High Thermal Conductivity Graphite Foams for Compact Lightweight Radiators

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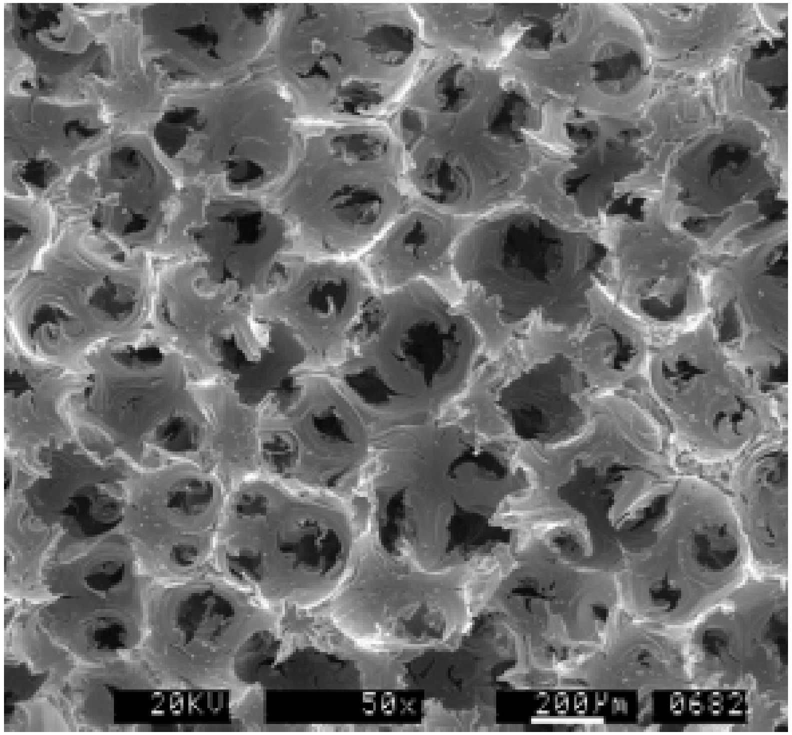
ORNL High Conductivity Graphitic Foam

- Highly ordered graphitic ligaments
  - Ligament Thermal Conductivity >1700 W/m·K
  - Apparent bulk conductivity >180 W/m·K
- Dimensionally stable
  - Low CTE - ~2 - 4 μin/in/°C
  - Low modulus
- Open Porosity
  - Permeable to fluids
  - High surface area
  - High heat transfer coefficients
- Excellent thermal management material

2000 R&D 100 Award Winner



Questions and Suggestions from FY2001

- Questions?
  - How do you join the foam
  - Thermal cycling issues?
  - Durability, Corrosion, and Vibration?
    - On-road conditions?

- Suggestions
  - Conduct environmental characterization
  - Attempt to address cost
  - Work closer with industry

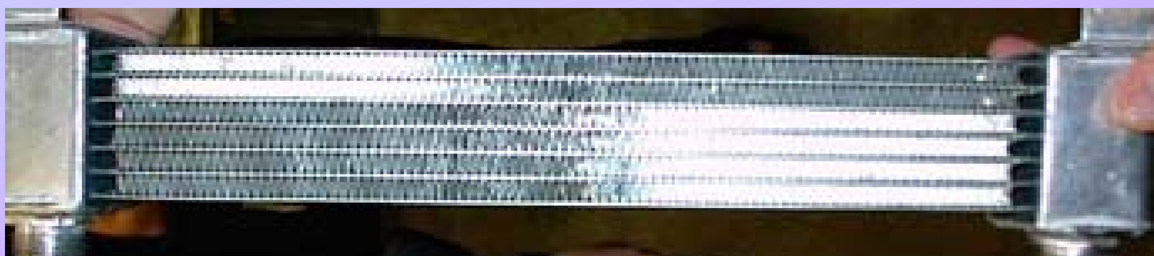
History of Program

- Graphite Foam work began 1998 – primarily for power electronic heat sinks.
- Carbon foam for Radiators began in April 2001
  - Lower ΔT between coolant and ambient
  - Harder to reject heat
  - Larger radiators, larger drag
- Compact ultra efficient radiators are needed
  - CRADA begun with major radiator manufacturer to explore the use of the foam
  - Co-funded with OHVT, so a diesel engine manufacturer and a heavy truck manufacturer joined the CRADA

Flow-By Design

Graphite Core rejects 34% more heat than High Performance Radiator used by Racing Industry

C&R Aluminum Core



Louvered Aluminum Fins

Core size = 12 in. x 3 in. x 1.5 in.

