Steady State Thermal Analysis of Heat Sinks having Different Types of Fins with Different Types of Perforation Using ANSYS

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ABSTRACT

This paper introduces the way of heat extraction from heated sink by using different shapes of extended surfaces (fins) under natural convection. Finned heats sinks are used to cool power electronic Components. The shape which is used is of Hollow rectangular fin (HRF), Hollow circular fin (HCF), Hollow elliptical fin (HEF). They are provided with perforation of different shape such as rectangular, triangular, square, circular and elliptical. The heat sink i.e. base is of dimension (l×b×h) 70×60×10 mm and height of the fin is 70 mm. As per industrial demand there are numerous of research are going on to enhance the thermal transmission from the surface of the heat sink through fins and this is done by increasing the contact surface area. The Perforations on the hollow fins are done to achieve the maximum contact surface area. This results in improved rate of heat dissipation from the surface of the fin. All the fins are designed using SOLIDWORKS and the thermal properties are analyzed by using ANSYS R13 Workbench. The main aim of this research is to observe variation of thermal properties such as temperature distribution, total heat flux and direction heat flux over the different shapes of fins having different perforations. There are many materials which have good thermal conductivity such as copper, stainless steel and aluminum. As compare to aluminum, copper and stainless steel have better thermal conductivity but here aluminum is selected as fin material as it is lighter in weight as well as good thermal conductor.

Keywords - Extended surface, Fin, Perforation, Heat sink, Natural convection, ANSYS R13 Work bench, SOLIDWORKS

1. INTRODUCTION

Enhancement of temperature drop is the key designed challenges for thermal and electronic devices due to its small shaped design. Natural convection-cooling through the designed fin is the most popular way as it does not need of fan or pumps, which is the cause of the most failure. Natural convection results due to bouncy forces as surrounded air comes in contact with the fin surface which results in heating of air due to which air density decreases and fresh air replace itA circulatory heat flow is created all over the finned-surface due to the sinking of denser air and rising hot air[1].

Extended surfaces (Fins) are popularly used in heat exchanging devices. Fins are generally enhanced by either decreasing the fin weight at a specific heat removal capacity or increasing thermal transfer rate at a specific fin weight. Extended surfaces are enhanced by utilizing surface or geometrical modification to the flow channel by adding additional devices. These processes are generally followed in different industrial application to enhance thermal dissipation rate between the heat sink and surrounding fluid.

Creating perforations on the periphery of the fins is the most useful method for enhancing thermal dissipation. Implementation of perforations on the fin surfaces increase the contact area results in improved thermal transmission and at the same time decreases the cost of the fin material [2].

Many designs of Fins are abundant in commercially and in academic literature. But there exits exploration of the improvement in thermal dissipation by reducing the material cost. As well perforated fins are lighter in weight than the solid fins; they were popularly applicable where weight of the instrument is one of the considerable points [3]. Perforated fins shows better contact surface with the fluid when compare to their solid counterparts in comparison with the solid fins. As well perforated fins have higher friction and low pressure drag than solid fins [4].

There exits two techniques to enhance the thermal transmission rate, they are Active and Passive methods. Active method is complex as it needs extraneous power supply input for required flow adjustment and to enhance the thermal transmission rate and thus application are limited. But in Passive method, there is need of geometrical or surface adjustment to the flow passage by including additional devices.

2. LITERATURE REVIEW

R.C. Adhikari et al. [1] **"**Optimizing rectangular fins for natural convection cooling using CFD". They investigated the combined effect of the spacing between the fins and height and length of fin by using multi-parametric computational fluid dynamics (CFD). They observed that there is more thermal transmission per unit base area and the maximum thermal transfer per unit base area and fin weight due to application of fin spacing, height and length.

Ambarish Maji et al. [2] **"**Thermal Analysis for Heat Transfer Enhancement in Perforated Pin Fins of VariousShapes with Staggered Arrays". In this paper researchers found that thermal transmission is elevated by using staggered fin with different types of perforation such as circular, diamond shaped and elliptical type. They carried out CFD simulation and results also shows that thermal transmission of perforated fin up to a certain number of perforation more than the solid fins.

