ENHANCING HEAT TRANSFER OF FINS BY PROVIDING SLOTS

Mr. Suraj R[1], Mr. Samarth Ghanate[2], Mr. Sameer Ahmed[3], Mr. Sameer Patki[4],

[1] Mr. Suraj R: Student, Department of Mechanical Engineering, PESIT-BSC, Bengaluru, Karnataka.
[2]Mr. Samarth Ghanate: Student, Dept. of Mechanical Engineering, PESIT-BSC, Bengaluru, Karnataka.
[3]Mr. Sameer Ahmed: Student, Department of Mechanical Engineering, PESIT-BSC, Bengaluru, Karnataka.
[4]Mr. Sameer Patki: Student, Department of Mechanical Engineering, PESIT-BSC, Bengaluru, Karnataka.

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Abstract - *Fins are surfaces that extend from an object to increase the rate of heat transfer to or from the environment by increasing convection. The rate of heat transfer from fins depends on various parameters, one being surface area. This surface area can be further increased by providing slots. Here we deal with theoretical and numerical steady state thermal analysis of a rectangular fin by providing slots of different shapes (rectangular, semi-circular and triangular) The performance parameters like heat transfer rate (Heat Flux) and temperature distribution of a regular rectangular fin and slotted fins are calculated and compared.*

After carrying out Steady State Thermal simulation, we can conclude that, for a rectangular fin, Rectangular Slots are proven to be more efficient than semi-circular slots, triangular slots and no slots.

Key Words: Fins, Heat Transfer, Slots, Rectangular Fins, Steady State Thermal.

1.INTRODUCTION

Heat transfer is the phenomenon in which heat or thermal energy is used, converted or exchanged between physical systems. Heat transfer is a phenomenon which occurs in day-to-day activities, from cooling of a cup of coffee to cooling of a room by an AC.

There are basically three modes of heat transfer: Conduction, Convection and Radiation. Conduction is the mode of heat transfer where the transmission or transfer of heat through collisions between neighbouring atoms or molecules. Convection is the mode of heat transfer due to the bulk movement of molecules. Radiation is the mode of heat transfer where energy is emitted by matter in the form of photons or electromagnetic waves.

Fins are extended surfaces used to increase heat transfer rate by increasing convection as surface area increases. Types of fins which are most commonly used are rectangular fin. The heat transfer first occurs by conduction from the base of the fin, which is attached to the surface to the end of the fin. During conduction, heat is lost from the surfaces of the fin by convection.

From Newton's Law of Cooling, we know that, the heat transfer rate due to convection is directly proportional to the surface area. By providing fins, the surface area has increased, in this project we further try to increase the surface area by providing slots of different shapes and dimensions, which then helps in increase in heat transfer by convection.

This project deals with theoretical and numerical study state thermal analysis of a rectangular fin by providing slots of different shapes (rectangular, semicircular and triangular) and sizes, since the cross-sectional areas of rectangular, semicircular and triangular slots provided to the fin are different hence increasing the overall surface area of the fin and hence increasing heat transfer.

The slots provided on the surface along the width. Each type of slot has different areas, hence heat transfer also varies. The heat transfer rate obtained as a result of providing these slots will be compared.

Aluminium is taken as the material of the fin for calculation and simulation as it has a good overall value, i.e., heat transfer coefficient, low weight hence easy to handle, manufacturability, availability and cost.

The analysis will be done in both forced and free convection conditions. Free convection or Natural Convection is the type of convection where the fluid motion is generated only by density differences in the fluid occurring due to temperature gradients, not by any external source. Forced convection is the type of convection where the fluid flow is due to an external source or pump.

We know that the convection coefficient of heat transfer is comparatively higher for forced convection that that of free or natural convection.

Forced convection condition is done under flow velocities of 10m/s, 20 m/s and 30 m/s and corresponding convection heat transfer coefficients are determined.

Modelling of the fins will be carried out in CATIA and simulation for steady state thermal analysis under forced and free convection conditions will be carried out in ANSYS.

2. LITERATURE SURVEY

This chapter of the report mentions the research work performed by different researchers in the field of heat transfer and design of fins. This forms the basis for work to carried out in the future in similar fields.

