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Study of Heat Flux Distribution in Sintered Bronze Metal Foam for Heat Transfer Enhancement

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***Abstract*— The flow analysis studies is how to enhance heat transport for given flow geometry and externally imposed physical constraints. To enhance convective thermal transport we have focused on the utilization of metal foam in thermal system. The motivation is attributed to enhance heat transfer due to the high surface area to volume ratio as well as flow mixing due to toutuosity of metal foam. The paper explores the use of open-cell porous metal foams use as a longitudinal finned of copper alloy with different sample grades 60K, 100K**

Keywords— Metal foam;Pore diameter ; pressure drop;friction factor,Heat transfer coefficient.

I. INTRODUCTION

The porous matrix of the foam consists of tortuous, irregularly shaped flow passages. Heat transfer takes place between the surface of the solid matrix and the fluid. The flow recirculates at the back of the solid fibers; and for high enough pore scale Reynolds numbers, turbulence and unsteady flows occur [1]. Kambiz Vafai; Sung-Jin Kim, [2] presents the convective flow and heat transfer through a composite porous system. The composite medium consists of a fluid layer overlaying a process substrate, which is attached to the surface of the plate. The simulations focus primarily on flow that has the boundary layer characteristics. Several important characteristics of the flow and temperature fields in the composite layer are reported. Various parameters such as Darcy Number the inertia parameter. The results of this are used in frictional drag reduction, and heat transfer retardation or enhancement of an external boundary layer. They have been used in aerospace applications, compact heat sinks for power electronics [1, 2], and geothermal operations and in petroleum reservoirs [3]. Ceramic foams are used in advanced burners and in heat pipes. And nickel foams have been used in higher power batteries for lightweight cordless electronics [2]. The open porosity, low relative density and high thermal conductivity of the cell edges, the large accessible surface area per unit volume, and the ability to mix the cooling fluid by promoting eddies [4], all make metal foam heat exchangers efficient, compact and light weight.

II MODEL DEVELOPED

Heat transfer model in the porous material fin. The directions, in which the temperature distribution is studied, and the dimensions of the fin are shown in Fig. 1.

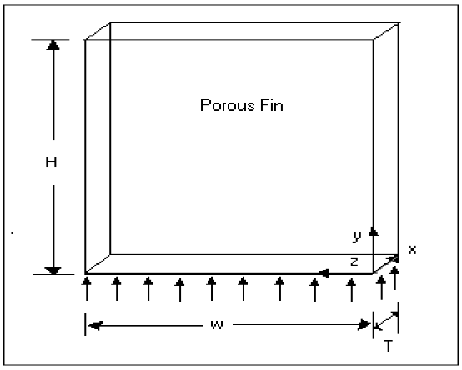

Fig. 1. Fin model used for ANSYS

To begin the analysis of the heat transfer in the fin, a control volume is defined are shown in Fig. 1. and the law of conservation of energy is applied to it. To balance the equation, the heat transfer by conduction through the copper alloy filaments and the air is combined with the heat transfer by convection that takes place inside the pores of the fin. Fig.2. shows the control volume defined inside the porous fin and used for the analysis, where *W* represents the width of the fin and *dx* and *dy* are small thickness in the *x* and y directions, respectively

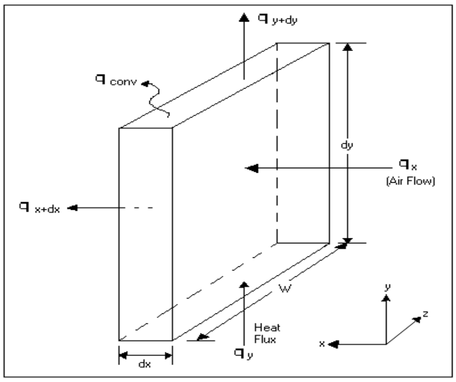

Fig. 2. Defined control volume

The energy fluxes due to the conduction and applying energy balance in the control volume, yields,

$$q_y + q_x = q_{y+dy} + q_{x+dx} + q_{conv} \quad (1)$$

Convection Heat fluxes by conduction and convection are introduced in Eqn.1. All substitutions of the fluxes, area and the algebraic manipulations to obtain the energy equation for porous fin are detailed in Eqn. 2

$$\frac{\partial^2 T_{fm}}{\partial y^2} + \frac{\partial^2 T_{fm}}{\partial x^2} - m_{fm}^{\ 2}\ (T_{fm} - T_\infty) = 0 \quad (2)$$