Overall Surface Area = 0.71 m^2

Heat Dissipation = 6 kW

Graphite Foam Core

Machined Carbon Foam Fins

Core size = 12 in. x 3 in. x 1.5 in.

Overall Surface Area = 0.42 m^2

Heat Dissipation = 8 kW

Graphite Core has only 60% of the fin surface area

Compact Radiator Demonstrates High Efficiency

- **Demonstrated on a modified 1.9L Volkswagen modified to run on natural gas**

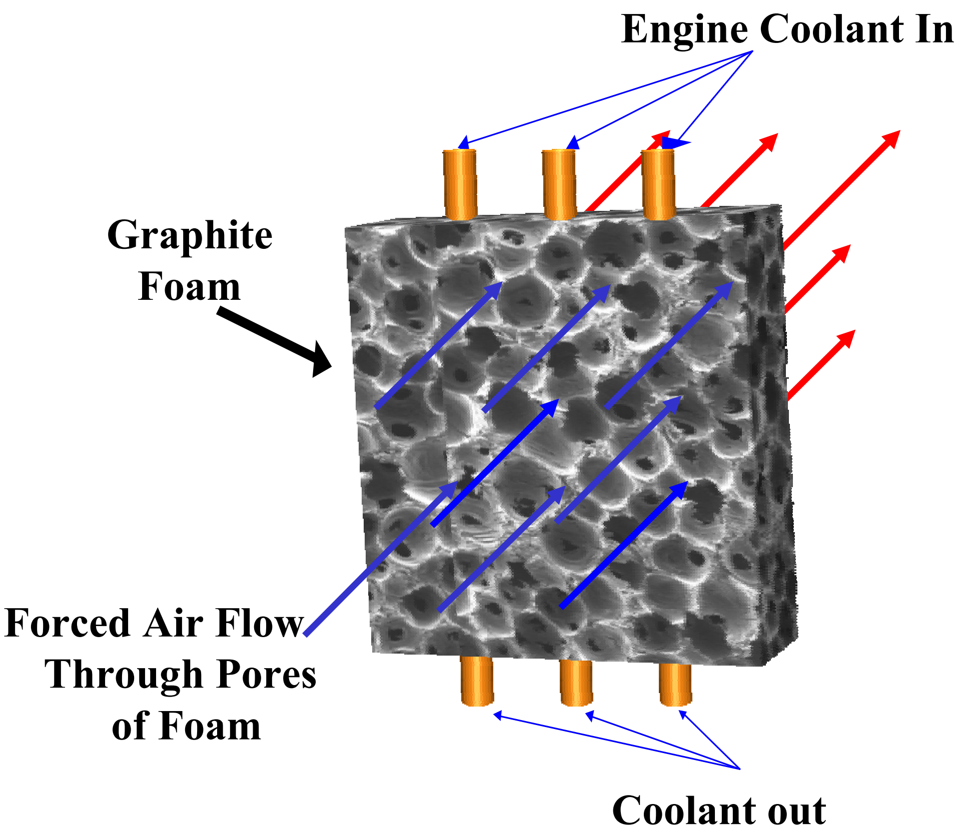
Standard Core
- Heat Rejected: 18.5 kW
- Efficiency: **23 W/in^3**

