiator

Main Issues with Fuel Cells and carbon foam cooling

- Temperature difference between cooling fluid and ambient is smaller
  - External fin surface area is more critical than ever
  - External heat transfer coefficient is more important than before

- Large water flows due to required small thermal gradient through fuel cell

- Parasitic losses very critical

- Position in vehicle an issue

Industrial Interactions

- Discussions with potential partners have been successful in generating significant interest in the radiator community.
  - Modine,
  - Valeo,
  - Ricardo,
  - Honeywell,
  - Visteon

- Discussions on licensing is ongoing

Major Milestones

- Demonstrate concept of reduced size and improved efficiency
  - 9/00
- Industrial interaction for critical input and partnering on designs
  - 9/00
- Demonstrate improved radiator concept, >50% improvement in heat transfer to weigh ratio
  - 9/01