Vidyadhar Karlapalem et al. [3] "Design of perforated branching fins in laminar natural convection". This research paper investigates the two orientation fin vertical base horizontal fin and horizontal base vertical fin with single perorated branching fins. They varied the size of perforation between 1.1 mm to 6.6 mm. They found that perforation in vertical base horizontal fin orientation results in higher thermal dissipation over solid fins, at any pore size and distribution. They also found for certain pore distribution shows lesser thermal extraction than the non-perforated in horizontal base vertical fin orientation. This is due to feeble contribution of pore in fin-stem.

Ambarish Maji et al. [4] "Computational Investigation of Heat Transfer Analysis through Perforated Pin Fins of Different Materials". This paper investigates the effect of material of fin and the number of perforation on thermal transmission. They performed CFD simulation and they found that copper perform better than aluminum. They also found that for different materials shows increasing thermal transmission with the increase of perforation at certain number (5) and diameter of perforation up to 3mm. The pressure drop through heat sink decreases with increasing number and size of perforation. Perforated fins work better than solid fins. There is variation in pressure drop with respect to the materials.

Ambarish Maji et al. [5] **"**Improvement of heat transfer through fins: A brief review of recent developments". This review paper presents a reviewon heat transfer increment using fins different types of fin like porous, perforated. Porous fins transfer better heat as compared with solid ones of the same size and weight by increasing the area of convection.The perforated fins have much higher contact surface with the fluid possessed to it with compare to solid fins. They also proposed the used of different material such as aluminum, HSS, copper. They concluded that using perforation of different geometries also influence the transmission of heat through fins. Variation of Reynolds number, Nusselt number, and pressure drop can be analyzed through fins with variable perforations and these can be compared with a no perforated fin. The fin with smaller perforations gives a better thermal transmission. The micropinfin surface has a better thermal transmission rate than the smooth surface. CHF as well as heat transfer coefficient also increases in the composite micro/nano-structured surface rather than the smooth surface. On the other hand, CHF and heat transfer performance is much more effective around a bi-structured surface.

3. DESIGN AND BASIC PARAMETERS

SOLIDWORKS software is used to design the heat sink with different types of fins. The SOLIDWORKS software is user friendly software use to design 2-D and 3-D objects fluently. It is a Mechanical design automation application that lets designers quickly sketch out ideas, experiment with features and dimensions and produce models and detailed drawings.

The following steps are used to draw the design:-

i. Heat sink is designed having dimension L×B×H= 80×65×10 mm

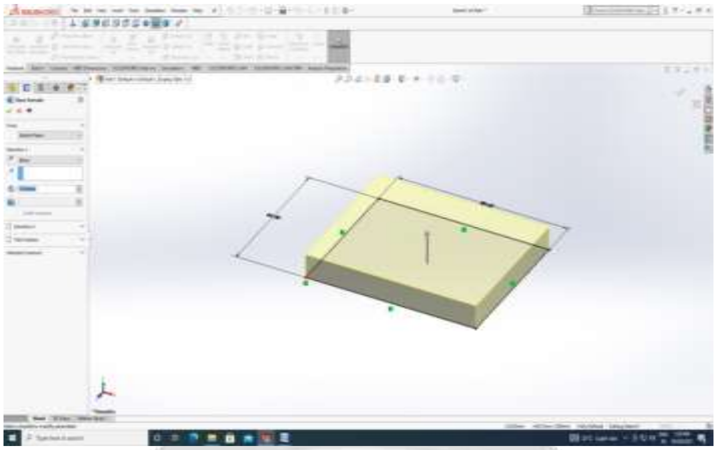


Fig.3.1 Design of Heat Sink (Isometric view)

ii. Length of the Fin= 70 mm

iii. Numbers of each Fin = 9

a. Circular Fin = Outer Diameter = 15mm

Internal Diameter = 10 mm

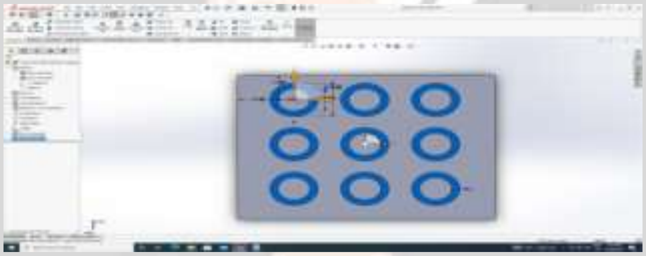


Fig.3.2 Hollow Circular fin (Top View)