Graphite Core
- Heat Rejected: 17.6 kW
- Efficiency: **81 W/in^3**

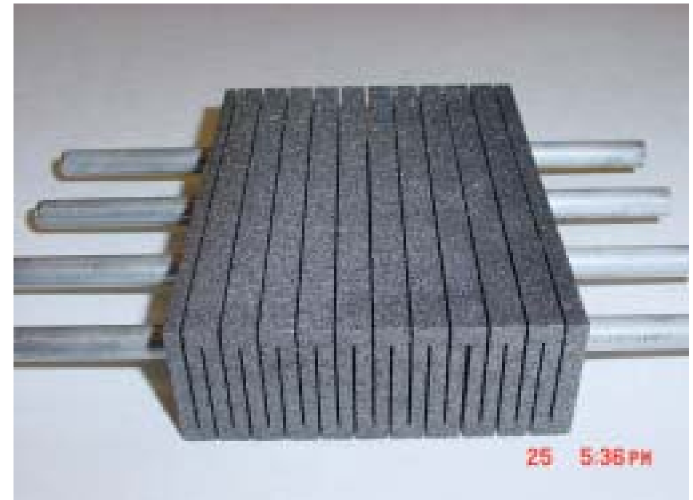
Graphite Radiator 350% more efficient than standard core

