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Heat transfer enhancement with discrete heat sources in a metal foam filled vertical channel☆

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ABSTRACT

This paper reports the results of experimental investigations of convective heat transfer in a vertical channel lined up with three discrete heat sources on one vertical wall of a vertical channel and cooled by air. The channel is filled with a metallic foam. The objective of the study is to investigate the heat transfer enhancement with the presence of metal foam and to identify the ratio of heat sources so as to achieve near isothermality of the heat source surfaces. The results of the study show that with the presence of a metal foam over the discrete heat sources the temperature variation among the heat sources drastically reduces which can be further optimized using a coupled artificial neural network (ANN)–genetic algorithm (GA) hybrid technique for a given velocity and heat input condition. A sensitivity analysis of the optimum thus obtained was also carried out to study the effect of inlet velocity and heat input on the isothermality of the heater surfaces.

1. Introduction

Modern electronics demand a high heat dissipation rate per unit volume for a reliable operation of the components, with a view to limiting the maximum temperature in the devices. This is invariably non-negotiable. In an application like a tall printed circuit board, heat generating components are present at different locations and do not usually fill up the whole wall. In view of this, such an arrangement cannot be treated as a fully heated wall. The design goal in such a geometry is to normally minimize the maximum temperature in the heat sources, with a view to increasing the reliability and longevity of the electronic components. The use of heat sinks to augment the heat transfer rate in order to decrease the maximum temperature is a very viable thermal management solution. However, for long life of the electronic components and to reduce the thermal stresses, a stricter goal of maintaining isothermality on the heater surfaces is desirable.

Metal foams are engineered porous media that have high surface area to volume ratio. They generally have a porosity (ratio of void volume in the porous matrix to the total volume) of 0.7 to 0.98 and therefore are light in weight. Metal foams are commonly made of aluminium and copper alloys. The cells or pores are evenly spread inside the foam and are also visible on the surface. These interconnected paths provide a tortuous path for the fluid flow, that helps in additional mixing of the fluid which is known as dispersion. Therefore, in an application wherein a compact, light weight heat sink is required for high heat dissipation, metal foams are promising candidates.

Many researchers have used a fully heated plate to study the heat transfer in the presence of metal foams. Kim et al. [1] investigated experimentally the pressure drop and heat transfer characteristics of metal foams in a plate fin heat exchanger arrangement. Compared to a louvered fin arrangement, metal foams gave similar heat transfer performance but with a small increase in the pressure drop. Hwang et al. [2] estimated the interstitial convective heat transfer coefficient and friction drag using a transient blow technique. Bhattacharya and Mahajan [3] studied the performance of a finned metal foam and longitudinal finned heat sinks in buoyancy induced convection. The finned metal foam heat sinks were found to have a superior thermal performance compared to the longitudinal finned heat sinks. The present authors too have studied, experimentally [4] the heat transfer performance from a fully heated plate in a vertical channel filled with metal foams. The heat transfer performance was found to be significantly higher compared to the case of a channel without any metal foam.

Cui et al. [5] experimentally investigated the flow through a porous channel with discrete heat sources on the upper wall. The heat transfer was higher near the leading edges, for higher values of Reynolds

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numbers. Yu and Joshi [6] experimentally studied the heat transfer enhancement from enclosed discrete components using pin fin heat sinks in horizontal and vertical orientations for closed and vented enclosures. They found that for completely closed enclosures, vertical orientation produced a lower thermal resistance.

Optimization studies on the discrete heat source geometry sans porous media have also been performed by many researchers [7–9].

The preceding literature review shows that quite a few researchers have employed metal foams for study of heat transfer enhancement from a fully heated plate. Studies with discrete heat sources in a vertical channel filled with metal foam are scarce. The objective of the present study is to determine the heat transfer enhancement and to find the ratio of the total heat distribution to the three heat sources to achieve near isothermality on all heater surfaces for a given inlet velocity.

2. Experimental setup

The experimental setup consists of a vertical wind tunnel with a test section made of hard wood and placed over the converging cone of the wind tunnel. It has a rectangular duct inside whose walls are made of non-rubberized cork. A discrete heater plate assembly is placed at the center of the rectangular duct and is filled with metal foam on both sides. The metal foam used in the present study has 10 number of pores per inch (PPI) with a width of 250 mm, length of 150 mm and thickness of 20 mm and supplied by m-pore®, Germany. The foam has a porosity of 0.94 and is made of aluminium alloy (AlSi7Mg). The hydrodynamic characteristics of the foam namely the permeability and form drag coefficient were estimated by conducting experiments. These values of the above two quantities for the foam used in the present study are 6.7×10^{-7} m^2 and 167.5 m^{-1} respectively.