b. Rectangular Fin

Outer Dimension = 20×10 mm

Inner Dimension = 10×5 mm

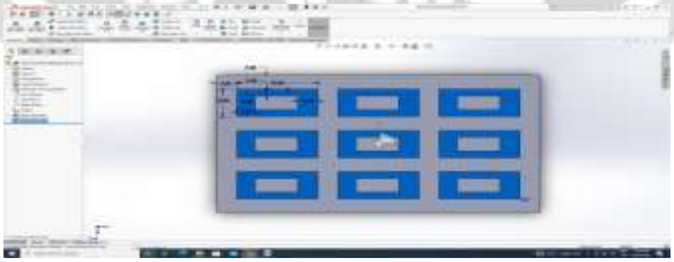


Fig.3.3 Hollow Rectangular Fin (Top View)

c. Elliptical fin

Outer dimension= $D_{1=}$ 20 mm, D_2=10 mm

= Inner dimension= d_1=10 mm, d_2= 5mm

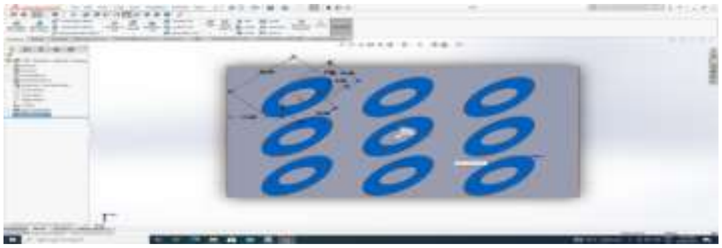


Fig.3.4 Hollow Elliptical Fin (Top View)

iii. There are different types of perforation is done on the peripheral of HCF, HRF and HEF. The perforations are-

a. **Circular holes**- They are of diameter 10 mm. There are four holes on one fin which is separated by distance of 5 mm. Hence there are total 36 holes.

Fig.3.5 Circular hole dimensions (Front view)

b. **Rectangular hole**- They are of dimension 10×5 mm. There are five holes on one fin which is separated by distance of 10 mm. Hence there are total 45 holes.

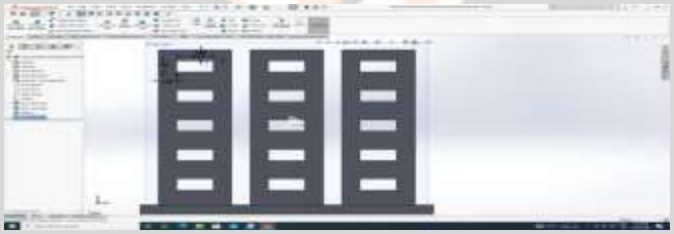


Fig.3.6 Dimension of Rectangular Hole (Front View)

c. **Square Hole** - They are of dimension 10×10 mm. There are four holes on one fin which is separated by distance of 10 mm. Hence there are total 36 holes.

Fig.3.7 Square Hole Dimension (Front View)

d. **Triangular Hole-** They are having sides of dimension 11.50 mm each.There are four holes on one fin which is separated by distance of 5 mm. Hence there are total 36 holes.

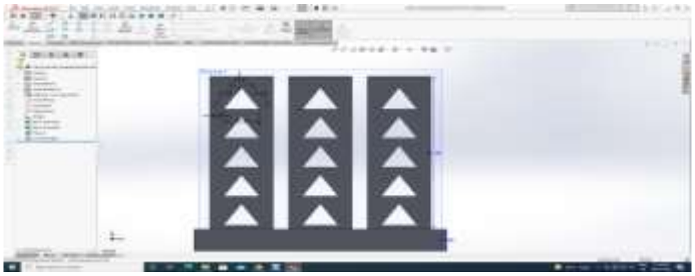


Fig.3.8 Triangular hole dimension (Front View)

e. **Elliptical Hole** – They are having D_1=10 mm and D_2 = 6 mm each.There are four holes on one fin which is separated by distance of 5 mm. Hence there are total 36 holes.