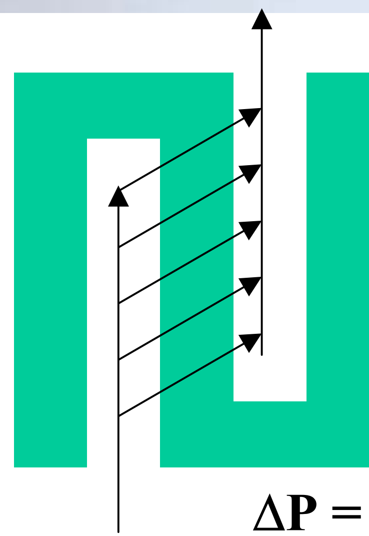
Flow-Through Design

Flow through porosity to enhance heat transfer



$\Delta P = 3.6$ psi



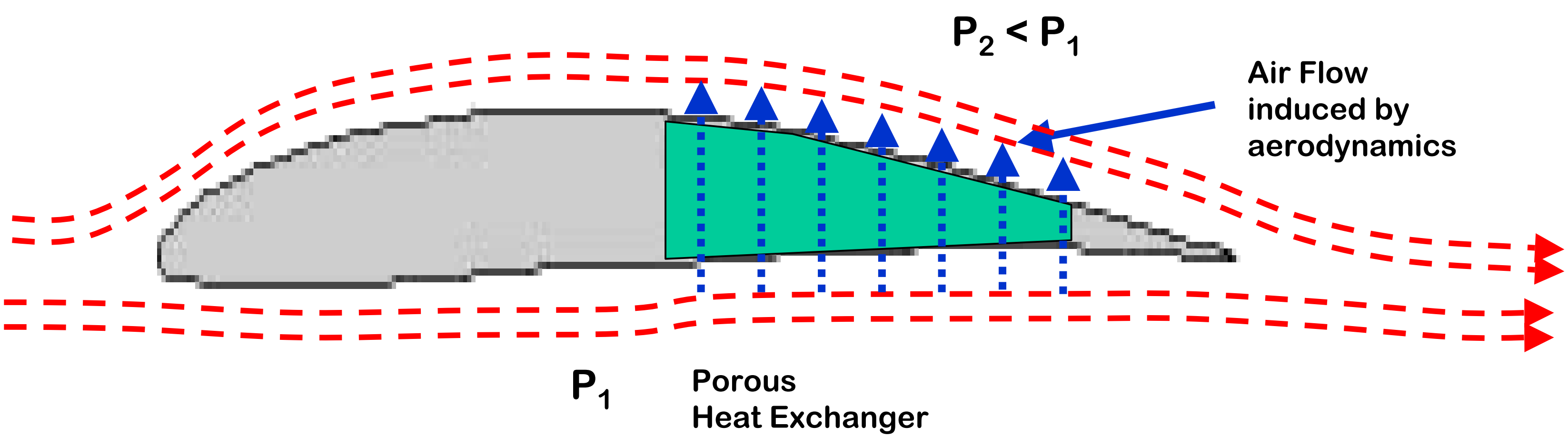


$\Delta P = 0.24$ psi

Combine best points of both systems

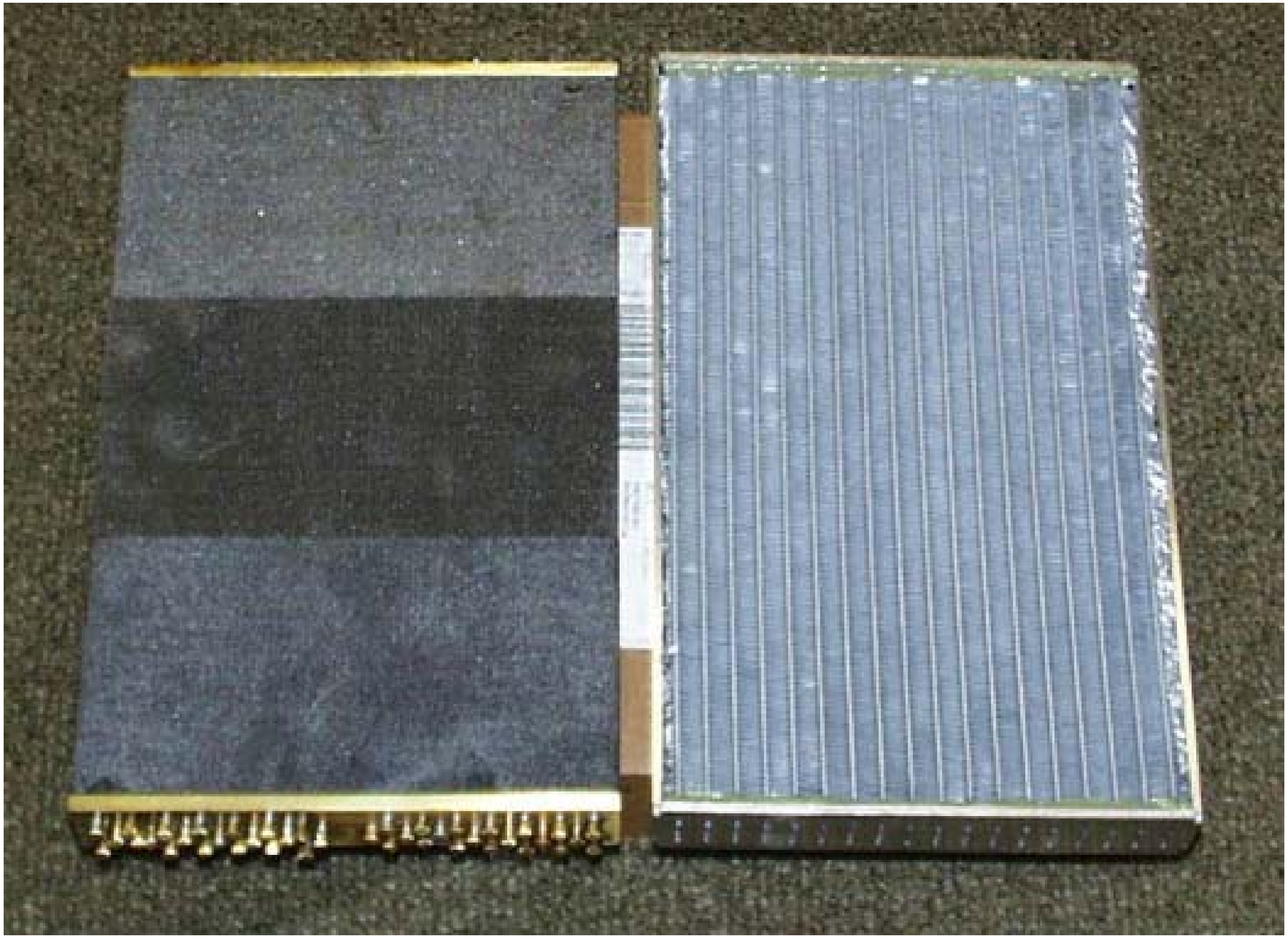
Optimized Air Foil Design

- By incorporating the heat exchanger into an air-foil, the system can be very efficient (Georgia Tech Research Institute).
  - Eliminate large drag induced by flat radiator in front of vehicle
  - Pressure difference across air-foil induces air flow through heat exchanger
  - Supplemental air flow or heat dissipation required at low speeds only



