

A Study on the Heat Transfer Enhancement of Fin with Grooves by Natural Convection

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ABSTRACT: The heat transfer performance of fin is analysed by the design of rectangular fin with various grooves such as rectangular, trapezoidal, triangular and semi-circular. The heat transfer performance of fin with the same geometry having various grooves and without grooves is compared. Near about ranging 3% to 30% more heat transfer was achieved with the various grooves on fin when compared with other types having same geometry of fin. Fin with various groove design and analysis had done with the help of ANSYS 16.2. In this, thermal analysis flow occurs through the fin is analysed. Grooves on the surface of the fins are used to increase the surface area of the fin. So, as the surface area increase, there will be a more fluid contact which results in increased rate of heat transfers from the base. On comparison, rectangular grooves provided on fin gave higher heat transfer than that of other grooves having the same length and width attached to the finned surface. Also, the effectiveness of fin with rectangular grooves was higher when compared to other grooves.

KEYWORDS: Ansys16.2, CFX, Heat Transfer, Fins, Effectiveness, Convection

I. INTRODUCTION

Heat transfer enhancement through fin in any thermal application has a lot of significance. For example in an IC Engine, computers, etc., a tremendous amount of heat is generated inside during their operations. This heat has to be removed continuously from them for their efficient functioning. The efficient design of fin has lots of thermal application which need to be explored.

Generally, heat transfer takes place by three modes – conduction, convection, and radiation. In this paper, heat transfer within the solid is due to conduction. The base plate is a high-temperature source from where heat has to be removed by the finned surface. Heat transfer across the fin surface is due to convection and it follows the Newton's law of cooling. So, the increase in surface area of the fin could result in an enhancement in heat transfer. Radiation effect is not considered, so we assume its effect is negligible though it can produce some nonlinearity in the result. There are mainly two types of heat transfer method, active method, and a passive method. In Active method, some external power source is required to enhance the heat transfer and in the Passive method, no external power is required to enhance the heat transfer. By design modification of the component itself, the heat transfer can be enhanced.

Different design on fin was considered for thermal analysis. To simplify the heat source, the base plate of very small thickness was considered. Fins such as rectangular cross-sectional fin being implanted on the base plate. The simulation is performed as steady state thermal analysis and temperature distribution along the length of the fin is observed. After the simulation, analytical analysis of fins was done to get the required thermal performance. Different performance parameter such as enhancement in heat transfer, effectiveness, efficiency etc. was also analysed with the help of analytical equation.

I. Introduction to fins

Fins are normally used to increase the rate of heat transfer to or from the environment by increasing convection. Convection heat transfer between a surface and the fluid surrounding can be increased by attaching thin strips of metal to the surface, called fins. An extended surface or fin is a surface that extends from an object to increase the rate of heat transfer to or from the surrounding by increasing convection. There is two way to increase the rate of heat transfer. The first way is to increase the convection heat transfer coefficient 'h'. Increasing 'h' may require the

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installation of a pump or a fan. The second way to increase heat transfer is by replacing the existing fin with a larger fin having more surface area. The alternative is to increase the surface area by attaching fins. The geometry of the fin depends on a lot of factors which are explained in below section. A large variety of fin geometries is manufactured for heat transfer applications.

When heat transfer takes place by convection from both interior and the exterior surface of a tube or a plate, generally fins are used on the surface where the heat transfer coefficient is low. For example in a radiator of a car, the outer surface of the tubes is finned because the heat transfer coefficient for air at the outer surface is much lesser than that for water flow at the inner surface. The problem of finding the heat flow through a fin requires knowledge of temperature distribution through the fin.

II. LITERATURE SURVEY

[1] The design of fin with various extensions such as rectangular, trapezium, triangular and circular extensions was considered for the analysis. The heat transfer performance of fins having same geometry with various shapes of extension and without extension has been compared. About 5% to 13% enhancement in heat transfer is obtained. In this thermal analysis, temperature variation along the length of the fin at which heat flow occurs through the fin was also analysed. Extensions on the fin are used to increase the surface area in contact with the ambient fluid flowing around it. Since the surface area increases, it tends to increase the heat transfer due to convection. Thus there will be an increase in overall heat transfer due to conduction and convection.

[2] Different shapes of notched such as rectangular, triangular etc. has been designed on rectangular fin array. Natural convection heat transfer for fin without a notch and notched fin has been investigated theoretically and experimentally. The central position on the fin array becomes ineffective to heat transfer because of single chimney flow pattern. On the central position, the heated air rises upward and in that case already hot air is present so there is a notched portion due to that fresh air can move across it. By performing the experimentation, it was observed that average heat transfer coefficient for a fin with notched portion results in high heat transfer coefficient compared to fin without a notched portion. Also copper material results in high heat transfer as compared to aluminium.