1. K. Satishkumar et al [1], have carried out computational analysis on fins with notches of different shapes and determined the flow of heat at various notches by performing simulation on ANSYS CFD Fluent software.

2. Saurabh Dolas et al [2], focused on the improving the heat transfer rate of a fin by making micro channels or pores on it and carrying out CFD Analysis on ANSYS and calculation by theoretical methods. They varied the heat flux and flow to check any variation in heat distribution for the porous fins.

3. L. Prabhu et al [3], analyzed heat transfer performance of different types of fins like cylindrical, rectangular and square on ANSYS Workbench using Aluminium as the base metal. They have determined that rectangular fin configuration has more heat transfer rate and effectiveness than other types.

4. Pardeep Singh et al [4], provided extensions of different shapes like rectangular, trapezoidal, triangular and circular shapes on fins and analysed the heat transfer performance. The design was done in AutoCAD and analysis in Autodesk Simulation Multiphysics.

5. NA Nawale et al [5], have carried out experimental analysis on fins with and without notches of different shapes and determined that heat transfer coefficient is highest for sets of fins with triangular notches.

6. Sampath SS et al [6], carried out simulation in ANSYS CFX to estimate the heat dissipation from plate with multiple tapered, rectangular and triangular fins and concluded that rectangular fins dissipate less heat than triangular fins because of exposure of the base to the ambient conditions.

7. Ganesha BB et al [7], performed experimental analysis for rectangular fins of different shapes of perforation and found out that the heat transfer rate is significantly influenced by geometry of perforations and determined that square perforated fins perform almost same as solid fins, thereby reducing the overall weight of system.

3. RESEARCH GAP

1. Previously, internal slots have been provided, but doing so reduces convection. External slots hence, create more exposure for convection.
2. External slots are better as the cross-sectional area is not affected, hence not affecting the conduction in the fin compared to unslotted fin.

4. OBJECTIVES

1. To perform theoretical and numerical steady state thermal analysis of rectangular fins by providing slots of rectangular, semi-circular and triangular slots under forced and free convection conditions.

2. To perform a comparative study of heat transfer rates of the various types of fins and different types of slots provided.

5. METHODOLOGY

This section gives a brief description about the methodology followed to complete this project.
The following flowchart represents the methodology process:

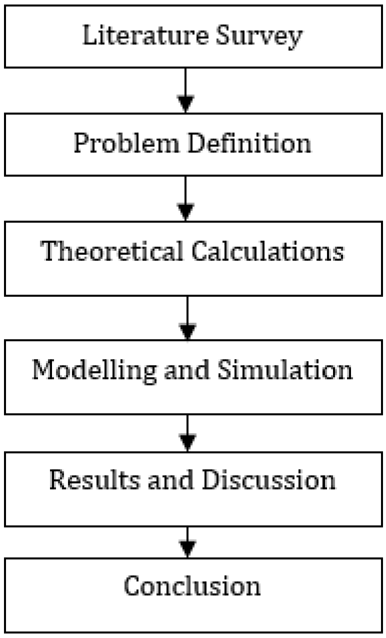

Fig 1: Methodology Flowchart

6. DESIGN CALCULATIONS

Design Calculations are carried out for fins made of Aluminium under free and forced convection conditions.
The following calculations are performed to find Heat transfer rate of Unslotted Rectangular Fin.

Forced Convection:
The value of convection heat transfer coefficient h, is given by the equation [2]

$h = 10.45 - v + 10v^{1/2}$

v: relative speed between object surface and air (m/s)
We take 3 velocities 10 m/s, 20 m/s, 30 m/s:

v=10 m/s

h= 10.45- 10 + 10 = 37.29 W/m²K

h = 37.29 W/ m²K

v= 20 m/s

h = 10.45 - 20 + 10 = 40.903 W/ m²K

h = 40.903 W/ m²K

v= 30 m/s

h = 10.45 - 30 + 10 = 40.96 W/ m²K

h = 40.96 W/ m²K

Rectangular Fin:

