The Use of Graphite Foam for Thermal Management in On-Board Fuel Reforming Processors (FASTER)

James Klett, April McMillan and Glenn Romanoski
Oak Ridge National Laboratory

Introduction: A collaborative effort has been undertaken within DOE Laboratories to demonstrate the feasibility of on board fuel processing for automotive fuel cell systems. The goal of the FASTER (Feasibility of Acceptable Start Time Experimental Reactor) project is to design, build and demonstrate an annular fuel processor that can start up within 60 seconds and generate reformate gas consisting of greater than 30% hydrogen and less than 50 ppm carbon monoxide. The FASTER project is led by Argonne National Laboratory (ANL). Pacific Northwest National Laboratory (PNNL) is providing a microchannel heat exchanger for the fuel reformer, Los Alamos National Laboratory (LANL) is providing preferential oxidation (PrOx) reactors for the removal of carbon monoxide, and Oak Ridge National Laboratory (ORNL) is providing five carbon foam heat exchangers for the water gas shift (WGS) and PrOx reactors.

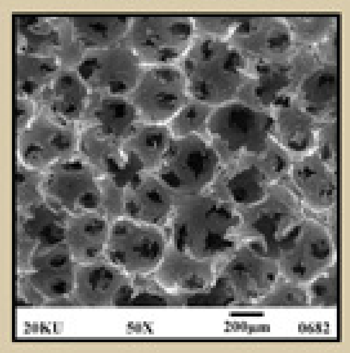
Approach

A CFD model was used to design an annular graphite foam heat exchanger capable of handling the heat duty and pressure drop requirements of the FASTER application. By utilizing high thermal conductivity graphite foam, with bulk thermal conductivities of 50 to 180 W/mK and an open celled structure, an effective heat exchanger was made.

Requirements
- Annular heat exchanger
- A pressure drop (ΔP) less than 0.1 psi
- Gas Flow – 300 slpm
- Two phase coolant flow (water/steam)
- Minimum of 100C temperature change in the gas stream

Novel Material

- Utilize graphite foam with high thermal conductivity ligaments
- Highly ordered graphitic ligaments
  - Near perfect graphite along ligament axis
  - Ligament conductivities of 1700 W/m·K (greater than polycrystalline diamond)
- Dimensionally stable
  - low CTE - ~2 - 4 min/in/°C
- Open porosity
  - Permeable to fluids
  - Surface area more than two orders of magnitude greater than diamond structure

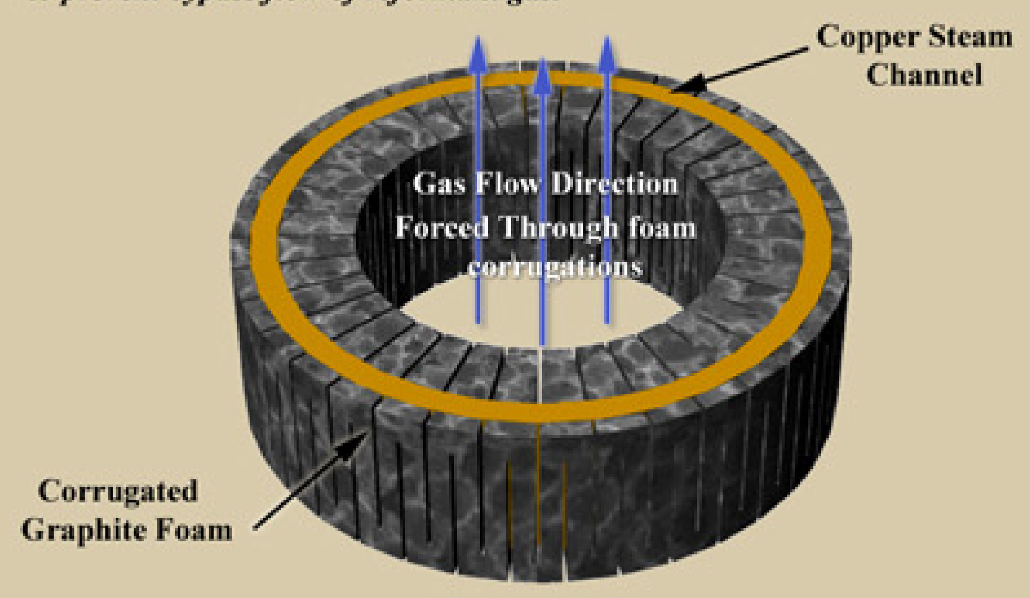


	Relative Density [%]	Ligament Conductivity [W/m·K]	Bulk Conductivity [W/m·K]
Aluminum Foam	25	180	15
Copper Foam	25	400	35
ORNL Graphite Foam	25	1700	170

