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Numerical and Experimental Study of Cooling in CPU with Metal Foam Heat Sink

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ABSTRACT: Evolving, Enhancing and Ensuring the optimum design of metal foam heat sink complying with applicable requirements for Central Processing Unit (CPU) cooling led to a need for new and more effective methods to enrich the digital world. The aim of this study was to investigate the heat transfer development and properties of Copper foam heat sink to increase the performance and efficiency of CPU. The CPU capacity and heat, increase with increasing the speed and its performance. In order to run the system effectively, the heat must be removed and the surface temperature of the CPU must be kept below critical temperature.The numerical and experimental approach is carried out to compare various parameters such as temperature, fan speed with respect to metal foam characteristics to evaluate the thermal performance. An experimental investigation of heat-transfer characteristics of copper metal foam material was carried out.

KEYWORDS: Heat sink,Heat transfer coefficient, Nusselt Number, Reynolds Number, mass flow rate, thermal resistance

I. INTRODUCTION

Enriching the digitalized world by managing the waste heat produced by computer components is the need of world. Components that are susceptible to temporary malfunction, permanent failure if overheated include integrated circuits such as CPUs, chipset, graphic cards, and hard disk drives. Heat sinks are used to cool by airflow reducing the temperature rise. Attention to patterns of air flow can prevent the development of hotspots. To reduce the temperature by actively exhausting hot air,computer fans are used along with heat sinks.A passive heat exchanger, here heat sinkconverts the heat generated into a coolant fluid in motion. The fluid in motion transfers heat out of the device which will regulate the device temperature at physically feasible levels. The cooling of CPUs are done via heat sinks.A heat sink carries heat energy from a higher temperature device to a lower temperature fluid medium. A heat sink also called as heat reservoir can absorb some amount of heat without a change in temperature. Copper which have excellent properties that includes thermal conductivity, corrosion resistance and many more makes it eligible as better heat sink. Copper has wide applications in industrial facilities, electronic systems, power plants, solar thermal water systems,forced air heating and cooling systems,HVAC systems, gas water heaters, geothermal heating and cooling. Metal foam is a new form of structure formed by dispersion of various gases that form air gaps within a metal body. The defining characteristic of metal foams includes low densities and novel thermal, mechanical, and acoustic properties and have a very high porosity: typically 75- 95% of the volume consists of void spaces making it a ultralight material. Metal foams are classified into open cell and closed cell metal foam. The applications of metal foams which includes heat exchangers in compact electronic cooling, PCM heat exchangers and cryogen tanks generally use open celled metal foams.The metal foam material are high in cost but it reduces the physical size of heat exchanger, and so fabrication costs.

[1].In this experiment it was found that the pore diameterisanimportantparameterthatdeterminesthepressuredropandheattransferrate. Both pressure drop and heat transfer rate increases as face velocity increases. In order to exploretheeffects,thesamplesofsamegeometrywithdifferentbasemetalssuchascopper and aluminium were constructed. They were compared on their heat transfer rates with respecttofacevelocity.Theheattransferratedependso

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nsurfacearea.Asthesurfacearea increasestheheattransferrateincreases.The40PPIfoamhadthelargestheattransferrate underallfacevelocitiesduetohavingthehighestsurfaceareatovolumeratio,whilethe5 PPI foam had the smallest heat transfer rate. The geometry of metal foam reduces the pressuredropwithoutcomprisingtheheattransferrate.Itconcludedthatforgeometrically similar samples the metal foam heat exchanger provided better performance compared to other designs employing plain fins or louver fins with much larger heat transfer coefficients.

[2].In this experiment the open cell aluminium foams were compressed making it desirable to use as heat exchangers for electronic cooling applications which dissipate large amount of heat. The aluminium metal foam with porosities between 60.8 and 88.2% were tested for their thermal and hydraulic characteristics. The Nusselt number for open cell aluminium foam heat exchangers were calculated at various coolant flow rates and coolant flow speed. The coolant flow rates weremeasuredbyrotameter.Thekeyfindingoftheresearchisopencellaluminiummetal foam exhibits the desirable properties of efficient heat exchanger and it decreased the thermal resistance by nearly half when compared to traditional heat exchangers designed for similarapplications.

