Thermal Performance in High Porosity Open-Cell Aluminum Foams

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Abstract

The objective of the experiment was to prove the thermal viability of high porosity open-cell aluminum foams as heat sinks with electronic cooling applications. The scope of the project encompassed the variation of several operating parameters including: flow rate, inward heat flux, and linear pore density of the heat sink. The experiment was conducted using a high porosity ($\epsilon = 0.91$) open-cell aluminum foam, manufactured using 6061-T6 aluminum. The experiment limited the range of flow values to Reynolds numbers which fell within the Brinkman-Forchheimer flow regime. The experiment used a non-dimensional index of performance to compare the thermal efficiency of each of the varied porosities. The parameter used pumping power, and dimensionless Nusselt number to establish the comparison. The results yielded that the sample with the linear pore density of 10 PPI had the highest thermal efficiency.

Keywords: Electronics cooling, Heat transfer, High porosity aluminum foam, Forced convection.

Nomenclature

Greek Letters:
- $\rho$, Density
- $\mu$, Dynamic Viscosity
- $\epsilon$, Porosity
- $q$, Gradient
- $\partial$, Partial Differential
- $\beta$, Brinkman Coefficient

Abbreviation:
- Re, Reynolds Number
- Nu, Nusselt Number
- $h$, Local heat transfer coefficient
- $D$, Diameter
- $x$, y, z, Cartesian coordinates
- $U$, Fluid velocity
- $k$, Thermal conductivity
- $I$, Dimensionless thermal efficiency

Subscripts:
- eff, Effective
- p, Pressure
- f, Within the Forchheimer flow regime
- x, y, z, operates in the corresponding Cartesian direction

1. Introduction

The purpose of this pursuit was to establish, using both numerical and empirical techniques, the relationship between linear pore density and the thermal effectiveness of high porosity open-cell aluminum foams as heat sinks with electronic cooling applications. The study is distinct from previous analyses in its geometry, the general nature of its scope, and its focus on practical application evaluating potential for commercial implementation. The final result of this paper shall be to propose the optimal linear pore density for development based on the system thermal efficiency.

2. Content

Numerical and experimental models were developed. The intent of these models is to establish a set of optimal performance parameters based on the collected data.

2.1. Experimental Analysis

The experimental apparatus was developed to include instruments to read and record the surface temperature distribution, the pressure drop across the test section, and the flow rate through the system. The parameters were varied as follows. The flow rate varied through 0.1, 0.15, 0.18, 0.22 GPM. The linear pore density varied between 10, 20, and 40 PPI. The heat flux was varied by using a voltage and current combination. To control the heat flux consistently only the current was varied. The value was varied between, 1.00, 1.25, and 1.60 amps. A Teflon heater was measured and cut to 37.5 mm by 37.5 mm to closely match the dimensions of an intel i7 processor. The metal foam was cut and sized to match the heater. This geometry allowed the authors to evaluate the thermal entry behavior. The pressure was recorded off of a manometer. The pressure drop was incorporated into the measurement of the thermal efficiency index. The geometry of the test section is as pictured in Figure 1 below.
2.2. Numerical Model

The numerical model used the input parameters based on the experimental conditions. The outputs of the model were tabulated and compared to the experimental results to verify the integrity of the experiment. The boundary conditions are as shown below in Figure 2.

The internal structure of the porous media was modeled according to the Brinkman-Forchheimer equation which is stated as:

\[
\frac{\rho}{\epsilon} \left( \frac{\partial U}{\partial t} + (U \cdot \nabla) \frac{U}{\epsilon} \right) = \nabla \cdot \left( -pI + \frac{\mu}{\epsilon} (\nabla U + (\nabla U)^T) - \left( \frac{\rho}{\epsilon} + \beta |U| \right) U + F \right)
\]

and the energy equation which was stated as:

\[
(\rho c_p)_{\text{eff}} \frac{\partial T}{\partial t} + (\rho c_p)U \cdot \nabla T = \nabla \cdot \left( k_{\text{eff}} \nabla T \right)
\]

3. Conclusion

The results obtained from the experiment yielded conclusively that the best sample based on the previously defined thermal efficiency for electronics cooling applications is the 10 PPI sample. The comparison of all of the samples operating at constant heat flux with varied Reynolds number is shown below in Figure 3.

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References: