A Study and Analysis on the Thermal Performance of a Pin Fin Heatsink for Natural Convection using CFD

Hari Raghavan.J
Department of Mechanical Engineering
The Oxford College of Engineering
Bangalore, India

Rangu.P
Department of Mechanical Engineering
The Oxford College of Engineering
Bangalore, India

***Abstract*—Thermal problems can be solved by a cheapest, simple and best means by using heatsinks. Where there is a need to dissipate the heat from a hot body to another medium, heatsinks are used. The heatsink application is widely spread across many domains. In this paper, we would like to understand the thermal benefits of using a porous pin fin heatsink when compared to a conventional pin fin heatsink. The cross section of the heatsink used in the analysis is square shaped. The Heatsink is to be analyzed numerically for natural convection assuming steady state condition. Finite volume method is considered for doing the thermal analysis using a Computational Fluid Dynamics tool called FloTHERM.**

Keywords*— Cheapest; electronic component; heat sink; porous fin; thermal analysis; natural convection; FloTHERM; finite volume method

I. INTRODUCTION

The heat can be dissipated by attaching the heatsink to the surface of the hot body [1]. Several design parameters needs to be taken into account before designing a heatsink [2-5]. The parameters in the design of heatsink include arrangement of fins along with the cross sectional shape, number of fins, material, surface finish in case of natural convection solutions, inclination of fins etc., [6-14]. The parameters of the heat sink are determined based on nature of fluid flow. The fluid flow parameters into consideration are air flow properties, quantity of power dissipation, design for manufacture, cost for manufacture, type of fluid, pressure drop, etc.,

Pin fin heatsinks are predominantly used in natural convection problems. Modest cooling requirements are highly dependent on pin fin heat sinks for heat dissipation. Pin fin heatsinks are advantageous in natural convection solutions as the heat per unit mass heat dissipation is high [16]. There are many studies being conducted for improvisation in the efficiency of pin fin heat sinks [17-21]. Advancement in the performance is done by modifications in length and diameters of pins, void fractions of pins, aspect ratio of pins and distance between adjacent fins [22-27].

Based on the need for providing effective thermal solutions various kinds of pin fin optimization were considered in the recent decade or so and thus lead to the design of porous or slotted square fins, hollow pin fins and splayed-pin fin heatsinks. The pin fin heat sink design is purely based on the deployment circumstances in the design of the heatsinks.

II. MODELLING

The proposed model of the pin fin heatsink is that of an unconventional modelling of heatsink. It can be known as porous or slotted fin heat sink. The base of the new pin is same as before but there are slots or pores in the fins of the heatsink. More vividly, it can be considered as a porous pin fin heatsink.

In Fig. 1, the isometric view of conventional square shaped fin pin fin heat sink with material as Aluminum is shown and in Fig. 2, the isometric view of porous pin fin heatsink with material as Aluminum is shown. In Fig. 3, the isometric view of porous pin fin heatsink with material as Aluminum is shown. It can be seen that the only difference is the pores in the fins of the heatsink. In Fig. 2, the porous pins are slotted with a pore of 11 mm in length and 3 mm in width.

Heat transmission is considered to be started from the heatsink base. It is assumed that no other heat source is connected to the heatsinks.

The heat is transferred to the heatsink in the form of solid conduction. There is a thermal interface material added in between the surface of the hot body and the heatsink to deflect the thermal barrier in between them. The heat transmission between the solid body and the ambient air is happened by convection.

The heat source also is modelled with the dimension of 54 mm in length and 54 mm in width. The thermal resistances that are considered for the hot device is the resistance from junction to board is taken as 3.5 K/W and the resistance from junction to case is taken as 0.2 K/W.

The interface material is modelled as a conducting block and it is placed in between the hot device and the pin fin heatsink in all the cases of the design. The thermal interface material was modelled to eliminate the surface irregularities arising due to micron level unevenness in the flatness due to the manufacturing of the components.

The modeling was done with Computational Fluid Dynamics tool known as FloTHERM.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 05, May - 2017

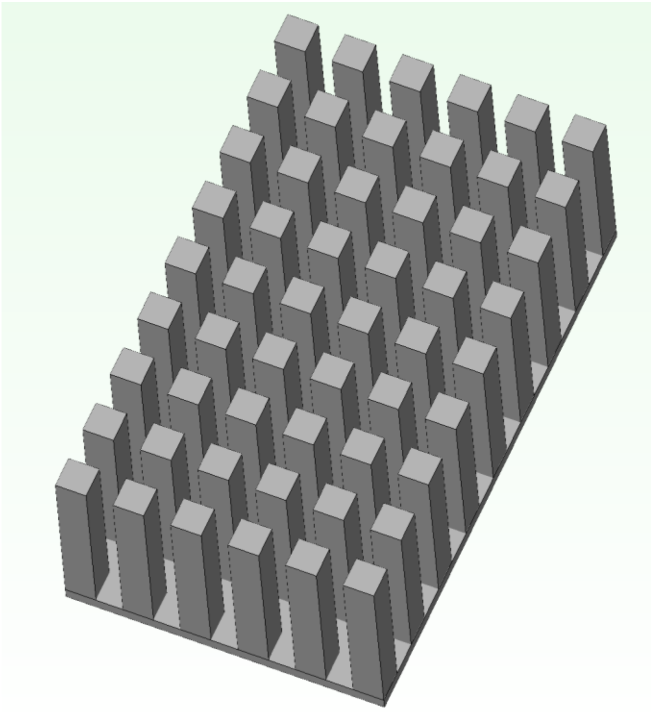

Figure 1: Conventional Aluminium Inline pin fin heatsink
(Isometric view)

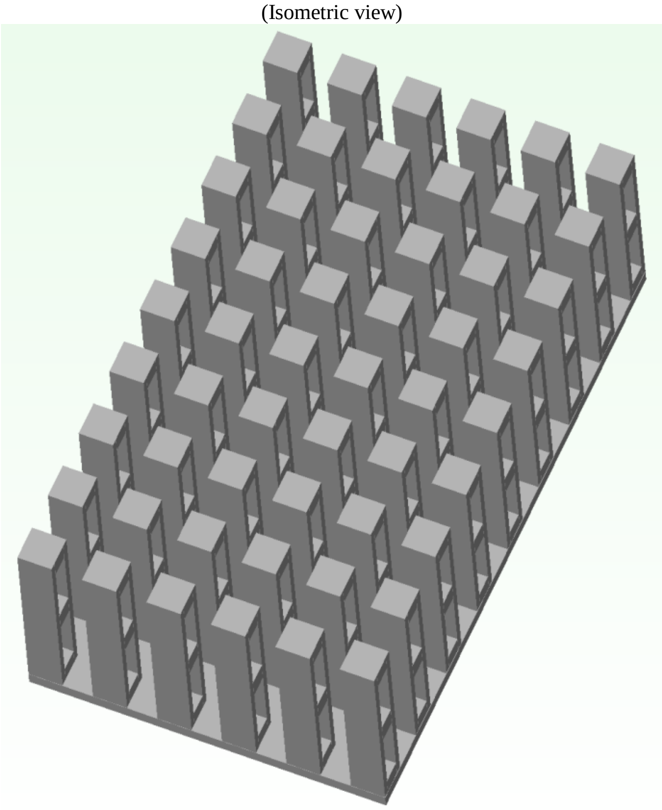

Figure 2: Slotted or porous Aluminium Inline pin fin heatsink
(Isometric view)

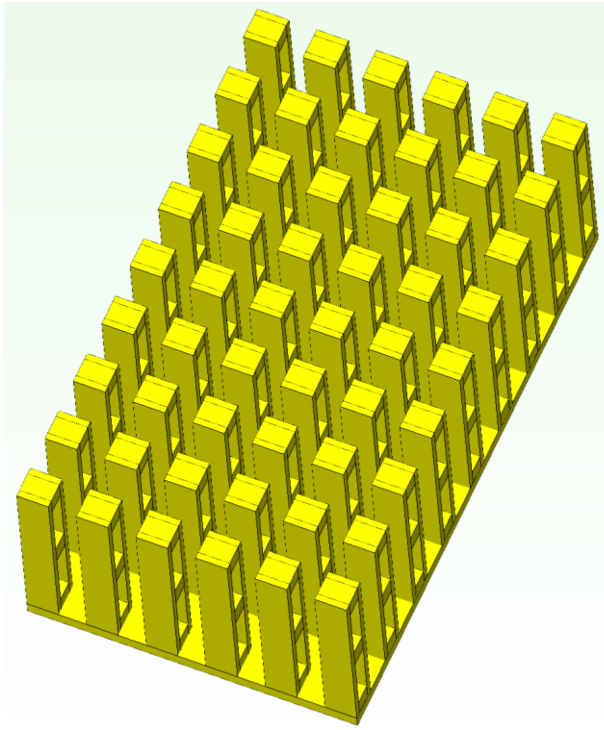

Figure 3: Slotted or porous Copper Inline pin fin heatsink
(Isometric view)

A. Physical Model and the Geometric Parameters

The physical model of the conventional square shaped pin fin heatsink, used here, is expressed with isometric view of the model as shown in Fig. 1. The length, width and height of the sink are expressed with L, W and H respectively. Under fixed volume condition, these three parameters will exactly be the same for the slotted or porous pin fin heat sink.

The geometric parameters used for both of the models are as follows:

- Sink length, L = 88 mm
- Sink width, W = 52 mm
- Sink height, H = 31 mm
- Thickness of the baseplate, t = 2 mm
- Fin number, N = 54
- Length and width of the square fin edge attached to the base of the heatsink, L_f = 5 mm, W_f = 5 mm.

The pins dimension are the same for the porous heatsinks except that there are two pores or slots with a dimension as follows:

- Pore length, L_p = 5 mm
- Pore width, W_p = 3 mm
- Pore height, H_p = 11 mm
- Pores are distanced at 2.9 mm from the base of heatsink.
- Two pores are kept apart from each at a distance of 3.2 mm

The thermal interface material used in the design in between the heatsink and heat source is as follows:

- Interface length, L_t = 45 mm
- Interface width, W_t = 45 mm
- Interface height, H_t = 0.2 mm

B. Assumptions

The subsequent conditions are assumed to be true for the analysis:

- The working medium, air is incompressible throughout the process.
- The air flow is happened by natural convection.
- Convection heat transfer coefficient is uniform.
- The temperature of the sink does not change with time.
- No existence of heat source is included in the sink itself.
- Bottom face of the baseplate receives the heat from the heat source first.
- The bottom face of the baseplate has uniform temperature.
- Heat transfer by radiation is considered with an emissivity of 0.8.
- Contact resistance between the baseplate and the fin material is considered.
- Sink material used for the analysis is isotropic and homogenous.

C. Boundary Conditions

The following boundary conditions are applied for the analysis:

- Bulk ambient temperature. T_a = 303 K (i. e. 30°C)
- Convective heat transfer coefficient, h = 22 $W/m^2.K$
- Power of the heat source, P = 20 W

D. Material Properties

Frequently used heatsink materials such as Aluminum alloys and Copper alloys have been used to continue the analysis.

Some common parameters related to the properties of Aluminum alloy 6061are mentioned as follows:

- Thermal conductivity: 170 W/m.K
- Density: 2700 Kg/m3
- Specific Heat: 1300 J/Kg.K
- Thermal expansion coefficient: 24×106 K-1
- Melting point: 650°C

Some common parameters related to the properties of pure Copper are mentioned as follows:

- Thermal conductivity: 385 W/m.K
- Density: 8930 Kg/m3
- Specific Heat: 385 J/Kg.K
- Thermal expansion coefficient: 17×106 K-1
- Melting point: 1085°C

III. THERMAL ANALYSIS

The simulation, used for the thermal analysis, was carried out in an environment of FloTHERM Simulation with the help of finite volume method. Three steps had to be executed to complete the analysis: pre-processing, solver execution and post-processing.

Figure 4: Conventional Inline pin fin (side view)

Figure 5: Slotted or porous Inline pin fin heatsink (side view)

In Fig 4, the side view of the convectional inline pin fin heatsink is shown and in fig 5, the side of porous inline pin fin heatsink is shown. The heatsink are same for both material heatsinks.