Design

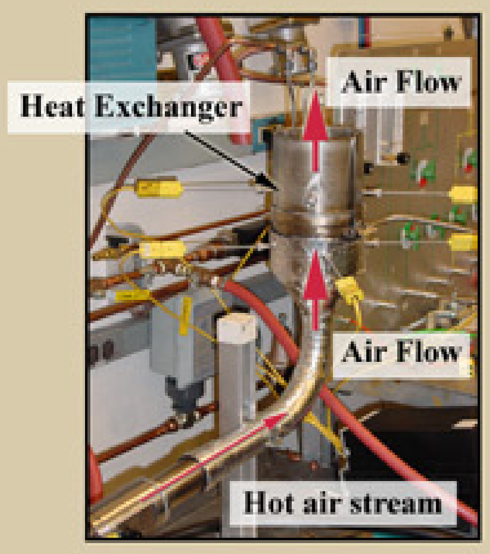
- An illustration of the graphite foam geometry is shown below.

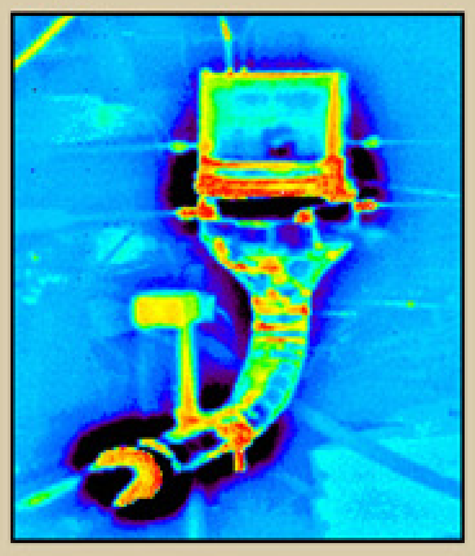
Radial slots were made 75% through the thickness of the annular graphite foam core but stopped short of the inside and outside cylindrical surfaces to prevent bypass flow of reformant gas.



Prototype

Testing



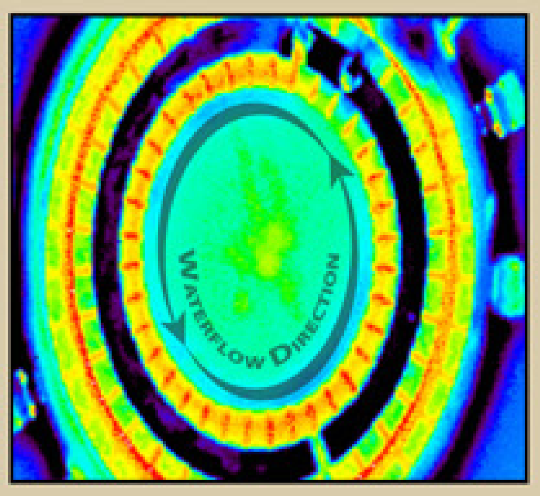


- Subscale test was developed to verify design
- Supply water at desired flow rate was delivered
- Air was preheated with 3 kW hot air gun modified to run on plant air
- Air flow was controlled to match the design requirements

Results

- Actual pressure drop (ΔP) less than 0.04 psi
- Gas flow – 307 slpm
- Two-phase coolant flow achieved
- Nearly 200°C gas temperature change
- 350°C inlet gas temperature
- 147°C outlet gas temperature

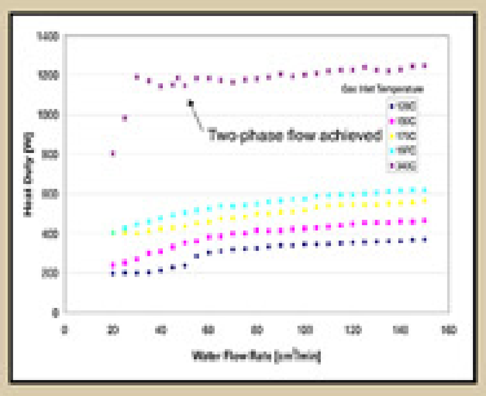
Infra-red Image of Heat exchanger illustrating uniform temperature distribution



Results

- Two phase flow maintained at almost all water flow ranges and inlet gas temperatures
- System will be very difficult to control with changing water flow
  - During two-phase flow, cold jacket remains at constant temperature
  - Constant temperature cold jacket means fairly constant heat duty
  - Heat Exchanger Effectiveness of >80% was achieved.
  - This is solely due to two phase flow and the added benefit of latent heat of vaporization

Plot of Heat duty versus water flow rate indicating two-phase flow (During two-phase flow, heat duty will remain constant as long as two-phase flow is maintained).



Conclusion

Graphite foam can be configured to provide light weight heat exchangers capable of heat duties in excess of 1KW while meeting the design constraints of the FASTER fuel reformer.

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