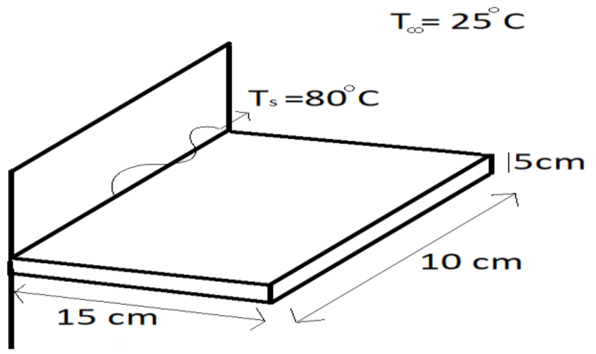

Fig 2: Rectangular Fin

A rectangular fin of dimensions 15cm, 10cm and 5cm in length, breadth and depth respectively is considered. The Base temperature is 80°C and room temperature is 25°C.

$A = 10\times5 = 50\ cm^2 = 5\times10^{-3}\ m^2$

$P = 2\ (b+t) = 2(10+5) = 30\ cm = 3\times10^{-1}\ m$

h= 6.5 W/ m²K (Free convection)

K= 205 W/mK (For Al)

$$m = \sqrt{\frac{hP}{KA}} = \sqrt{\frac{6.5\times 3\times 10^{-6}}{205\times 5\times 10^{-3}}} = 1.379$$

$$Q = \sqrt{hPKA}\ (T_\circ - T_\infty)\left[\frac{\tan ml+\frac{h}{mk}}{1+\frac{h}{mk}\tan ml}\right]$$

$$Q = \sqrt{6.5\times 3\times 10^{-1}\times 205\times 510^{-3}}\ (80\text{-}25)$$

$$\left[\frac{\tan(1.379\times 15\times 10^{-2})+\frac{6.5}{1.379\ X\ 205}}{1+\frac{6.5}{1.379\times 205}\tan(1.379\times 15\times 10^{-2})}\right]$$

Q= 77.75 × 0.0266

Q = 2.06 W

Similarly, for Forced convection, using same formula:

For v=10m/s, h= 37.29 W/ m²K: Q = 11.84 W

For v=20 m/s, h=40.903 W/ m²K: Q=12.85 W

For v=30 m/s, h=40.960 W/ m²K: Q=13.02 W

8. MODELLING AND ANALYSIS

Modelling of Fins:

Modelling of fins (Rectangular, Variable, Pin Fin) with and without slots (Rectangular, Semi Circular, Triangular) were done using CATIA.

The dimensions of the fins are as mentioned:

Rectangular Fin:

Length of the Fin: 150mm
Width of the Fin: 100mm
Thickness of the Fin: 50mm

Slot Dimensions:

1. The number of slots provided is taken as 3
2. The dimension of the slots is taken as 20mm (Which is less than 50% of fin thickness, hence providing enough material for conduction).

Wall dimensions:

A Square wall of 250mm × 250 mm is placed on which the fin is mounted.

A total of 4 models were made according to the above-mentioned dimensions using the Part Design feature of CATIA as shown:

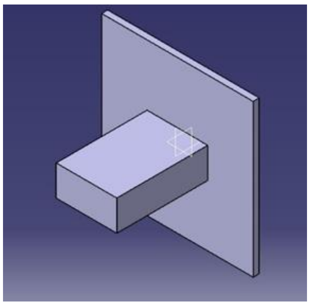

Fig 3: No Slot

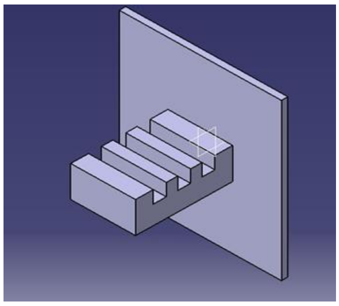

Fig 4: Rectangular Slot

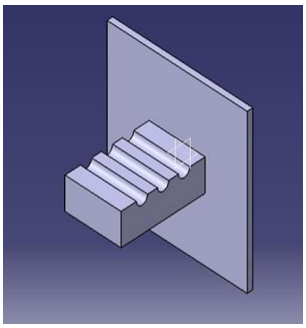

Fig 5: Semi Circular Slot

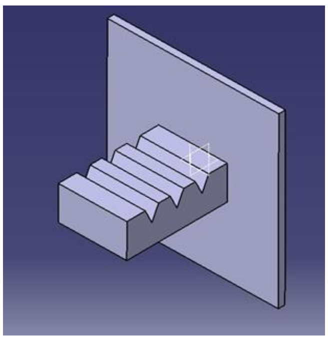

Fig 6: Triangular Slot

SIMULATION:

Meshing of Fins in ANSYS:

Meshing of the fin was carried out in ANSYS. To find the right mesh, we simulated the fins under the following boundary conditions:

a. Wall temperature = 80°C
b. Convection heat transfer coefficient (h):
6.5 W/ m^2K (for free convection)
40.96 W/ m^2K (for Forced convection; v=30m/s)

c. Ambient temperature = 25°C

40.96 W/m^2K was taken as value for h for forced convection as that gave highest value in theoretical calculations for forced convection.
Simulations were done for different mesh sizes on rectangular fin with no slot and checked which size gives an output value closer to the theoretical value calculated.
The range of 5mm to 6mm element size was found to be closer to required value.
The below table shows the obtained results after simulation of rectangular fin:

Table 1: Meshing Values

Element size (mm)	**Number of Nodes**	**Tip Heat Flux (W/m²)**
5	16411	415.54
5.2	14513	408.43
5.4	12928	420.28
5.6	11849	417.83
5.8	10780	422.3
6	9940	423.56

After simulating for different mesh sizes, 5.2mm size was found to be a better value which gives a closer value to theoretical value.
Hence the mesh size of 5.2mm was considered for further simulation of Rectangular Fins.
The below shown figure shows the rectangular fin meshed with 5.2mm element size.

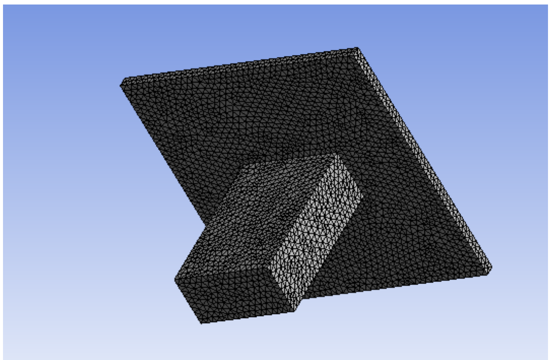

Fig 7: Meshing of Fin

Simulation:
Using ANSYS, Steady State Thermal Analysis was carried out subjected to the boundary conditions previously mentioned for meshing.
The Steady State Thermal Analysis was carried out for Rectangular Fin with No Slot, Rectangular, Semi Circular and Triangular Slot under Free and Forced Convection.
The Heat Flux and Temperature distribution for each fin under each type of convection is as shown:

NO SLOT:

For Free Convection:

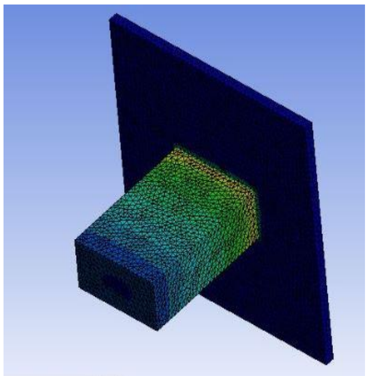

Fig 8: Heat Flux – No Slot

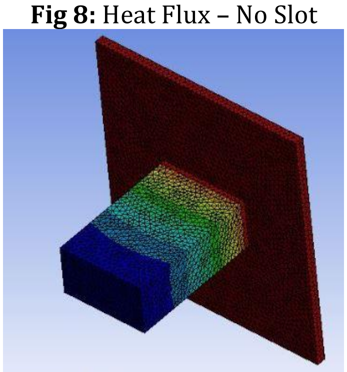

Fig 9: Temperature Distribution – No Slot

Average Heat Flux: 836.29 W/m^2
Maximum Heat Flux: 5850.2 W/ m^2
Tip Temperature: 78.466 °C

For Forced Convection:

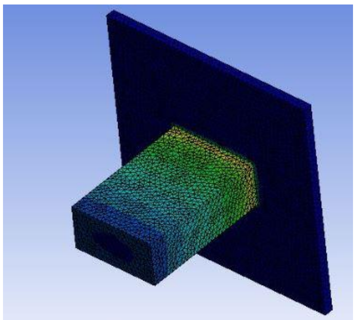

Fig 10: Heat Flux – No Slot

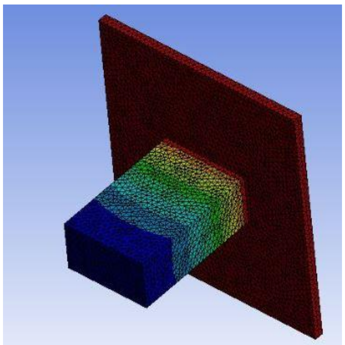

Fig 11: Temperature Distribution – No Slot

Average Heat Flux: 4700.4 W/ m^2
Maximum Heat Flux: 33541 W/ m^2
Tip Temperature: 71.397 °C

RECTANGULAR SLOTS:

For Free Convection:

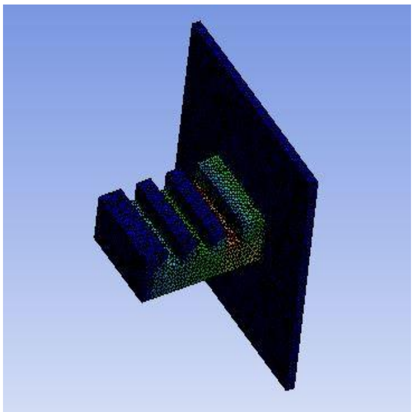

Fig 12: Heat Flux – Rectangular Slot

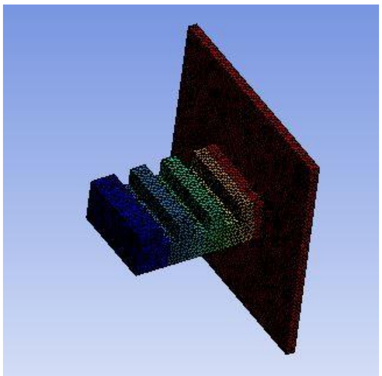

Fig 13: Temperature Distribution- Rectangular Slot

Average Heat Flux: 1234.7 W/ m^2
Maximum Heat Flux: 7960.2 W/ m^2
Tip Temperature: 77.428 ° C
For Forced Convection:

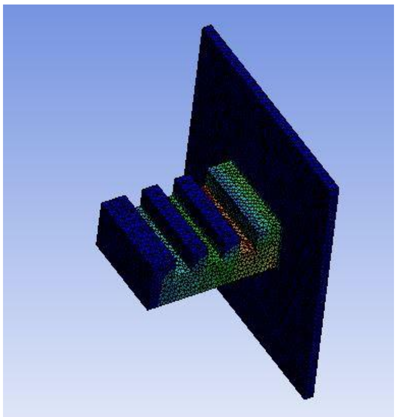

Fig 14: Heat Flux – Rectangular Slot

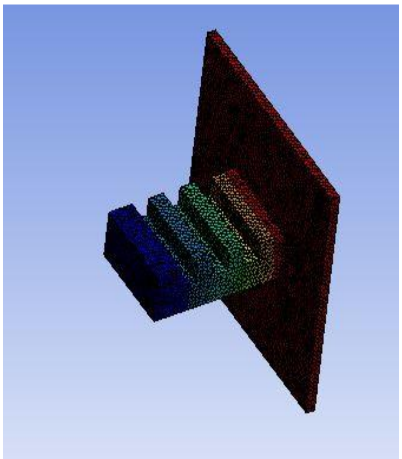

Fig 15: Temperature Distribution- Rectangular Slot

Average Heat Flux: 6474 W/ m^2
Maximum Heat Flux: 42011 W/ m^2
Tip Temperature: 66.586 °C

SEMI-CIRCULAR SLOTS:

For Free Convection:

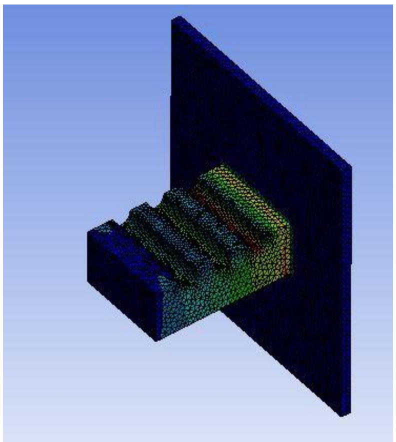

Fig 16: Heat Flux – Semi-circular Slot

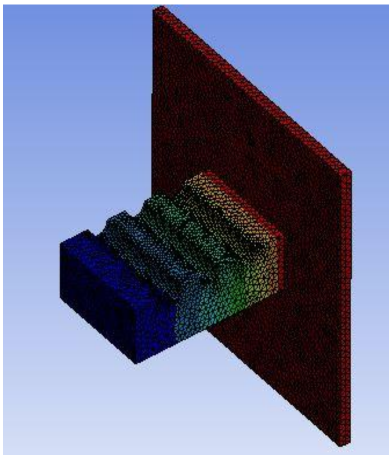

Fig 17: Temperature Distribution – Semi-Circualar Slot

Average Heat Flux: 1237.1 W/ m^2
Maximum Heat Flux: 5696.7 W/ m^2
Tip Temperature: 78.22 °C

For Forced Convection:

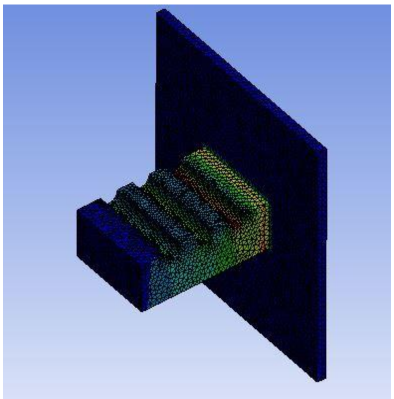

Fig 18: Heat Flux – Semi-Circular Slot

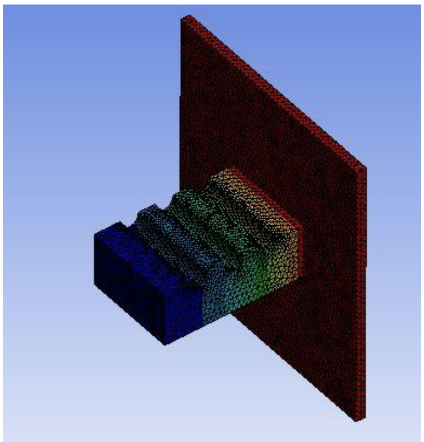

Fig 19: Temperature Distribution – Semi-Circualar Slot

Average Heat Flux:6819.3 W/ m^2
Maximum Heat Flux: 32329 W/ m^2
Tip Temperature:70.196 °C

TRIANGULAR SLOTS:
For Free Convection:

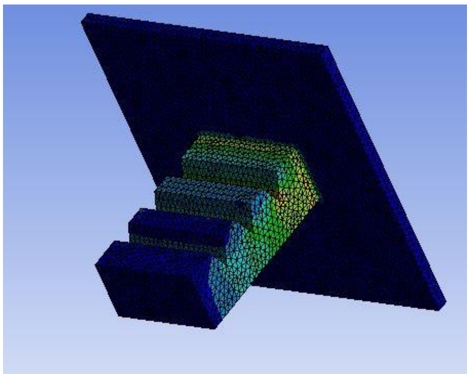

Fig 20: Heat Flux – Semi-Circular Slot

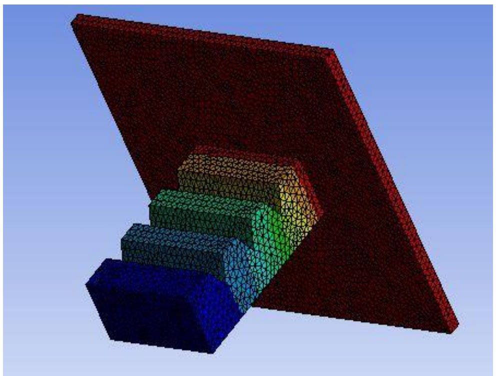

Fig 21: Temperature Distribution – Triangular Slot

Average Heat Flux:1062.7 W/ m^2
Maximum Heat Flux: 7003.1 W/ m^2
Tip Temperature:77.886 °C

