Heat Exchangers Based on High Thermal Conductivity Graphite Foam

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INTRODUCTION

Approximately two thirds of the world's energy consumption is wasted as heat. In an attempt to reduce heat losses, heat exchangers are utilized to recover some of the energy. A unique graphite foam developed at the Oak Ridge National Laboratory (ORNL) and licensed to Poco Graphite, Inc., promises to allow for novel, more efficient heat exchanger designs. This graphite foam, Figure 1, has a density between 0.2 and 0.6 g/cm^3 and a bulk thermal conductivity between 40 and 187 W/m· K. Because the foam has a very accessible surface area (> 4 m^2/g) and is open celled, the overall heat transfer coefficients of foam-based heat exchangers can be up to two orders of magnitude greater than conventional heat exchangers. As a result, foam-based heat exchangers could be dramatically smaller and lighter.

EXPERIMENTAL

In order to characterize the behavior of the foam, a test chamber (Figure 2) was built to quantify its power dissipation capacity. As shown in Figure 2, the foam is mounted to an aluminum plate (usually by brazing) and placed in a cavity where the cooling fluid flows. The system is designed with no gap around the foam, thereby forcing the fluid to pass through the pores of the foam. The system is sealed with o-rings, and pressure taps are inserted into the chamber to measure the pressure drop of the system. A simulated power inverter (cartridge heaters in a 5 cm x 5 cm x 2 cm aluminum block) is mounted to the aluminum plate and is capable of generating up to 800 Watts (32 W/cm^2). As the cooling fluid passes through the system, the temperatures of the heater and inlet and outlet fluid are measured. The overall heat transfer coefficient (U_o) is calculated from Equation (1) where ΔT_{LM} is the log mean temperature difference, A is the area of foam attached to the aluminum plate, and q is the heat dissipated to the cooling fluid.

$$U_o = q / (A \cdot \Delta T_{LM}) \qquad (1)$$

RESULTS

In the first experiment a solid block of foam (5 cm x 5 cm x 3.175 cm) at a density of 0.47 g/cm^3 was brazed to the aluminum using SuperBraze® low temperature braze. Ambient air was passed through the foam at 140, 280, and 420 liters per minute. The temperature of the heater versus heater power density at various flow rates is plotted in Figure 3. The overall heat transfer coefficient versus airflow is plotted in Figure 4. The overall heat transfer coefficient is very high compared to that of a standard automobile radiator (2500 vs. 30 W/m^2· K). Since the pressure drop was significant (Figure 5) and not acceptable in certain situations, a second experiment was performed in which 20 vertical fins running parallel to the airflow were machined into the foam block. The experiment was repeated with similar air flow rates, and the overall heat transfer coefficient for this design is shown in Figure 6. In this case, the pressure drop was eliminated, but the heat transfer coefficient was reduced by 50 percent.

CONCLUSIONS

The high conductivity graphite foam presents a unique solution to the increasing cooling demands of power electronics and other automotive components. With novel designs, it is possible to eliminate cooling water and utilize air as the primary cooling fluid. This is a logical step since the heat is rejected to air eventually. In a parallel effort, radiators designed with the carbon foam exhibit a 10-fold increase in heat transfer coefficients. Higher heat-transfer coefficients should lead to significant reductions in the number of tubes (i.e. reduction in surface area) needed for similar heat transfer. Therefore, a typical automotive radiator that is 48cm x 69cm might be reduced to 20cm x 20cm in cross section with the same heat removal rate. Such a reduced size will reduce overall weight, cost, and volume of the system, thereby improving fuel efficiency.

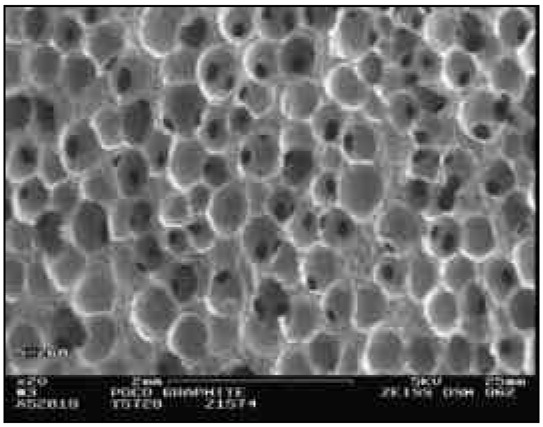

Figure 1. SEM image of the graphite foam.

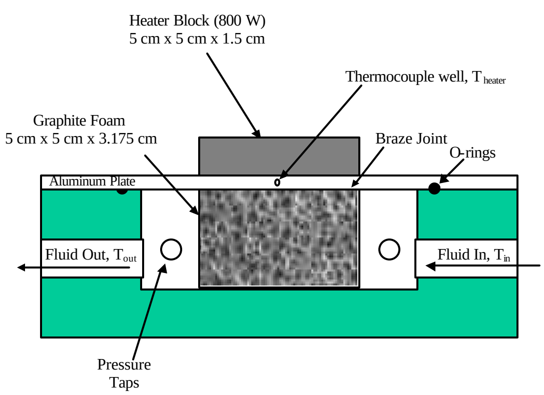

Figure 2. Schematic of test rig.

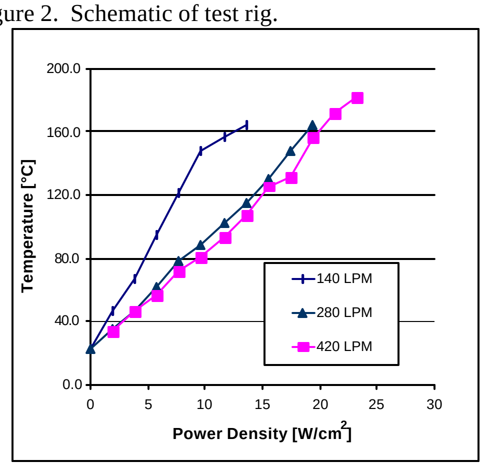

Figure 3. Temperature vs. Power.

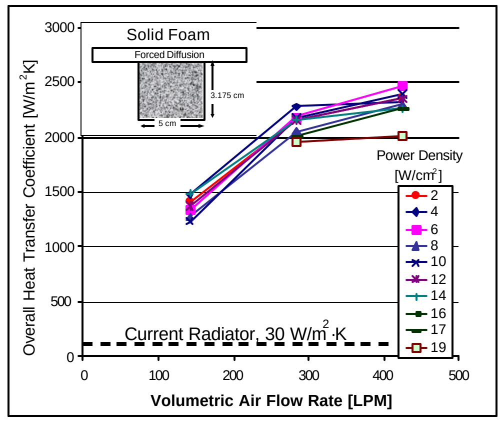

Figure 4. Overall heat transfer coefficients.

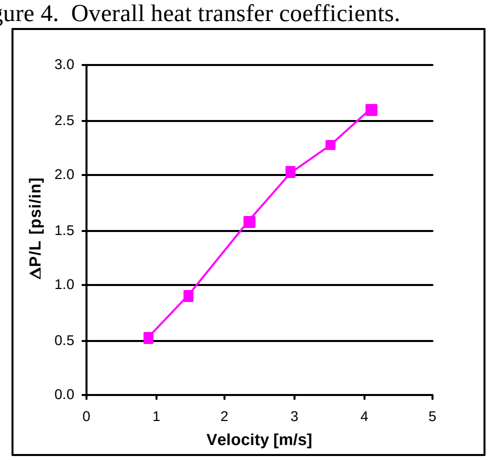

Figure 5. Pressure drop through the foam.

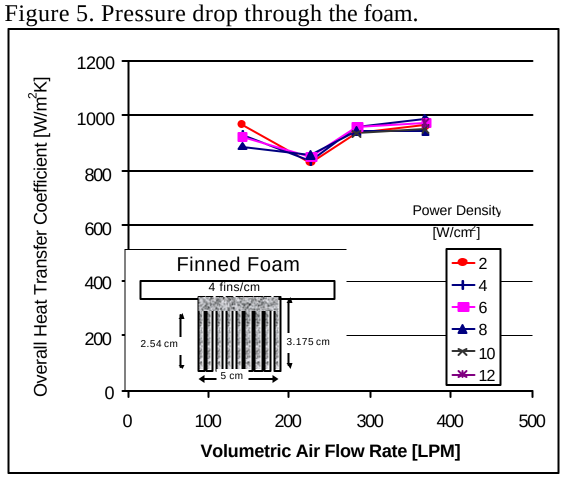

Figure 6. Heat transfer coefficient for finned foam