In the Fig 6, the temperature monitor graph is shown. The graph has the number of iterations and the Temperature (°C) in the x-axis and y-axis respectively

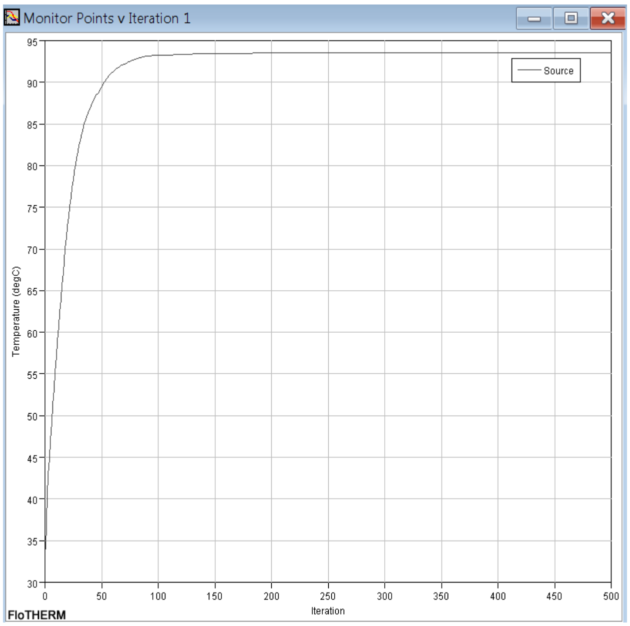

Figure 6: Temperature monitor graph for convetional pin fin heatsink

After the selection of material, boundary conditions were specified. Then, solid mesh was created. Standard mesh with

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 05, May - 2017

fine quality was selected for the mesh generation. The simulation was run afterward.

The temperature is taken as the measurement of the heatsink from the graph, once the curve has stabilized.

These graph show us the temperature stabilization during the performance of thermal simulation for a given condition in the FloTHERM solver.

As a result the temperature contours of the different heatsinks that simulations were performed have their temperature contours displayed in the figures shown.

In Fig 7, the thermal simulation results of the aluminum conventional inline pin fin heatsink are shown.

In Fig 8, the thermal simulation results of the aluminum porous inline pin fin heatsink are shown.

In Fig 9, the thermal simulation results of the copper porous inline pin fin heatsink are shown.

These temperature contours from the thermal results helps us to interpret the results of the analysis carried out.