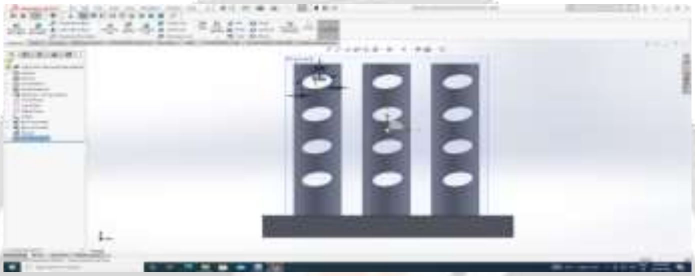


Fig.3.9 Elliptical hole dimensions (Front View)

4. ANALYSIS AND MATERIAL SELECTION

4.1 Steady State Thermal Analysis

Steady State Thermal analysis (SSTA) is done by using ANSYS 2019 R3 WORKBENCH. SSTA is advance simulation software used to analyze different Analysis such as static analysis, dynamic analysis, fluid flow analysis, thermal electric, transient thermal etc. ANSYS come up with a productive approach to explore the performance of products or processes in a virtual environment. This type of product development is termed virtual prototyping. With virtual prototyping techniques, users can iterate various scenarios to optimize the product long before the manufacturing is started. This enables reduction in the level of risk, and in the cost of ineffective designs.

4.2 Material Properties

The material selection is most important part as heat dissipation depends on thermal conductivity of materials. In this research aluminum alloy is selected as materials of fins and heat sink. Aluminum is one of the lighter elements and has good thermal conductivity as well. It is also cheaply available comparison to other materials. The properties of aluminum are tabulated in Table 4.1.

4.3 Mesh Generation

The Fin models are imported to the ANSYS Workbench and the mesh is generated. ANSYS meshing capabilities help to reduce the amount of time and effort spent to get accurate results. Since meshing typically consumes a significant portion of the time it takes to get simulation results, ANSYS helps by making better and more automated meshing tools. The meshed information’s of fins with heat sinks are shown in Table 4.2.

Steps involved in Steady State analysis:-

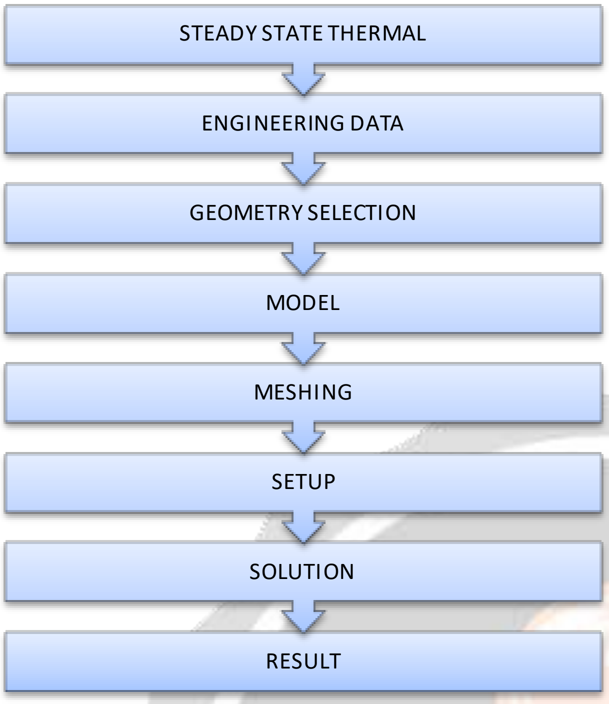


Table 4.1 Properties of Aluminum Alloy

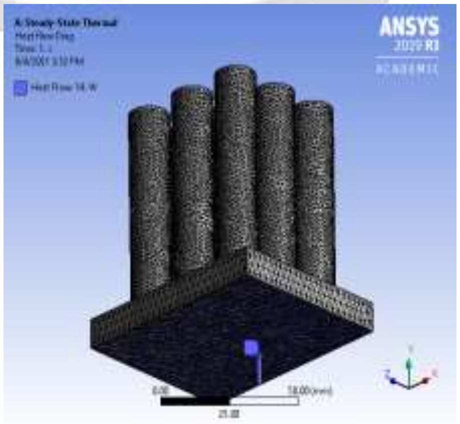
Density	$2.77\times10^{-6}mm^{-3}$
Coefficient Of Thermal Expansion	$2.3\times10^{-3}C^{-1}$
Specific Heat	$8.75\times10^{5}mJ\ Kg^{-1}\ C^{-1}$
Compressive Yield Strength	280
Tensile Yield Strength	280
Tensile Ultimate Strength	310
Young's Modulus	7100 M Pa
Poisson's Ratio	0.33
Bulk Modulus	69608 M Pa
Shear Modulus	26692 M Pa