[3].Different cases have been considered, such as varying pore velocities, porosities and pore densities, in order to derive a simplified heat transfer model for metal foams. Lee and Vafai presented a model which was summarized and used in the experimentation of this study in order to determine results. In the experiment, three different foams having different porosities were tested in order to determinetheobtainedtemperaturedistribution.Experimentalandtheoreticalresultswhen compared,providedsomeminordeviationsfromeachother.Thiswasprimarilydueerrors thatareaddedduetocompressioninfoam,whichdeviatesitspropertiesfromidealvalues. The model underestimated the temperature near the foam’s entrance, and predicted the temperatures inside the foam. The study concludes that possibility of determining of temperaturesinsideofmetalfoamsisachievable,butduetoerrors,thevaluesdeviatefrom thetheoreticalvalues.So,compressioninfoams,being oneofthemajorreasonsthatcauses this, should be avoided in order to obtain accurate results.

[4].The fibrous materials which are classified in randomly stacked fibres and metallic foams are discussed here. Porosity is a differentiating factor in case of boththematerialssincesurfacearea,weight,heattransfercharacteristicsaredependenton theporosityoftheselectedmaterials.Incaseofrandomlystackedfibres,methoddeveloped involvedpreparationofstacksusingvibrationsofpredeterminedamplitude,frequencyand duration.Theexperimentconcludedthatporosityvaluesincaseofrandomlystackedfibres are function of fibre aspect ratio. For determining porosity characteristics in case of metal foams, image analysis techniques were used. Effective thermal conductivity of both the materials was derived. In case of randomly stacked fibres, thermal conductivity remained fairly stable for different values of aspect ratios, and for metallic foams, thermal conductivitymainlydependedonthecontactqualitywithwall.Formetallicfoams,thermal efficiencies were close to perfect fins. Heat transfer characteristics for randomly stacked fibres were calculated using numerical experimentation, which aided in determining temperature field throughout the medium. Thermal conductivity is increased when sintering of the porous material is carried out, this happens primarily due to increase in exchange coefficient. The study concludes that fibrous materials present us unique characteristics which increase efficiency of thermal properties. These materials provideus withexcellentheatexchangingpropertiesandcanbeusedinheatsinkstoreplaceexisting heat exchangers. The advantage lies in weight reduction and low manufacturing costs.

[5].In the experimentanaluminiumfoamheatsinkwassubjected toauniformheatfluxrangingfrom13.8 to 8.5 W/cm2 which was compared to a numerical model developed using finite elementtechnique.Theheatdevelopmentandthermalentrylengthofthealuminiumfoam heat sink were examined and presented. It was observed that the thermal entry length was longerforhigherReynoldsnumbersanddecreasesastheReynoldsnumbersdecreasesand that the local surface temperature increases as the heat flux increases, the Reynolds number decreases, increasing the flow direction axis. It was concluded that by using water as a coolant instead of air there was 68% less uniformity index in the foam with lesser average surfacetemperatures.

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II. WORKING PRINCIPLE OF HEAT SINK

Considering Fourier's law of heat conduction,to understand the principle of a heat sink, Fourier's law of heat conduction, simplified to a one-dimensional form in the x-direction, shows that when there is a temperature gradient in a body, heat will be transferred from the higher temperature region towards lower temperature region.

$$q = -k\frac{\partial T}{\partial x}$$

Considering a duct which include a heat sink in it, where air flows through the duct, is shown in figure. Assuming higher temperature of heat sink basethan the air and applying the conservation of energy, for steady-state conditions, and Newton's law of cooling to the temperature nodes shown in figure we get the following equation

