Experimental Study and Comparison of Enhancing Heat Transfer through Open-Cell Metallic Foam and Solid Rectangular Fin Using CFD

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Abstract *The necessity for devising more effective heat transfer technologies capable of increasing performances while keeping power consumption, size and cost at reasonable levels is well recognized. Under this prospect metal foams are good medium for improving thermal efficiency of heat enhancing devices and allowing at the same time the use of smaller and lighter equipment.*

In this paper the experimental investigation on the open cell metallic foam (Aluminium 6101) and solid rectangular fin (Aluminium 6101) for various heat inputs at steady state in natural convection have been carried out. With respect to weight and volume of the open cell metallic foam two solid rectangular fin test samples have been prepared. During the experimentation process the test samples are electrically heated at the base with a constant heat flux. The temperature variations along the length for open cell metallic foam and for the solid test samples were tabulated for the heat input 30W, 60W and 90W respectively. Fluent in Ansys 15 simulation software is used for analysis. The results shows that the amount of heat convected through the open cell metallic foam is better compared to the solid test samples with respect to weight as well as the volume basis.

Keywords —*Open cell metal foam, Solid rectangular fin, CFD.*

1.*INTRODUCTION*

Heat transfer is energy transfer due to a temperature difference in a medium or between two or more media. Different types of heat transfer processes are called different modes of heat transfer. Conduction heat transfer is due to a temperature gradient in a stationary medium or media. Convection heat transfer occurs between a surface and a moving heat transfer occurs between a surface and a moving fluid at different temperatures. Radiation heat transfer occurs due to emission of energy in the form of electromagnetic waves by all bodies above absolute zero temperature net radiation heat transfer occurs when there exists a temperature difference between two or more surfaces emitting radiation energy.

Natural convection has many applications and thus it strongly influences the heat transfer from pipes and transmission lines, as well as from electric baseboard refrigeration units to the surrounding air. It is, also, relevant to the environmental sciences, where it manipulates oceanic and atmospheric motions. The most relevant use of natural convection for the chemical engineer, however, is in the cooling of electronic components.

Both the performance reliability and life expectancy of electronic equipment are inversely related to the component temperature of the equipment. The relationship between the reliability and the operating temperature of a typical silicon semi-conductor device demonstrates that a reduction in the temperature corresponds to an exponential increase in the reliability and life expectancy of the device. Therefore, controlling the temperature of the device by natural convection (which is a free resource) is of vital importance. Icoz and Jaluria Computer engineers, by studying and mastering natural convection, are better able to arrange the area, position, and location of heat sinks to cool their electronic components.

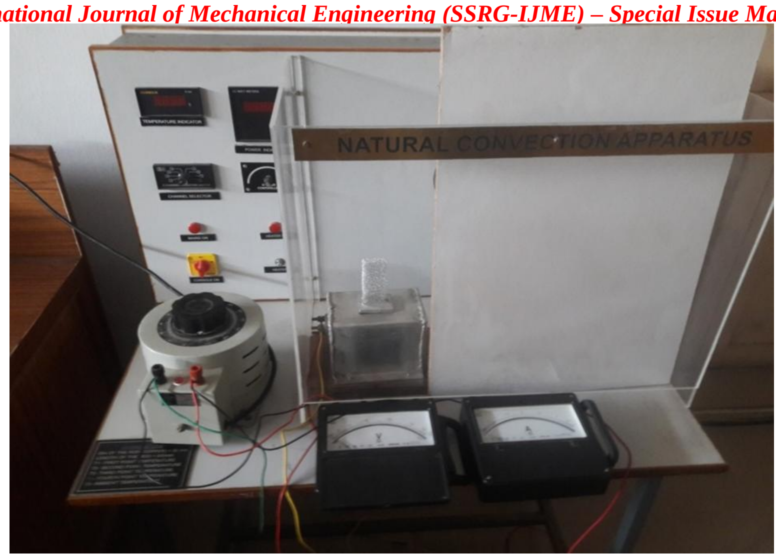

Fig 2.1Experimental set up

2. Experimental Set up

The experimental setup is as shown in figure below. The voltmeter is connected in parallel to the auto-transformer and heat source. The ammeter is connected in series to the heat source. The regulation of voltage and current produces change in wattage input to the base plate. Thus by varying the voltage and current values heating was done at different values at regular intervals and the temperature readings were tabulated.

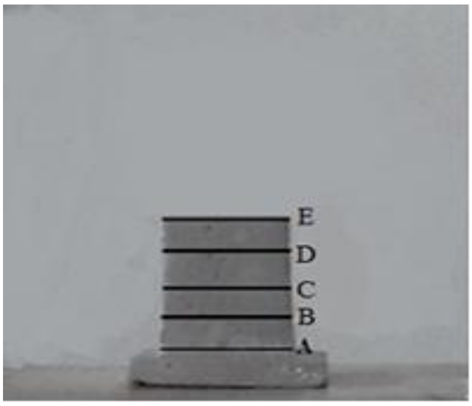

Fig2.2. Solid rectangular fin with reference to metallic foam weight

After setting to the rated supply we let for sometime till it reaches the steady state. After reaching the steady sate the base temperature was taken at ten different locations and average of which gives average base temperature. The length of the foam on the base plate is 80mm.