Name of Fins	Element Size(mm)	Nodes	Element
Hollow Circular Fin (HCF)	1.35	239487	134430
HCF with Circular hole (CH)	1.20	229673	124744
HCF with Rectangular Hole (RH)	1.20	234024	126825
HCF with Square Hole (SH)	1.10	249419	134884
HCF with Triangular Hole (TH)	1.23	234568	128330

HCF with Elliptical Hole (EH)	1.20	243028	133992
Hollow Rectangular Fin (HRF)	1.05	208186	119008
HRF with Circular Hole (CH)	1.00	255844	124875
HRF with Rectangular Hole (RH)	1.00	233013	128970
HRF with Square Hole (SH)	1.00	218645	118686
HRF with Triangular Hole (TH)	1.05	233150	130252
. HCF with Elliptical Hole (EH)	1.00	233013	124612
Hollow Elliptical Fin (HEF)	0.95	210195	120795
HCF with Circular hole (CH)	1.20	229673	124744
HEF with Rectangular Hole (RH)	0.90	233369	127765
HEF with Square Hole (SH)	0.90	208436	113011
HEF with Triangular Hole (TH)	0.90	232328	128716
HEF with Elliptical Hole (EH)	0.90	216954	119628

Table: 4.2 Details of Meshed Fins

The Figures represents the boundary condition applied on the fin model analysis. Heat flow applied to all model is 14 W. Initial temperature is considered as 22^0C and coefficient of heat convection applied is 0.00006 W/mm$^{2\,o}$ C. Convection process is applied to all the other faces except where load is applied.

Entities	Diagram
Heat Flow	

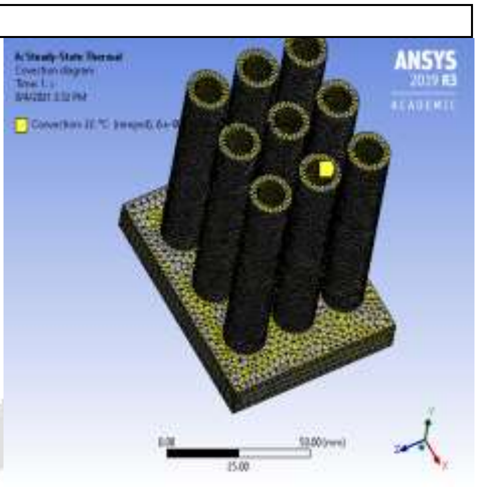
Coefficient of Convection	

Fig. 4.1 Heat Flow & Coefficient of Convection

5. SIMULATION PROCESS AND RESULTS

The designed heat sinks with different types of fins are imported to ANSYS R3 Workbench where steady state thermal analysis (SSTA) is performed applying 14 watt Heat flow at the bottom of the heat sink under ambient temperature 22^0C. On the other hand all the remaining surfaces undergo natural convection having co-efficient of convection 0.00006 W/mm^{20}C. By performing analysis under given conditions Temperature distribution along the surface of the fins, Total Heat Flux and Direction Heat Flux is obtained.

5.1 Heat sink of Hollow Circular Fin (HCF)

As Heat sink of HCF is imported to ANSYS Workbench and then analysis is done and we get the temperature distribution on the surface of heat sink. We obtain the maximum temperature of 64.758 ^{0}C and minimum temperature of 61.144 ^{0}C.

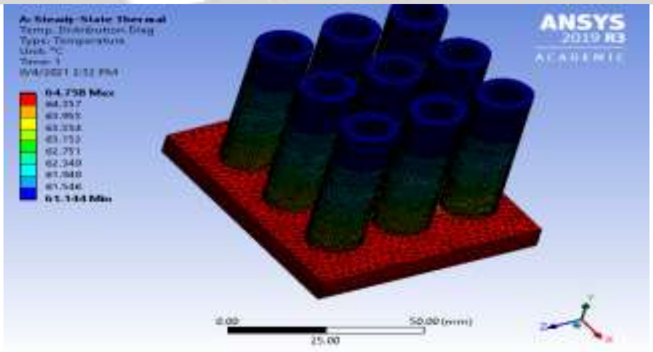


Fig. 5.1 Temperature Distribution of HCF (Isometric View)

As analyzing we get the total heat flux distribution of maximum amount of 0.020282 W/mm^2 and minimum 0.00019172 W/mm^2.
As analyzing we get the Directional heat flux distribution in the direction of X-axis of maximum amount of 0.010649 W/mm^2 and minimum -0.011475 W/mm^2.