$$q = (T_{outlet} - T_{inlet})$$

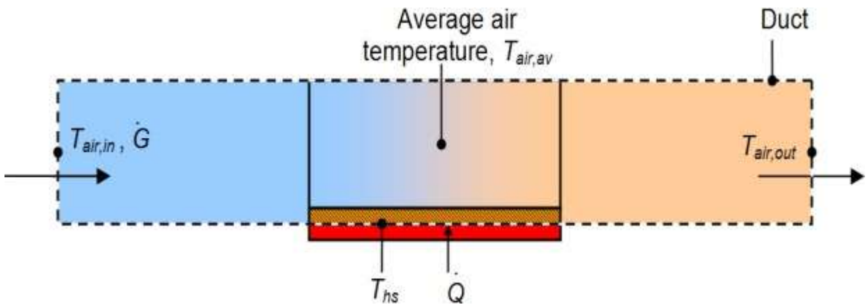
where,

m = Mass flow rate

Cp = Specific Heat

T_{outlet} =Temperature of air at outlet

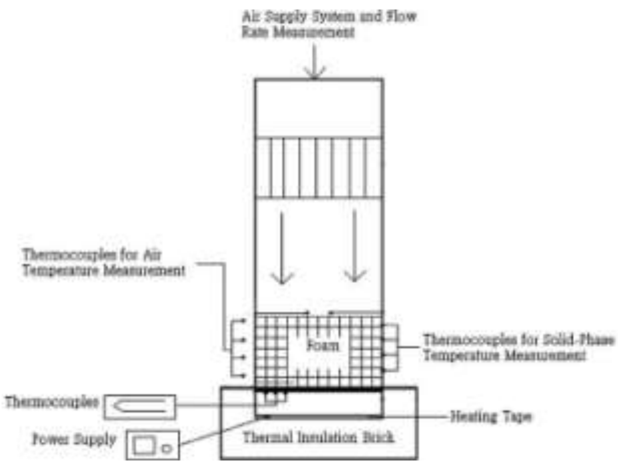
T_{inlet} = Temperature of air at inlet



Sketch of Heat Sink in a duct used to calculate governing equations

III. EXPERIMENTATION

The setup consists of a thermal insulating base which holds the heater, heating plate and foam. Heater is provided to heat the foam block to suitable temperature. The foam block to be tested is placed on base plate. Digital Temperature sensors are placed at various locations as shown in the figure. To measure the inlet air temperature probe of sensor is placed at a distance of 10 mm from fan. To measure the outlet air temperature probe of sensor is placed at a distance of 5 mm from foam block. The goal of the experiment is to measure the hydraulic and thermal performance of the open cell metal foam heat sink in a forced convection flow arrangement. The concept is to direct the air flow through a rectangular channel in which the copper foam heat sink is placed, occupying the entire cross- section of the channel. A heater is attached to the foam via the heat spreader plate through which the heat is conducted and eventually convected into the coolant stream. The characterization of the open-cell metal foam heat exchangers includes measuring the temperature of the heater block, the temperature of the heat spreader plate, the air temperature at inlet & outlet of heat sink, the power delivered to the heating device.



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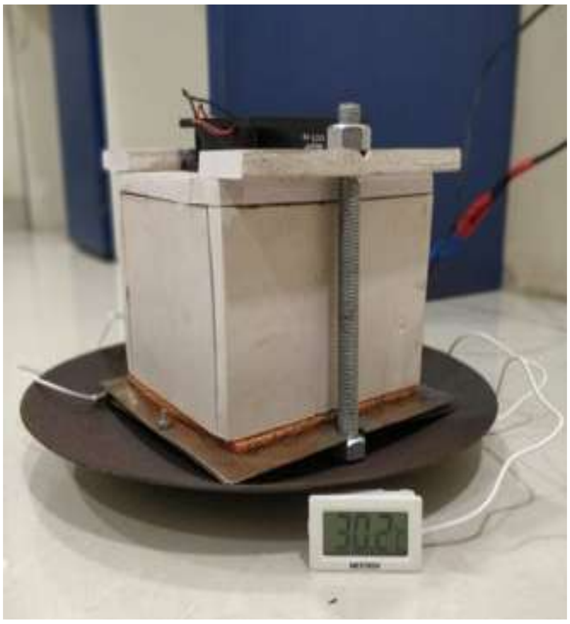
Experimental apparatus for the measurements of heat transfer characteristics of heat sinks



IV. OBSERVATIONS AND RESULTS

Observations in K

Parameters	Values
Surface Temperature $T_{surface}$	338 K
Inlet Temperature T_{in}	304 K
Outlet Temperature T_{out}	314 K
Mass Flow Rate $\dot{m}$	0.0301 kg/s
Air Velocity v	2.0 m/s

V. RESULTS

Showing values of Re, Nu, h, R_{th}

Sr. No	Air velocity	h	Nu	Re	R_{th}
1	2	0.68	3.22	1535.8	112.21

VI. CONCLUSION

The overall outcome of results to be observed and are evaluated to conclude the objectives. Our first objectivewas to calculate the heat transfer characteristics of copper foam heat sink and was all almost achieved. More specifically, next objective, the weight of metal foam heat sink was calculated and compared with the weight of metal fin which concludes that metal foam heat sink is a lighter heat sink.However, our final objective, to measure thermal performance parameters i.e., Nusselt Number, Reynolds Number, thermal resistance was calculated. We are confident though that this objective of installing it as a heat sink in CPU can be met if more time for testing and facilities is given. This design is very realistic for the future for enhancing increasing demand for lightweight materials in miniaturisation of electronic components.

SOME OF THE ADVANTAGES FROM THE ABOVE RESULTS

a)Reduction in size and weight
b)Effective heat transfer coefficient.
c) Large exchange surface area.
d)Effective thermal, mechanical and acoustic properties.

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