Markings were made at eight different locations from bottom to tip the foam. At these points on the foam material the temperatures are noted and tabulated.

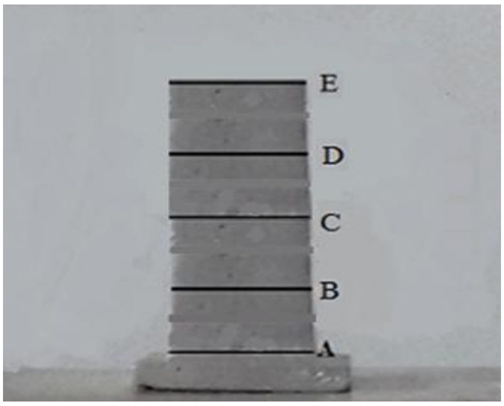

Fig 2.3.Solid rectangular fin with reference to metallic foam volume

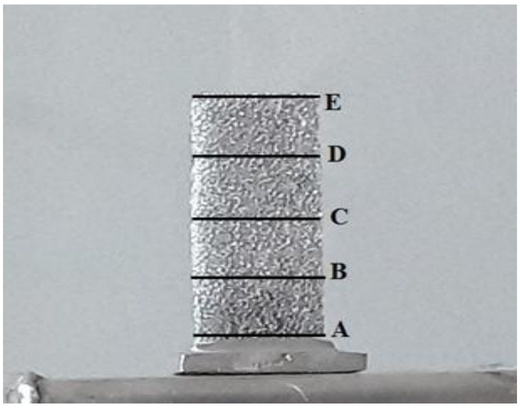

Fig 2.4 Metallic Foam

3. Results and Discussions

The contour in the above figure shows the distribution of temperature along the length of the porous material from base to tip. The given heat input at base is maintained at 356K, after attaining the steady state the temperature is varying from 356K at the base to 300K at the tip as shown in the above contour. Since the metallic foam is open celled structure there are more chances to circulate the atmospheric air through the metallic foam.

In natural convection the hot air rises up and is replaced by cold air this is due to difference in density the. As there are number of pores along the length of the material the hot air can easily escape from the hot surface. So it enhances the heat transfer of a material. Thus the porous material can replace a solid where enhanced heat transfer rate is necessary and where the place and weight are constraint. Temperature is Maximum at the base, intermediate at 1/4thof the distance from bottom, least at the tip.

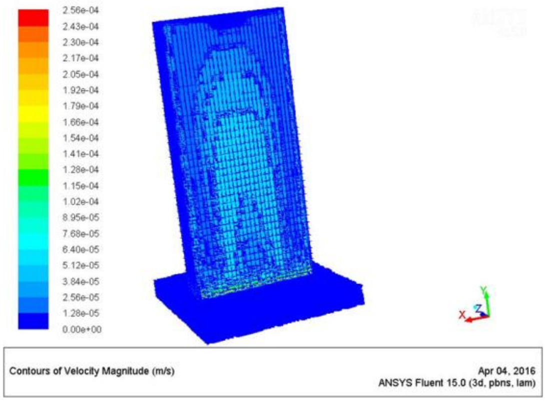

Fig 3. Velocity Profile inside Metal Foam
At a given heat input 90Watts.

Above figure shows air velocity profile inside the porous material. Heat transfer inside the material is based on Reynolds number.

Variation in density of air plays vital role in rising the velocity of hot air from base to tip. Diameter of the pore is very small. Change in Kinematic viscosity of the air is negligible. At particular Reynolds number velocity of hot air alone plays a key role in enhancing the heat transfer rate through the pores of the material.

From the figure we can infer that velocity at the base is high and it goes on decreasing along the length from the base of the porous material as the temperature reduces.

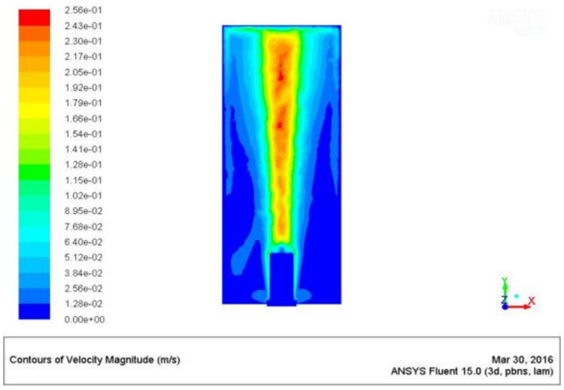

Fig 3.2 Velocity Profile outside the Metallic Foam at a given heat input 90Watts.

Above figure shows air velocity profile outside the porous material. In natural convection velocity outside the fin is due to temperature difference of the air. As the base plate maintained at high temperature than the base of the metallic foam the flow of natural convection heat from the base plate is generally passes over the metallic foam surface. Surrounding cold air moves in to space left by hot air. This movement of air sets up velocity.

