# Evaluation of Advanced Heat Recovery System


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## FAT Missions: using Graphite Carbon Foam (GCF)

To understand how GCF is best made to provide significant commercial benefits (cost, energy savings, and performance).

To design new products that use GCF either to provide significant competitive advantage or to create an entirely new market segment.

To respond to customer needs in the automotive, telephony, electronics, military, and energy sectors.

Current goal: To develop prototypes that quantify capabilities to satisfy customer needs in key markets, especially automotive, telephony, electronics, military, and energy sectors.

## Modeling: Geometry, thermal and hydraulic

Figure 1 (a) and (b) show the opened surface of the GCF made by Oak Ridge National Laboratory.

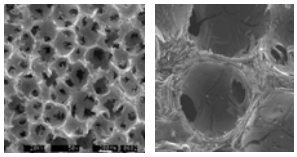

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Figure 1. (a) Electron micrograph of GCF surface; (b) Electron micrograph of GCF

A Unit Cube Geometry Model was developed to characterize the spherical void phase pore structure of the GCF. Solutions for the geometry and thermal-physical characteristic parameters, including the equivalent particle diameter, hydraulic diameter of the foam, pore window diameter, ligament diameter, internal surface area to volume ratio, effective thermal conductivity, permeability and Forchheimer coefficient, are derived from the Unit Cube Geometry Model. Figure 2 shows the a unit cube with a spherical void at its center.

Figure 2. GCF Unit Cube with a spherical void at its center

Figures 3 (a) and (b) are graphs of the exposed pore surface obtained by cutting the pore block shown in Figure 2 at a random location and angle.

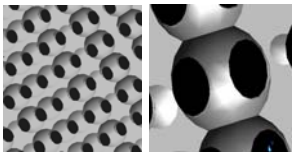

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Figure 3. (a) Exposed surface of a pore block; (b) Exposed surface of a single pore.

Figures 4 (a) shows the GCF enhanced surface attached onto a copper tube for heat recovery heat exchanger for microturbine CHP application; and (b) shows thermal resistance circuit.

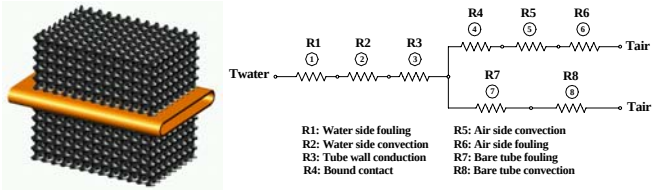


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Figure 4. (a) GFC enhanced surface attached onto copper tube; (b) Thermal resistance circuit

The air pressure loss $\Delta P$ across the GCF enhanced surface is determined by Darcy-Forchheimer law:

$$\frac{\Delta P}{L} = \frac{\mu}{K} V + \frac{c_f}{\sqrt{K}} \rho V^2$$

$L$ is the length of GCF along the flow direction. $\mu$, $\rho$ and $V$ are the air viscosity, density and velocity. $K$ and $c_f$ are the permeability and Forchheimer (form drag) coefficient.

## Benefits of Graphite Carbon Foam (GCF)

Consider the cases of forced convection heat transfer through blocks of uncompressed (Calmidi & Mahajan, 2000) and compressed (Boomsma et al., 2002) aluminum foam and porous GFC (Straatman et al., 2006) as shown in Figure 5.

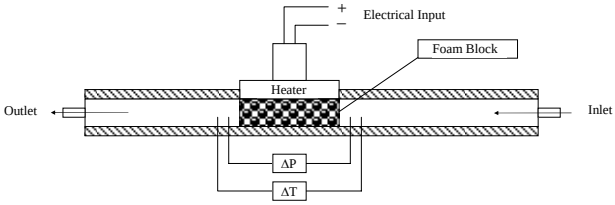


Figure 5. Teat set-up for GCF and aluminum foams

Porous GCF has a high potential for convective enhancement due to its highly porous, inter-connected void structure and its extremely high solid phase thermal conductivity.

Figure 6 shows that the heat transfer for uncompressed aluminum foam reaches its maximum for relatively thin layers due to its relatively low solid phase conductivity. The porous GCF shows a significant increase in heat transfer with increased thickness due to its extremely high solid phase thermal conductivity.

Figure 7 compares 2 mm-thick layers of compressed aluminum foams with 2 mm-thick GCF. Though the heat transfer for thin layers is comparable, if more heat removal is required, only the GCF yields significant increases in heat transfer with increased foam thickness.

Other advantages of GCF over aluminum foam include: lower density, higher compressive strength, and higher operating temperature (up to 500°C).

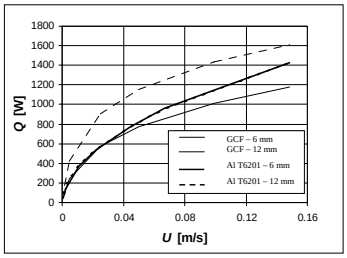


Figure 6. Influence of foam thickness on heat transfer for GCF and uncompressed aluminum foam

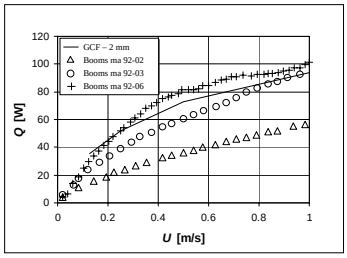


Figure 7. Comparison of heat transfer between GCF and compressed aluminum foam.

## Discuss Possible Microturbine Applications with FAT Inc.

Gas-to-liquid heat exchangers such as the heat recovery system for microturbine CHP applications and air radiators for automotive cooling systems.

Gas-to-gas heat exchangers such as recuperators for microturbines.

Electron cooling devises such as heat sink for computer processors.

Phase changing heat exchangers in heating, refrigerating and air conditioning.

## References


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