III ANALYSIS

The thermal conductivity of porous materials is influenced by porosity, pore size, pore shape, temperature, emissivity in the pore etc. However results showed that the effective thermal conductivity depend strongly on the porosity. The focus of this study is forced convection in metal foams & present work provides an approximate model for the heat transfer in open-cell metal foams, when they are used in a forced convective mode with a low conductivity fluid such as air. As a simplification, the model ignores the conduction in the fluid. The analysis uses the typical parameters reported by the foam manufacturers and other relevant engineering parameters. The model assumes and justifies that there is local thermal equilibrium between the solid and the fluid. The simplicity and applicability of the present approach eliminates the need for rigorous microscopic analytical or numerical modeling of the three-dimensional flow and the heat transfer in and around the pores. Another advantage is that the current model is easily verified by experiments, as described in this paper.

Table 1 Analysis Report

Sr No.	Sample Grade	PPI	Velocity m/s	$h_{eff.}$ $W/m^2 K$
1	60K	10	60.0	255
2			1.68	299
3			1.99	325
4			2.67	378
5	100K	20	60.0	237
6			1.68	286
7			1.99	305
8			2.67	389

For simulation using FEM (Finite Element Method) packages for thermal management and heat sink applications, the geometry of porous material can be treated as a solid geometry, considering effective heat transfer coefficient. This eliminates the need for any rigorous microscopic analytical or numerical modeling of the flow and heat transfer in and around the pores.

A fin model is developed for analysis having dimensions are 160 mm in height and 150 mm in width and 5 mm thickness. The two grades of fin samples having different pore densities i.e. 60K grade and 10 PPI, 100K grade with constant porosities nearly 60-65 percent are analyzed in the ANSYS. Higher velocities are not tried during the analysis because the application of such a fins is in electronic circuits, where the velocities normally exceed 5 m/s. At higher velocity boundary layer are formed at the pores of fin sample due to turbulence and eddies which reduces the heat transfer rate.

The boundaries conditions are taken during analysis are the constant base temperature, convection on the outside surfaces and insulation on thickness.

IV SIMULATION REPORT

To carry out the simulation study a two dimensional fin model was developed in the ANSYS. The model includes both the conduction in the ligaments, and the convection due to the air flow in and around the pores of fin. The two different grades of copper alloy (Sintered Bronze) fin samples having two different pore densities .Fig. 3 to 6 shows the thermal views (heat flux distribution) of the two grades of fin samples. These images of temperature are sharpening at all the velocities. In each of these pictures, the temperature profile is seen. The color gets lighter away from the heated base which has the red color corresponding to the highest temperature. Away from the base (the dark blue area) there seems to be a reduction in temperature. Fig. 7,to 9 provide comparison of the temperature profiles obtained by ANSYS simulation and by the experiment. These figures are representative sample of the eight study cases as shown in Table 1.