Fig. 1 shows a schematic diagram of the test section with the vertical duct filled with metal foam and a centrally placed discrete heater plate assembly, with the photograph of the discrete heat source used in the present study.

The discrete heat source assembly is made of alternate aluminium and Bakelite strips. The aluminium strips have a thin flat heater sandwiched inside that forms the discrete heat sources and the Bakelite strips reduce the axial conduction and also help in the seating of metal foam. The discrete heat sources are flushed with the Bakelite surface to avoid any protrusion and the metal foam seats uniformly on the heater plate assembly. Bakelite strips have a length of 290 mm, breadth of 22.5 mm, and thickness of 6 mm. Six milled grooves of size 1.5×2 mm are cut on the Bakelite pieces, three each on either side. These grooves are equally spaced along the breadth of the Bakelite. The surface of the Bakelite has been polished and the thickness is reduced to 6 mm, so as to have a final assembly of 6 mm thickness. Aluminium strips that are used to make the heater plate assembly have a length of 290 mm, breadth of 20 mm and thickness of 3 mm. Three milled grooves of size 1.5×2 mm are cut on each aluminium strip of different lengths. A 250 mm × 0.5 mm groove is also provided on the inner surface of the aluminium strips to accommodate the heater placed inside. Heaters of size 250×19 mm and thickness 1 mm are made by winding a flat Nichrome wire over a mica sheet and electrically insulating them with thin mica sheets on either side. The lead wires are taken out from the two ends of the mica sheet and the exposed portion of the heater wire is insulated with two more mica sheets of the same dimensions, one on each side of the heater. The sheets are bonded together with the commercially available bonding agent — Araldite and the heater has a thickness of 1 mm. Three such heaters are made and inserted in the vacant slots in the inner surfaces of these aluminium strips. Thermal heat sink paste is applied on the inner surface of each aluminium strip to avoid the formation of air pockets between the heater plate and the aluminium inner surface. Individual regulated DC power supply is provided for each heater that has a voltage uncertainty of ±0.01 V and a

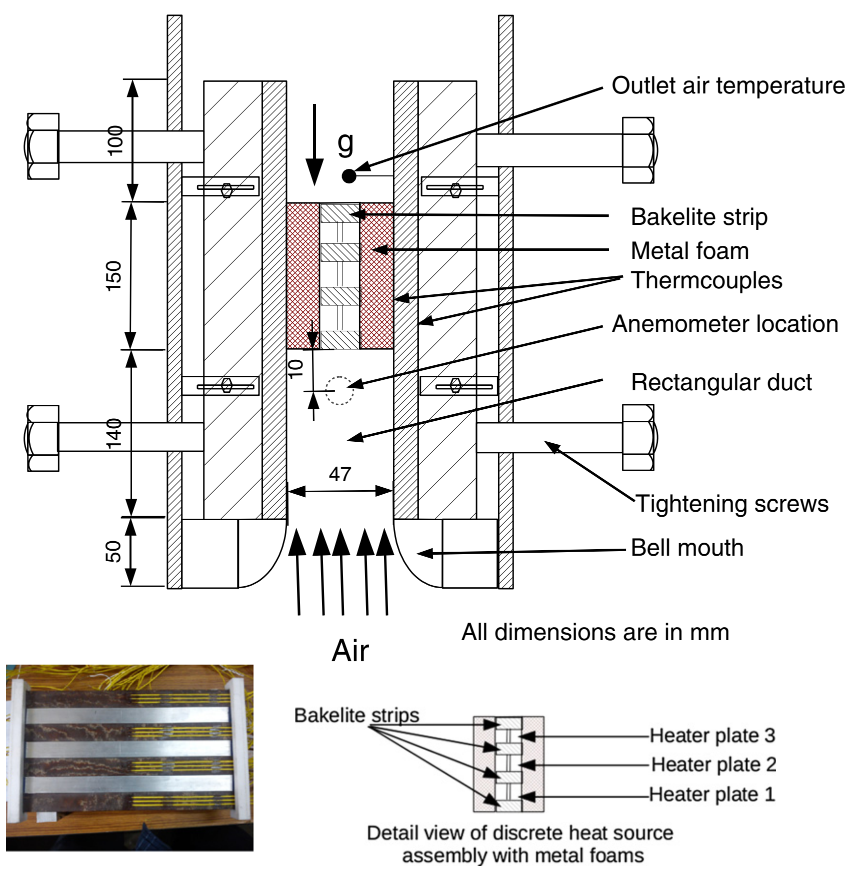

Fig. 1. Schematic diagram of test section with photograph of discrete heat sources.