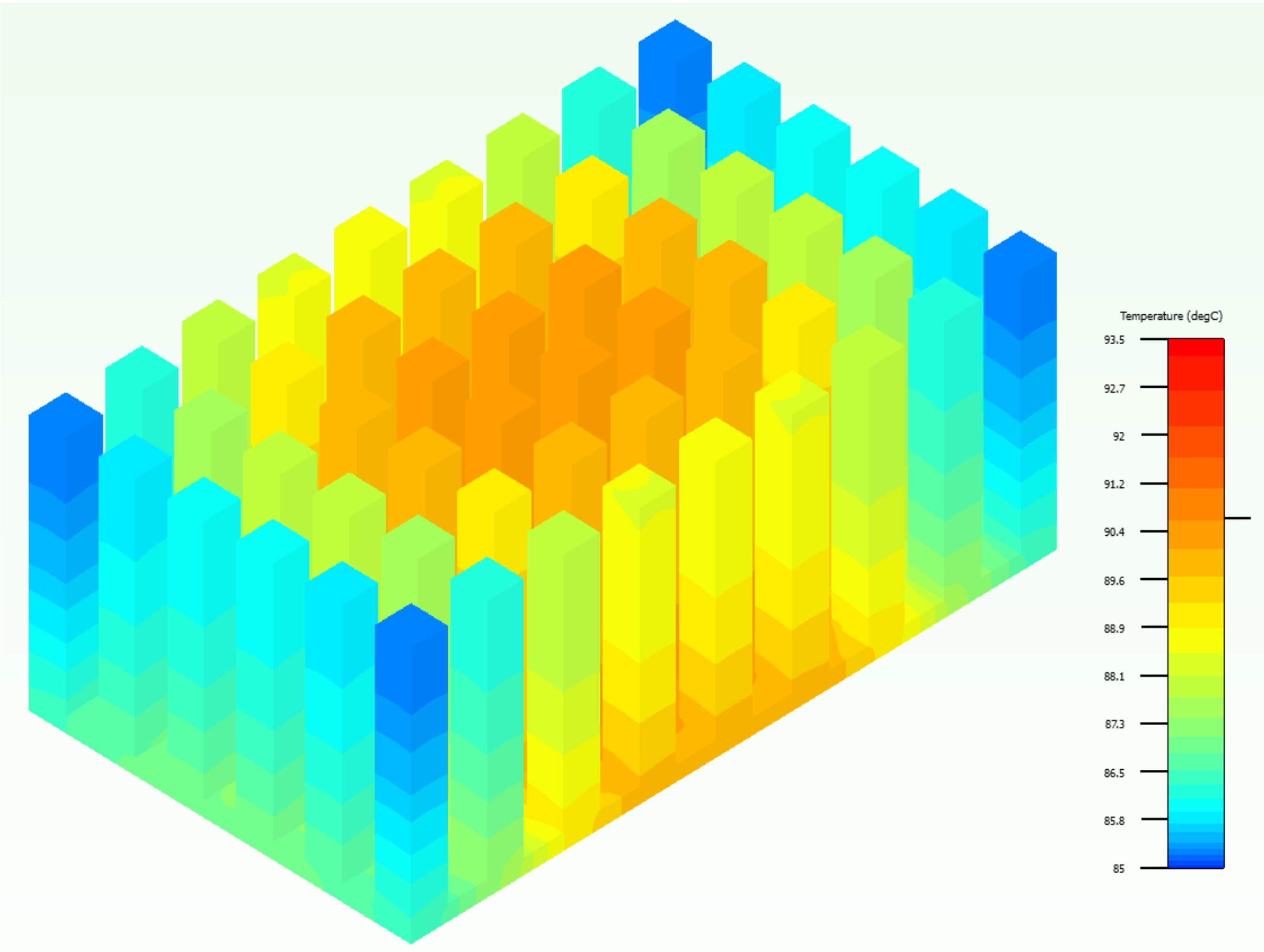

Figure 7: Thermal simulation results of Aluminum conventional pin fin heatsink

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 05, May - 2017

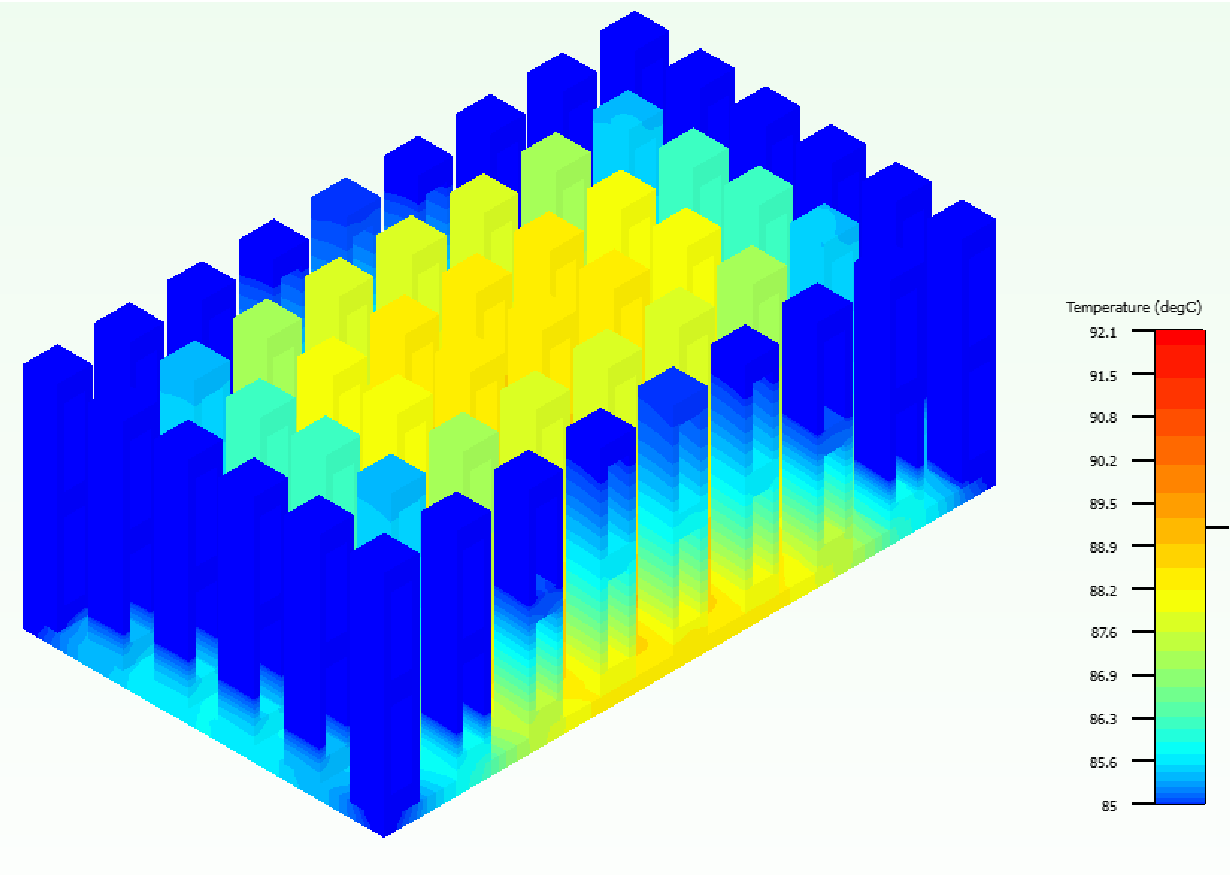

Figure 8: Thermal simulation results of Aluminum porous pin fin heatsink

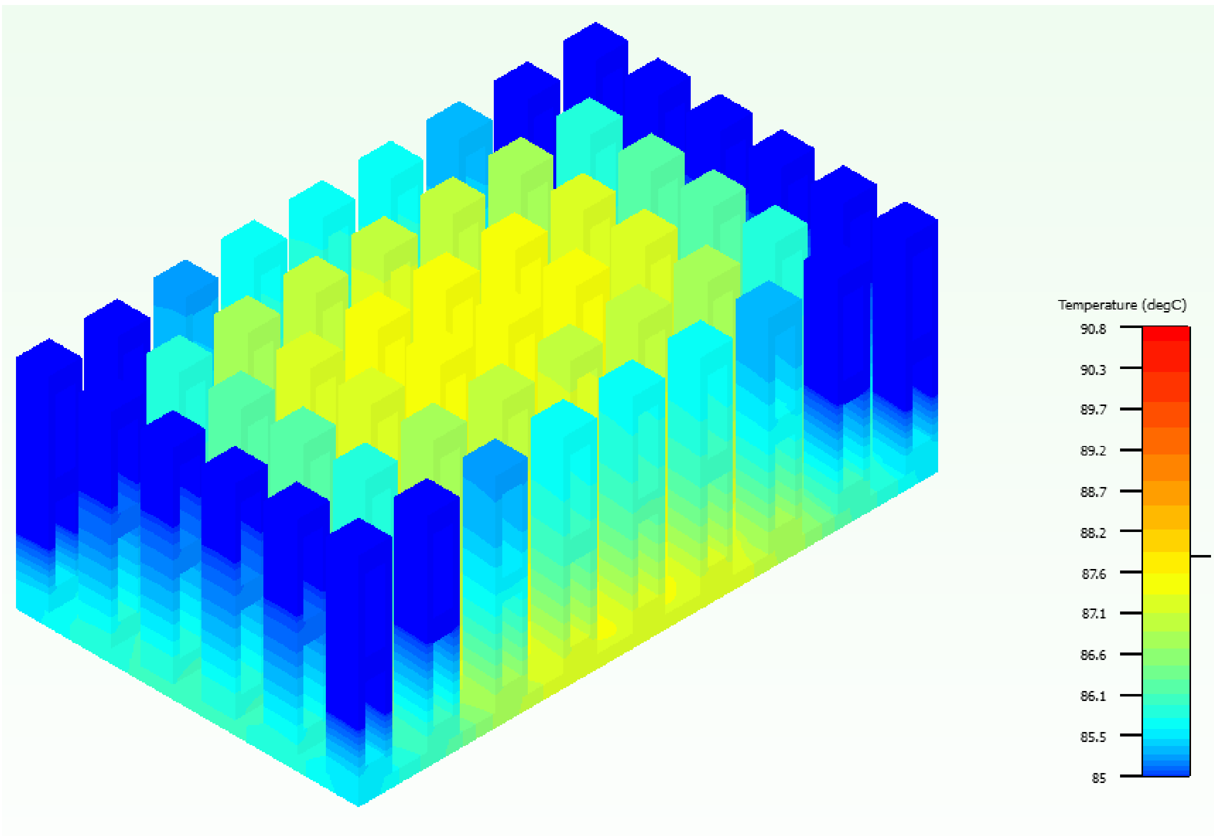

Figure 9: Thermal simulation results of Copper porous pin fin heat

IV. RESULTS AND DISCUSSION

The final results obtained from the FloTHERM Simulations are visually illustrated in Fig. 7, Fig 8 and Fig 9. The color of the solid body indicates the temperature of it. As the body gets more red, the more temperature it indicates and the more violet it gets, the less temperature it indicates.