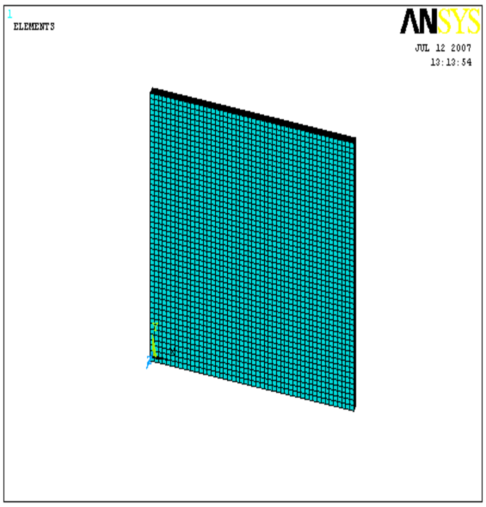

Fig. 3. Meshing Generation

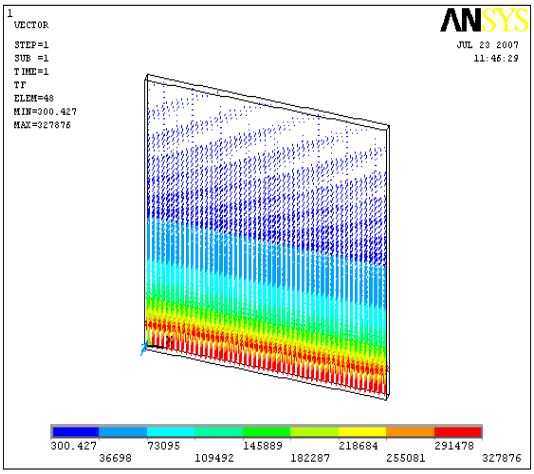

Fig. 4 . Heat flux distribution for 60K grade sample with air velocity1.68m/s

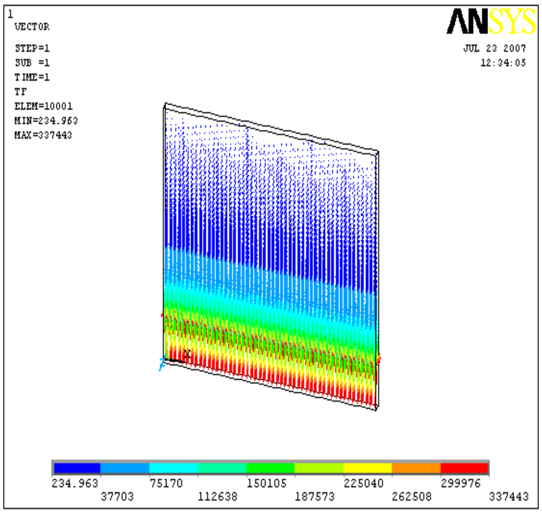

Fig. 5. Heat flux distribution for 60K grade sample with air velocity 2.67 m/s

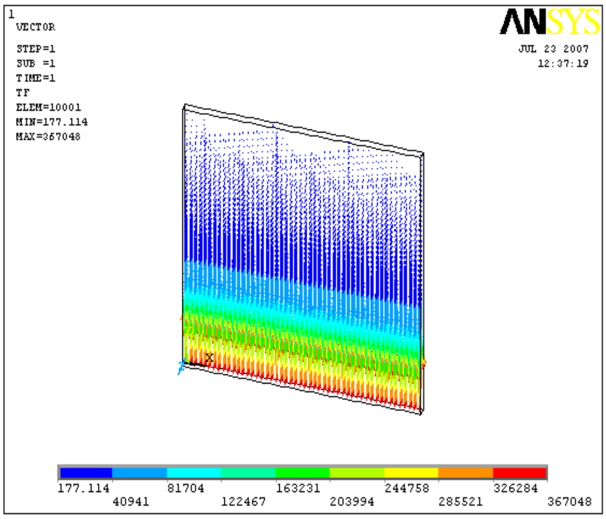

Fig. 6. Heat flux distribution for 100K grade sample with air velocity 2.67 m/s.

V RESULTS AND DISCUSSION

The two plots i.e. Fig. 7to9 shows the dimensionless temperature vs. dimensionless distance for the 60K grade fin sample at air velocity 1.63 m/s., 1.99m/s, and 2.67 m/s. It is seen that the temperature distribution in the direction of flow was observed to be hyperbolic in the fin samples (with the characteristics described in the present work). This fin sample is used to dissipate heat to which it is exposed. Such a type of temperature distribution along the fin is desirable and indicates the satisfactory trends both in experimental and simulation work.