For Forced Convection:

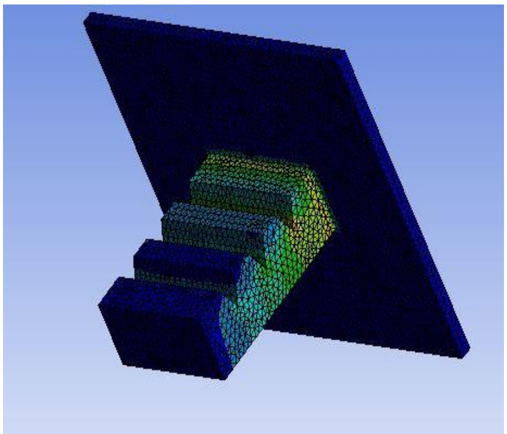

Fig 22: Heat Flux – Semi-Circular Slot

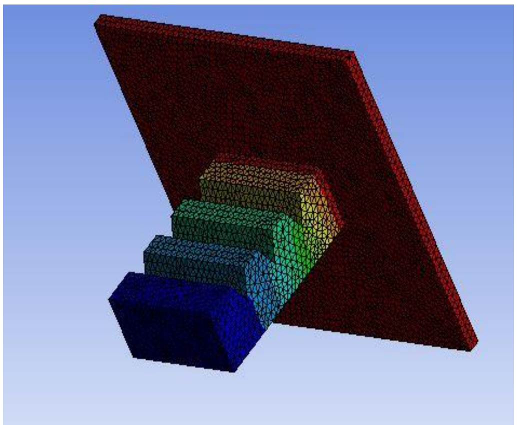

Fig 23: Temperature Distribution – Semi-Circualar Slot

Average Heat Flux:5741.5 W/ m^2
Maximum Heat Flux: 37902 W/m^2
Tip Temperature: 70.196 °C

9. RESULTS AND DISCUSSION

The results obtained from these simulations is as follows:

Table 2: Simulation Results – Forced Convection

Type of Slot	Max Heat Flux (W/m²)	Average Heat Flux (W/m²)	Tip Temperature (°C)
No Slot	33541	4700.4	71.397
Rectangular Slot	42011	6474	66.586
Triangular Slot	37902	5741.5	68.617
Semi-Circular Slot	32329	6819.3	70.196

Table 3: Percentage increase of slots w.r.t no slot- Forced Convection

Type of Slot	Maximum Flux		Average Heat Flux	
	Increase (W/m²)	% Increase	Increase (W/m²)	% Increase
Rectangular Slot	8470	25.25	1773.6	37.73
Triangular Slot	4361	13	1041.1	22.14
Semi-Circular Slot	-1212	-3.61	2118.9	45.07

Table 4: Simulation Results – Free Convection

Type of Slot	Max Heat Flux (W/m²)	Average Heat Flux (W/m²)	Tip Temperature (°C)
No Slot	5850.2	836.29	78.466
Rectangular Slot	7960.2	1234.7	77.428
Triangular Slot	7003.1	1062.7	79.886
Semi-Circular Slot	5696.7	1237.1	78.22

Table 5: Percentage increase of slots w.r.t no slot- Free Convection

Type of Slot	Maximum Heat Flux		Average Heat Flux	
	Increase (W/m²)	% Increase	Increase (W/m²)	% Increase
Rectangular Slot	398.41	47.64	2110	36.06
Triangular Slot	226.41	27.04	1152.9	19.7
Semi-Circular Slot	400.81	47.92	-153.5	-2.62

10. CONCLUSIONS

After carrying out Steady State Thermal Simulations for the above-mentioned fins, the following conclusions are made:

For Rectangular Fin, the heat flux increases more for **Rectangular Slots**

11. FUTURE SCOPE

As slots are provided on the surface of the fin, there is reduction in cross-sectional area.
This reduction in cross-sectional area can lead to variation in conduction through the fin.
Further study can be carried out to find the optimal slot size, in order to maintain an optimal balance between conduction and convection.

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