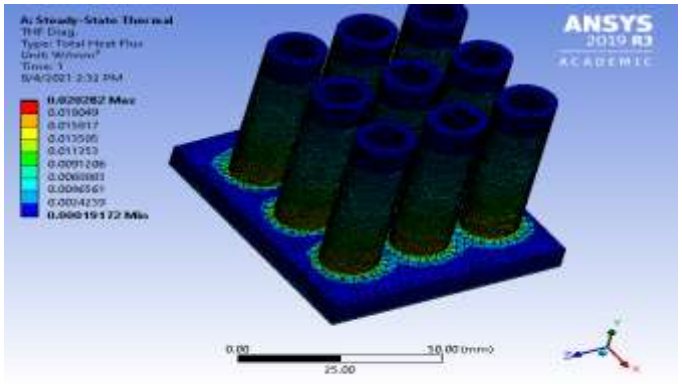


Fig. 5.2 Total Heat Flux Distribution of HCF (Isometric View)

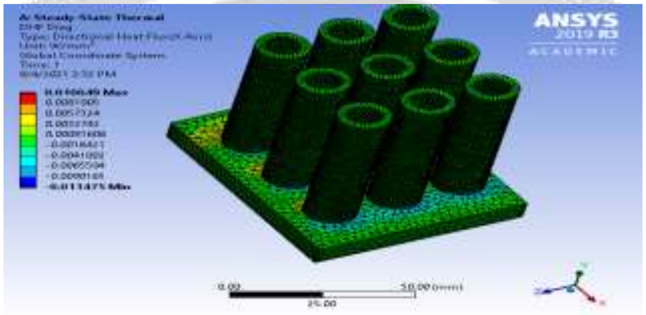


Fig.5.3 Directional Heat Flux Distribution HCF (Isometric View)

By going through all other designed hollow circular fin with CH, RH, SH, TH, EH, we get the temperature as given below.

Heat sink with		**Temperature(^{0}C)**		
		Max	**Min**	**Diff.**
HCF		61.144	64.758	3.644
HCF with	**CH**	64.364	70.017	5.657
	RH	65.892	72.458	6.566
	SH	65.157	71.729	6.572
	TH	61.260	67.142	5.882
	EH	62.207	67.281	5.074

Table 5.1 Variations of Temperature Hollow Circular Fin

5.2 Heat Sink of Hollow Rectangular Fin (HRF)

As Heat sink of HCF with TH is imported to ANSYS Workbench and then analysis is done and we get the temperature distribution on the surface of heat sink. We obtain the maximum temperature of 60.143 ^{0}C and minimum temperature of 57.602 ^{0}C.

	Total Heat Flux(W/mm^2	**Directional Heat Flux(W/mm^2**

Heat sink with		**^{0} C)**		**^{0} C)**	
		Max	**Min**	**Max**	**Min**
HCF with	**CH**	0.000066323	0.0557160	-0.0127230	0.0151480
	RH	0.000047822	0.0415860	-0.0264240	0.0259390
	SH	0.000052603	0.0487470	-0.0055164	0.0393440
	TH	0.000058511	0.0544940	-0.0183980	0.0147360
	EH	0.000129490	0.0779720	-0.0295510	0.0268670

Table 5.2 Variations of Total and Directional Heat Flux in HCF

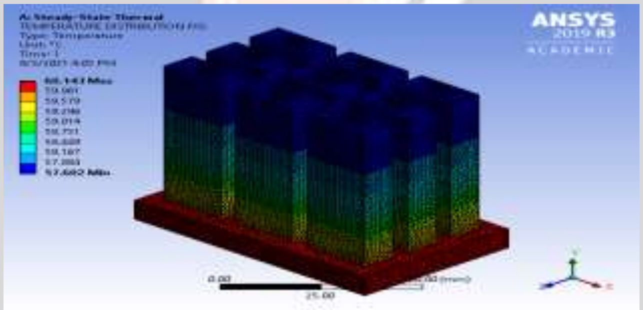


Fig. 5.4 Temperature Distribution of Heat Sink of HRF

As analyzing we get the total heat flux distribution of maximum amount of 0.015028W/mm^2 and minimum 0.0000528252W/mm^2.