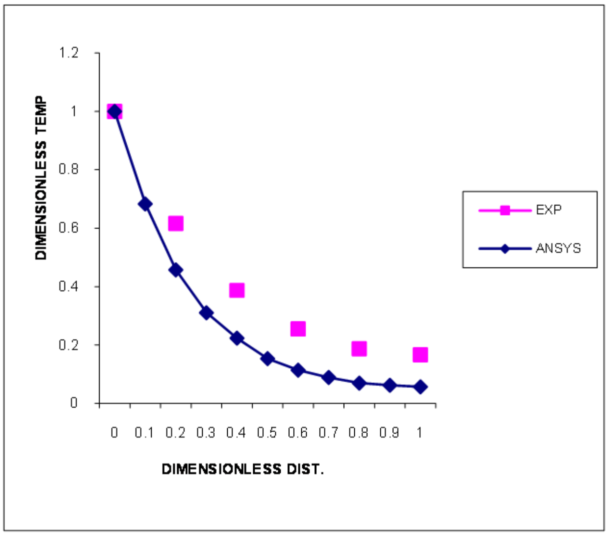

Fig. 7. Results for 60K Grade at Air Velocity 1.68 m/s.

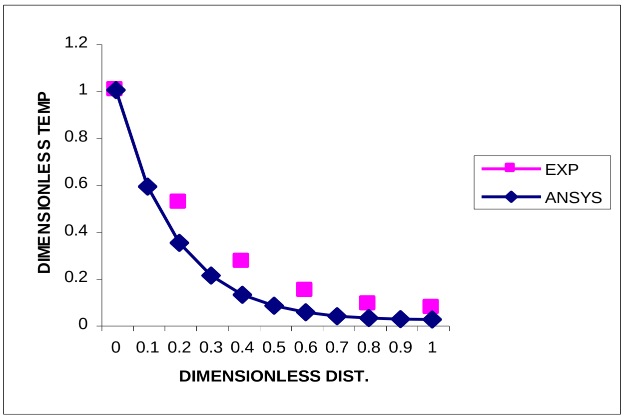

Fig. 8. Results for 60K Grade at Air Velocity 2.67 m/s.

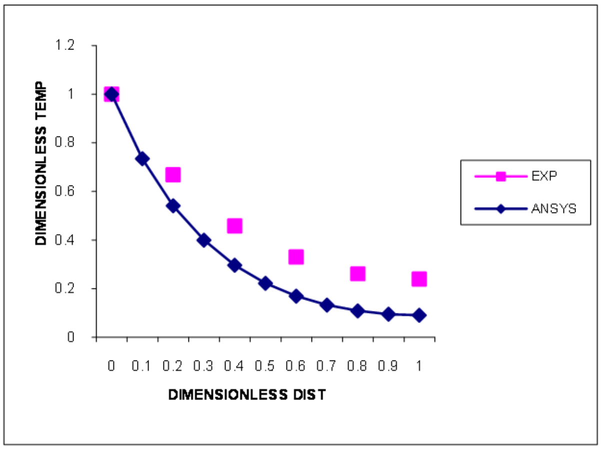

Fig. 9. Results for 100K Grade at Air Velocity2.67 m/s.

At higher velocity boundary layers are formed at the pores of fin sample due to turbulence and eddies which reduces the heat transfer rate. The boundary conditions taken during analysis are the constant base temperature, convection on the outside surfaces and insulation on thickness. At a fixed porosity, increasing the cell density increased the surface area to volume ratio, which therefore increased the flow resistance by lowering the permeability and increasing the pressure drop. So it was inferred that the permeability was influenced appreciably by both the porosity and the cell size.

VI CONCLUSION

The samples were tested in the lab and modeled in ANSYS. The results obtained with experimental work and simulation is quite in agreement. Encouraging results indicating the acceptability of porous fins are witness. This fin sample is used to dissipate heat to which it is exposed. Such type of temperature distribution along the fin is desirable and indicates the satisfactory trends both in experimental and simulation work.

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