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
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

- Carbon foam for Radiators began in April 2001
  - Lower $\Delta T$ 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 m²
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 m²
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/in³

Graphite Core
• Heat Rejected: 17.6 kW
• Efficiency: 81 W/in³

Graphite Radiator 350% more efficient than standard core
Flow-Through Design
Flow through porosity to enhance heat transfer

\[ \Delta P = 0.24 \text{ psi} \]

Engine Coolant In

Graphite Foam

Forced Air Flow Through Pores of Foam

Coolant out

\[ \Delta P = 3.6 \text{ psi} \]

\[ \Delta P = 0.24 \text{ psi} \]
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 5°C 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