A more detailed illustration of the whole simulation is provided in Table I & II. It is seen that the finite volume method was carried out with acceptable characteristics. The maximum temperature of the conventional pin fin heat sink with aluminum as material is found to be 93.5 ℃ and that of the porous pin fin heat sink with aluminum as material is found to be 92.1 ℃. Further, the porous pin fin heat sink with copper as material is found to be 90.8 ℃. So, the porous pin fin heat sink with copper as the material has mitigated the temperature roughly about 2.5 ℃.

TABLE I.

Information, Properties and Studies	**Heat sink characteristics**			
	Description	***Conventional heatsink***	***Aluminum Porous heatsink***	***Copper Porous heatsink***
Solid body properties	Model type	Linear Elastic Isotropic	Linear Elastic Isotropic	Linear Elastic Isotropic
	Material	Al-6061	Al-6061	Pure Copper
Mesh Information	Mesh quality	High	High	High
	Total elements	704340	705430	705430
	Maximum aspect ratio	6.34	6.34	6.34
Temperature	Maximum heatsink temperature	93.5° C	92.1° C	90.8° C
	Maximum hot source temperature	93.52° C	92.08° C	90.8° C

V. CONCLUSION

In the present study, the designed model of the porous pin fin heat sink has been devised using the virtual tools. The conventional model of pin fin heat sink was also created in the same virtual tool for comparison. Thermal analysis of the conventional model and the porous model was analyzed and studied successfully. It is clear from the study and numerical analysis that in the practical environment the porous pin fin heat sink will perform better than the conventional one. This kind of modification can be applied for special conditions, especially, when there is no possibility of changing the physical dimensions of the heatsink due to the placements constrains.

Future work of this study may include the optimal size of the pore, performance with good thermal conductivity materials for the porous pin fin heat sink and performance of porous pin fin heat sink for forced convection.

ACKNOWLEDGMENT

This paper is of great enormity and it can't be accomplished by an individual all by him. Eventually, we are grateful to a number of individuals whose professional guidance, assistance and encouragement have made it a pleasant endeavor to undertake this paper.

We take this opportunity to express our profound gratitude to Shri. G. Madhu sudana Reddy for his support and guidance.

We are grateful to The Head of the Department Dr. G. Srinivas Bhatt for his unfailing encouragement and suggestion given to us in the course of my paper publication.

REFERENCES

[1] W. E. Goldman, "An introduction to the art of heat sinking(Heat sink construction for semiconductor devices)", Electronic Packaging and Production, 1966.

[2] Amit Md. Estiaque Arefin, "Thermal analysis of modified pin fin heat sink for natural convection", 2016 5th International Conference on Informatics, Electronics and Vision (ICIEV), Year: 2016, pp. 1 - 5,

[3] T. Zapach, T. Newhouse, J. Taylor, P. Thomasing," Experimental verification of a model for the optimization of pin fin heatsinks", ITHERM 2000. The Seventh Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems, (Cat. No.00CH37069) Year: 2000, Volume: 1, pp. 69.

[4] K. P. Keller, "Cast heatsink design advantages", Thermal and Thermomechanical Phenomena in Electronic Systems, 1998. ITHERM '98. The Sixth Intersociety Conference on Year: 1998, pp. 112 – 117.

[5] A. Shah, B. G. Sammakia, H. Srihari, K. Ramakrishna, "A numerical study of the thermal performance of an impingement heat sink-fin shape optimization", IEEE Transactions on Components and Packaging Technologies, Year: 2004, Volume: 27, Issue: 4, Pages: 710 – 717.