Concept by Georgia Tech Research Institute – Bob Englar, et al.

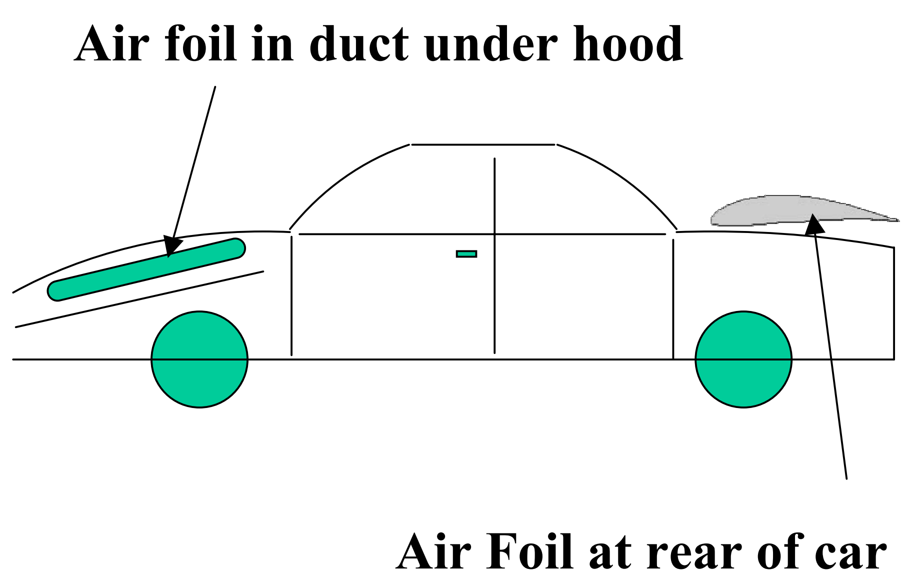
Final Heat Exchangers



Solid Corrugated

Aerodynamic Effects and Results

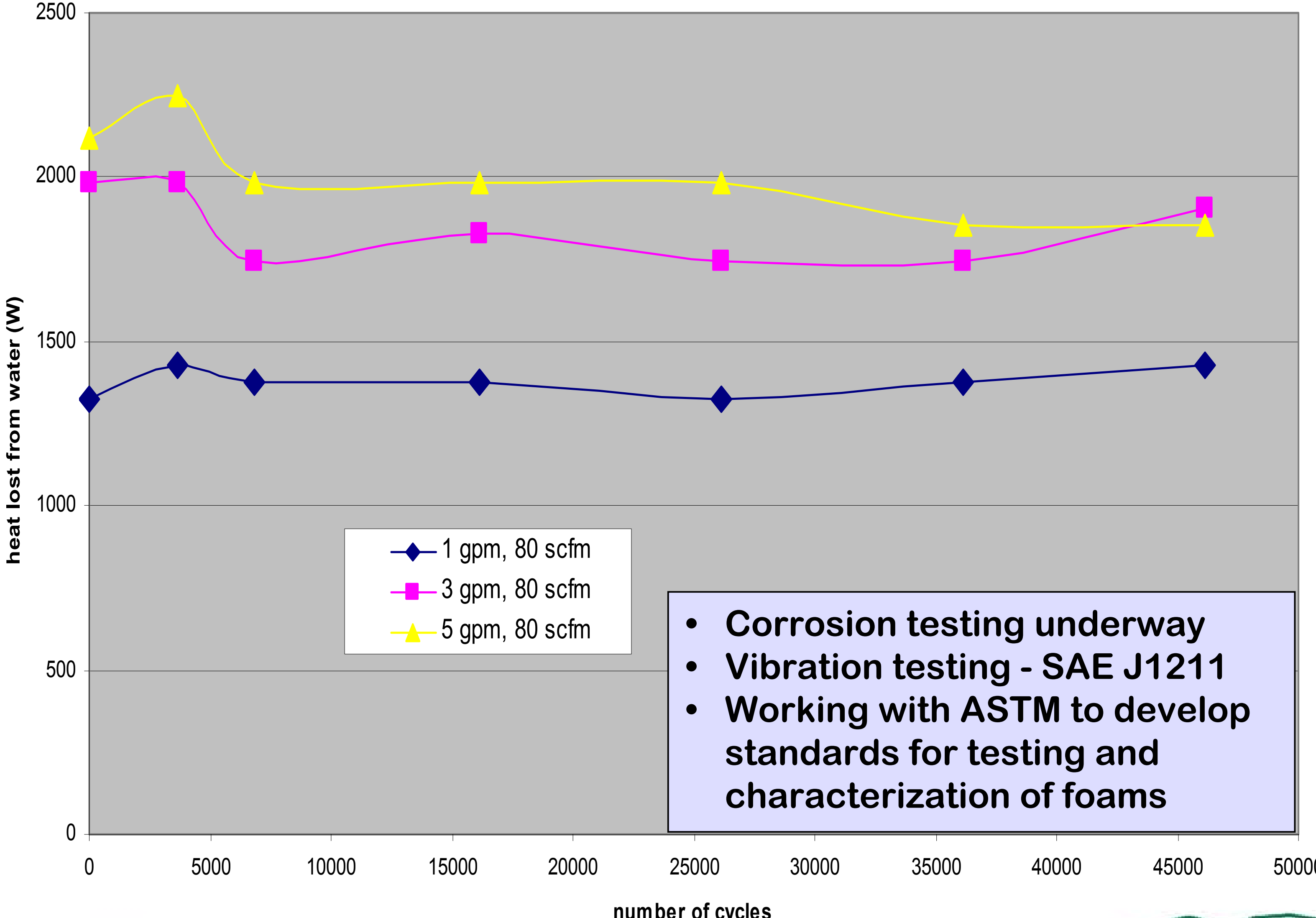
- Conventional radiator in front of car yields high pressure head and large drag coefficients
- Conventional radiator in airfoil yields high drag compared to normal airfoil
- Graphite foam core results in similar aerodynamics to that of normal airfoil
- Graphite core rejected as much heat as standard core, with significantly lower drag



Micro-Encapsulated Phase Change Materials

- **Combine all these designs with micro-encapsulated phase change cooling fluids developed at NC State University.**
- **Micro-encapsulated phase change materials allows heat to be adsorbed and desorbed at constant temperature.**
- **This allows more heat to be transferred from the fluid at a lower T while maintaining a constant fluid temperature throughout system.**
- **This results in about a 5C increase in temperature difference between hot fluid and air, yielding enhanced heat transfer.**

Thermal Cycling Effects



- Corrosion testing underway
- Vibration testing - SAE J1211
- Working with ASTM to develop standards for testing and characterization of foams

Conclusions

- Radiators have been fabricated and tested.
- High heat transfer coefficients of flow-by designs allow a reduction in size of the heat exchangers.
  - Demonstrated better heat transfer coefficients than high performance aluminum designs.
- Flow through designs have been demonstrated which are extremely efficient.
- Novel airfoil type heat exchangers present a unique opportunity to drastically reduce pressure drop while maintaining high heat transfer.
- Durability and Environmental testing is underway.

Future Work and Project End

- CRADA with Radiator Manufacturer expires in FY2004
  - Durability and Environmental studies
  - Core design for manufacturability
  - Full scale prototypes
    - Mass production
    - Joining
  - Perform full size and on-vehicle testing