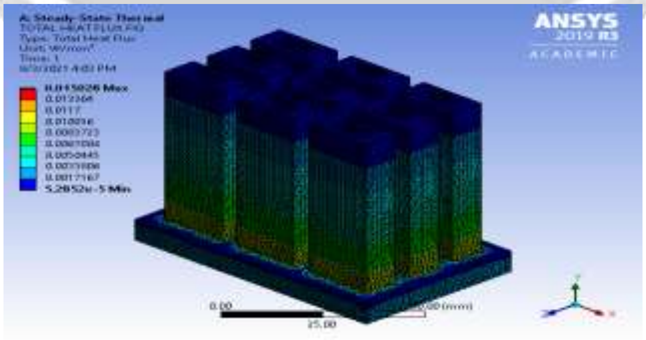


Fig. 5.5 Total Heat Flux Distribution of Heat Sink of HRF

As analyzing we get the Directional heat flux distribution in the direction of Y-axis of maximum amount of 0.013149 W/mm^2 and minimum -0.0013297 W/mm^2.

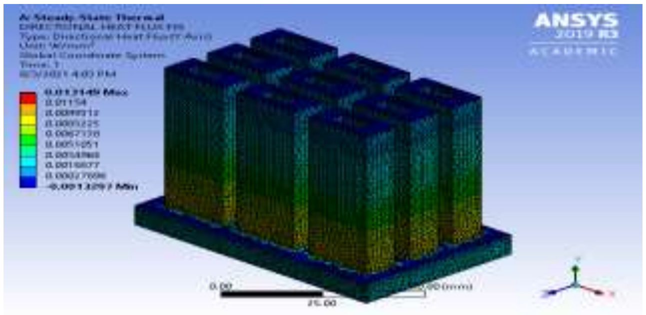


Fig. 5.6 Directional Heat Flux Distribution of Heat Sink HRF

By going through all other designed hollow rectangular fin with CH, RH, SH, TH, EH, we get the temperature as given below.

Heat sink with		**Temperature(^{0}C)**		
		Maximum	**Minimum**	**Diff**
HRF		57.602	60.143	2.541
HRF with	**CH**	62.095	65.425	3.330
	RH	60.197	63.597	3.400
	SH	66.377	69.971	3.594
	TH	61.254	64.727	3.473
	EH	58.887	61.656	2.796

Table 5.3 Variations of Temperature Hollow Rectangular Fin

Heat sink with		**Total Heat Flux(W/mm^2 ^{0}C)**		**Directional Heat Flux(W/mm^2 ^{0}C)**	
		Max	**Min**	**Max**	**Min**
HRF with	**CH**	0.000035537	0.0178360	-0.0018051	0.0178000
	RH	0.000015389	0.0323160	-0.0206690	0.0167540
	SH	0.000010508	0.0248040	-0.0170730	0.0153100
	TH	0.000135420	0.0154920	-0.0086187	0.0094614
	EH	0.000016470	0.0381940	-0.0056800	0.0329770

Table 5.4 Variations of Total and Directional Heat Flux in HRF

5.3 Heat Sink of Hollow Elliptical Fin (HEF)

As Heat sink of HCF with TH is imported to ANSYS Workbench and then analysis is done and we get the temperature distribution on the surface of heat sink. We obtain the maximum temperature of 86.396 ^{0}C and minimum temperature of 83.956 ^{0}C.

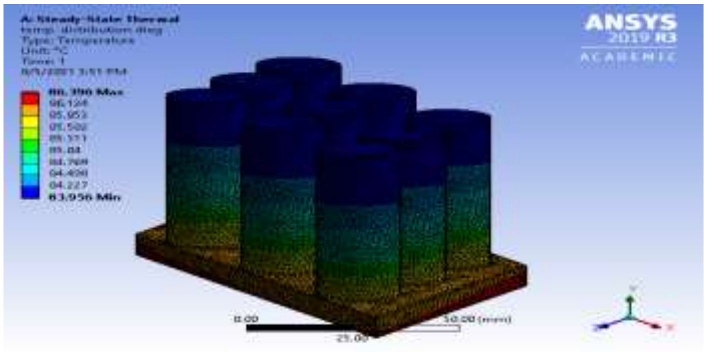


Fig. 5.7 Temperature Distribution of Heat Sink of HEF

As analyzing we get the total heat flux distribution of maximum amount of 0.016907 W/mm^2 and minimum 0.00037206 W/mm^2.