[6] N. D. Fitzroy, "Optimum spacing of fins cooled by free convection",Transactions of the ASME Journal of Heat Transfer. pp. 462-466, 1971

[7] H. Jonsson, and P. Bjorn, "Experimental comparison of different heatsink designs for cooling of electronics", American Society of Mechanical Engineers, Heat Transfer Division, HTD, Vol. 329, No. 7, Association of Mechanical Engineers, New York, 1996, pp. 27–34

[8] K. S. Sujatha and C. B. Sobhan 1996. Experimental studies on natural convection heat transfer from fin arrays. J. of Energy, Heat and Mass Transfer. 18: 1-7

[9] M. Iyengar and A. Bar-Cohen, "Least-material optimization of vertical pin-fin, plate-fin, and triangular-fin heat sinks in natural convective heat transfer", Thermal and Thermomechanical Phenomena in Electronic Systems, 1998, ITHE

[10] H. Yuncu and G. Anbar 1998. "An experimental investigation on performance of fins on a horizontal base in free convection heat transfer", Sprigler-Verlag Heidelberg, Heat and Mass Transfer. 33: 507-514

[11] M. Behnia, D. Copeland, and D. Soodphadakee, 1998, "A comparison of heat sink geometries for laminar forced convection", Proceedings of The Sixth Intersociety Conference on Thermal and Thermo mechanical Phenomena in Electronic Systems, Seattle, Washington, USA, May 27–30, pp. 310–315

[12] A. Bar-Cohen, M. Iyengar, and A. D. Kraus, 2003, "Design of optimum plate-fin natural convective heat sinks," ASME J. Electron. Packag., 125(3), pp. 208–216

[13] M. Iyengar, and A. Bar-Cohen, 2001, "Design for manufacturability of SISE parallel plate forced convection heat sinks," IEEE Trans. Compon. Packag. Technol., 24(2), pp. 150–157

[14] C. W. Leung and S. D. Probert 1997. Heat-exchanger performance: influence of gap width between consecutive vertical rectangular fin arrays. Applied Energy. 56: 1-8

[15] Y. Joo, S. J. Kim, "Comparison of thermal performance between platefin and pin-fin heat sinks in natural convection", International Journal of Heat and Mass Transfer Vol. 83, pp. 345–356, 2015

[16] P. A. Deshmukh and R. M. Warkhedkar, "Thermal performance of pin fin heat sinks—a review of literature", Int. Review of Mechanical Engineering, V. 5. N. 4, pp. 726-732, 2011

[17] A. A. Sertkaya, S. Bilir and S. Kargıc, "Experimental investigation of the effects of orientation angle on heat transfer performance of pinfinned surfaces in natural convection", Energy 36: 1513-1517, 2011

[18] A. I. Zografos, and J. E. Sunderland, "Natural convection from pin fin arrays," Exp. Thermal and Fluid Sci., vol. 3, pp. 440-449, 1990

[19] T. Aihara, S. Maruyama and S. Kobayakawa, "Free convective/radiative heat transfer from pin-fin arrays with a vertical base plate (general representation of heat transfer performance)", Int. J. of Heat and Mass Transfer 33(6): 1223-1232, 1990
[20] H. H. Jung, and J. G. Maveety, "Pin fin heat sink modeling and characterization", Sixteenth IEEE Semi-Therm Symposium, IEEE Publications, Piscataway, NJ, March 2000, pp. 260–265
[21] E. Yu and Y. Joshi, "Heat transfer enhancement from enclosed discrete components using pin-fin heat sinks", Int. J. of Heat and Mass Transfer 45:4957-4966, 2002
[22] K. Azar and C. D. Mandrone, "Effect of pin fin density of the thermal performance of unshrouded pin fin heat sinks", ASME J. of Electronic Packaging 116: 306–309, 1994

[23] D. K. Kim, "Thermal optimization of plate-fin heat sinks with fins of variable thickness under natural convection", Int. J. Heat Mass Transfer 55: 752–761, 2012
[24] H. S. Kang, "Optimization of a pin fin with variable base thickness", J. Heat Transfer, 132, pp. 034501-1-4, 2010
[25] E. M. Sparrow and S. B. Vemuri, "Natural convection/radiation heat transfer from highly populated pin fin arrays", J. of Heat Transfer 107: 190 – 197, 1985
[26] M. E. Lyall, A. A. Thrift, K. A. Thole, A. Kohli, "Heat transfer from low aspect ratio pin fins", J. Heat Transfer, 133, pp. 011001-1-10, 2011
[27] N. K. C. Selvarasu, D. K. Tafti, N. E. Blackwell, "Effect of pin density on heat-mass transfer and fluid flow at low Reynolds numbers in mini channels", J. Heat Transfer, 126, pp. 061702-1-8, 2010