From the figure it can be inferred that magnitude of velocity of air is maximum vertically above the fin, and is reduced as we move horizontally. Magnitude of velocity is minimum at base.

4. Literature Review

Agrawal [5,6] et al. carried out a detailed heat transfer and velocity field study for a similar LSMU arrangement but with plain walls. They found that agitation can lead to considerable activity inside a channel and can, therefore, cause significant heat transfer enhancement. Such an arrangement can find application in an electronics cooling heat sink. Agitation may be by an oscillating plate that mixes the flow inside a channel to augment the cooling provided by through flow. Yeom et al. [7] did experiments to test this idea for a single channel of the heat sink at the actual scale. The channel was cooled both by agitation and through flow. Frequencies of about 1000 Hz and amplitudes of about 1.4 mm were achieved using this technology. They were able to observe an improvement in heat transfer rate of about 55% compared to that with the non-agitated state.

Yu et al. [8] numerically studied factors influencing heat transfer for channels cooled by translationally oscillating agitators operating at the actual scale. Enhancements as high as 61% were observed. Heat transfer enhancement was found to increase with increases in amplitude or frequency. They found that heat transfer enhancement was primarily effected by the agitation velocity, the product of amplitude and frequency, with amplitude being only slightly more important than frequency. Yu et al. [9] numerically studied heat transfer enhancement obtained when heat sinks with fan-induced through flow are assisted by active devices like agitators and synthetics jets. Their study was done for a representative single channel of a heat sink. An enhancement of about 82% was found when the performance was compared with the channel-flow-only case.

In another study, Yeom et al. [10] found 91% enhancement when the channel with through flow was assisted by agitation at a frequency of 1140 Hz, compared to a channel with through flow only, both with 45 LPM of channel flow rate. Yeom et al. [11] reported that a thermal resistance for the heat sink of 0.053 K/W could be achieved, based on a test with a single channel with surface augmentation using pin fins when the agitator operated at a frequency of 686 Hz, an amplitude of 1.4 mm and the through flow velocity was 7.9 m/s. The experiments were done in an actual-scale channel. They computed the resistance by extending the single-channel results to a full-scale system with a 26-channel/blade array to cool a 1.0 kW heat sink.

Various studies can be found in the literature that explore the effectiveness of surface modifications on mixing and heat transfer. Roeller et al. [12] made average heat transfer measurements and detailed flow measurements using a Laser Doppler Velocimetry (LDV) near three-dimensional protrusions in a flow channel. Their study had application to electronics cooling. They found an increase in heat transfer with an increase in protrusion height. This increase was attributed to flow acceleration in the narrower passages caused by increasing the protrusion height. An increase in heat transfer was found also in certain cases when the protrusion height was decreased. This was due to the increased three-dimensionality of the flow and increased mixing due to turbulence generated.

Siw et al. [13] studied heat transfer and pressure drop characteristics with pin fins in a rectangular channel with the pins detached from one of the end walls. The channel simulated the internal cooling passage of a gas turbine airfoil. They experimentally studied heat transfer performance by measuring heat transfer coefficients over all surfaces, including the channel walls and the pin surfaces. The pins were detached from one of the walls to promote turbulent convection and to generate separated shear layers. This led to enhanced mixing and therefore greater heat transfer. An optimal size for the gap between the pin tops and the end wall was found. This optimum condition was when the heat transfer was maximum while the pressure drop remained low.

Moores et al. [14] studied the effect of tip clearance on pin fin array heat transfer performance. The clearance was introduced between the pin tips and the surrounding shroud. They reported an increase in mean heat transfer and a drop in pressure when the clearance was between 0.5 and 1.1 times the pin diameter. They explained that the increase in heat transfer was due to the additional surface area that was exposed to the flow. This area increase enhancement was, in some cases, partially offset by a lower heat transfer efficiency per unit of fin area when the fins were added.

Ames et al. [15] experimentally investigated the flow field in a staggered array of pin fins at various Reynolds numbers by making hot wire anemometry measurements with both single and cross-wire probes. Using a commercial CFD code, they made detailed 3D calculations, learning that flow shedding near the surface of the pins leads to the generation of unsteadiness.

4. CONCLUSIONS

The high thermal conductivity and low weight make the usage of metallic foams in cooling electronic systems a viable solution. In this experiment we used Aluminium 6101 40PPI (Pore Per Inch) metallic foam and it is compared to a pure solid rectangular fin of same weight and cross section. The heat is supplied at varying wattage and steady state readings were tabulated. The amount of heat dissipated through the foam material using simulation model is 28.56W. The amount of heat extracted from solid rectangular fin with respect to foam weight is 5.86W and with reference to foam volume is 4.68W which are calculated using extended surfaces fin equations.

From the obtained values we can conclude that experimental values are close to the results obtained in simulation with % error. When we compare the amount of heat dissipated out of the metallic foam to the solid rectangular fin we found that the amount of heat convected through aluminum metallic foam is more than the amount of heat dissipated out by solid fin of same weight by %.

Thus it is evident from the experiment that the use of metallic foam is advantageous and can enhance the heat transfer from a heat generating area when compared to pure aluminium.

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