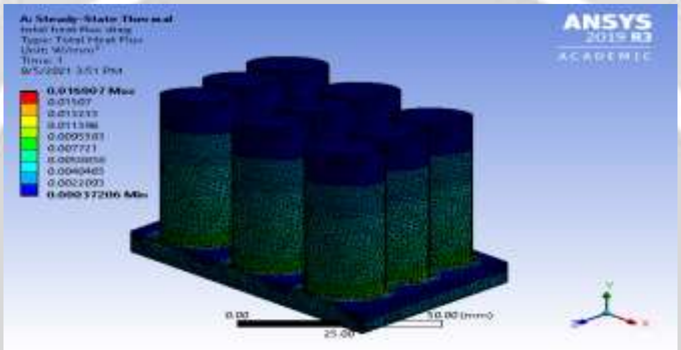


Fig. 5.8 Total Heat Flux Distribution of Heat Sink of HEF

As analyzing we get the Directional heat flux distribution in the direction of Y-axis of maximum amount of 0.014007 W/mm^2 and minimum -0.0013291 W/mm^2.

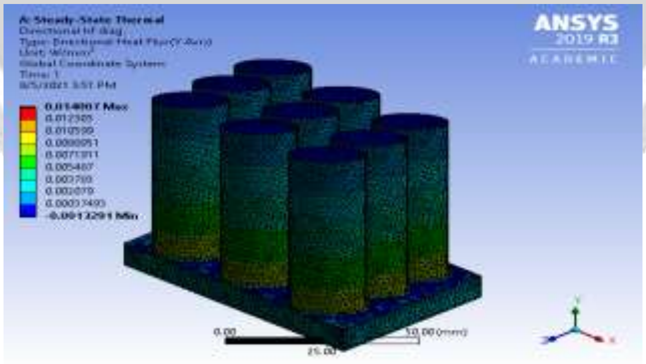


Fig. 5.9 Directional Heat Flux Distribution of Heat Sink HEF

By going through all other designed hollow circular fin with CH, RH, SH, TH, EH, we get the temperature as given below.

Heat sink with	Temperature(^{0}C)

		Max	**Min**	**Diff.**
HEF		61.144	64.758	3.644
HEF with	**CH**	64.364	70.017	5.657
	RH	65.892	72.458	6.566
	SH	65.157	71.729	6.572
	TH	61.260	67.142	5.882
	EH	62.207	67.281	5.074

Table 5.5 Variations of Temperature Hollow Circular Fin

Heat sink with		**Total Heat Flux(W/mm^2 ^{0} C)**		**Directional Heat Flux(W/mm^2 ^{0} C)**	
		Max	**Min**	**Max**	**Min**
HEF with	**CH**	0.000035537	0.0178360	-0.0018274	0.0458590
	RH	0.000015389	0.0323160	-0.0050443	0.0512410
	SH	0.000010508	0.0248040	-0.0037743	0.0439170
	TH	0.000135420	0.0154920	-0.0022509	0.0663700
	EH	0.000016470	0.0381940	-0.0068111	0.0503500

Table 5.6 Variations of Total and Directional Heat Flux in HEF

6. CONCLUSIONS

1. Heat sink of hollow circular fin with square hole among all the three fins with different perforations has more thermal transmission rate because the maximum temperature drop is found for Heat sink of hollow circular fin with square hole. As fins are hollow and perforated, increase the contact surface area of fluid medium with its surface. This is also due to the increase of porosity. Porosity of heat sink is the volume fraction of air inside the heat sink.
2. The minimum thermal rate is found for heat sink with hollow rectangular fin with elliptical perforation.
3. It is observed that hollow circular Fin with square holes (SH) have more total heat flux of value 0.0098873 W/mm^2 which is more than the HRF and HEF with CH, RH, SH, EH, TH.
4. As it is observed that hollow circular Fin with square holes (SH) have more average directional heat flux of value 0.0093188 W/mm^2 which is more than the HRF and HEF with CH, RH, SH, EH, TH.
5. As the Fins used in this analysis are hollow in nature so it can also be concluded that there will be less requirement of materials to manufacture these types of hollow fin than the materials required to manufacture solid Fins.

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