[3] Triangular and circular pin fins have been considered for the CFD analysis. With high air velocity at the inlet, the temperature of the bulk fluid present outside the fin increases. In the case of both fin due to the fact that high air velocity tends to increase the convective heat transfer. The conjugate heat transfer means conduction, convection and radiation effect has been considered. Up to a certain limit, the velocity of air can be increased. It is so because high velocity tends to increase the pressure drop which results in decreased thermal performance of the fin. The streamlines obtained by the simulation shows that at particular velocity there is an improved mixing and more recirculation of air. Circular pin fin performs far better than triangular pin fin in terms of thermal performance such as heat transfer etc. and pressure drop across the pin fins.

III. FIN DESIGN

The isometric view of fin or fin with base plate is shown in fig 1.1. There is a base plate which acts as a source of heat load by applying the particular boundary condition in CFX 16.2. To remove the heat from a particular source efficiently, fin or finned surface is being utilised in a lot of applications. Rectangular cross-section fin surface has been considered on a base plate and heat is transferred along the length of the fin by conduction. Convection occurs from the fin surface to the ambient fluid in the environment with the help of convection boundary condition on the fin surface.

Design modification has been done on the fin. Different shapes of the groove can be placed on the surface of rectangular fins such as a rectangular groove, triangular groove, trapezoidal groove and semi-circular groove. By placing the groove, there will be an increase in the surface area thus; there will be an increase in the value of heat transfer due to increasing in heat transfer due to convection. Heat transfer analysis of fins is carried out for the following geometric dimensions.

Base plate dimension: Length = 240mm, Width = 55mm, Height = 3mm [1]

Fin dimension: Length = 240mm, Width = 15mm, Height = 40mm [1]

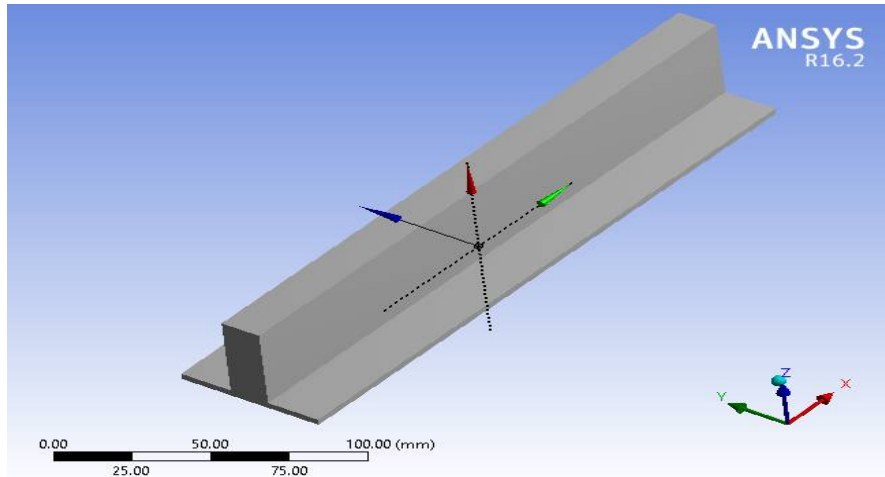


Fig 1.1: Rectangular fin without groove on its surface

A. Assumptions

To create an equation for the heat transfer of a fin, assumptions need to be made are as follows.

- The properties of material should be constant or independent of temperature variation.
- Heat generation per unit volume should be negligible.
- One-dimensional heat conduction along the length of the fin.
- The cross-sectional area along the length of fin should be constant.
- Convection between surface area and surrounding fluid should be uniform.
- Steady state thermal analysis.
- Radiation along the fin length is negligible and hence neglected in the analysis.

B. Equations used

For fins, there are different analytical equations available which are shown below. A derivation of some of the analytical equation has been presented.

- Temperature distribution along the length of fin

$$\frac{\theta(x)}{\theta(0)} = \frac{T(x) - T_{\infty}}{T_0 - T_{\infty}} = \frac{\cosh m(L-x) + \left(\frac{h}{mk}\right) \sinh m(L-x)}{\cosh mL + \left(\frac{h}{mk}\right) \sinh mL}$$

- Heat transfer

$$Q = \theta_0 \sqrt{hPkA} \left[\frac{\sinh mL + \left(\frac{h}{mk}\right) \cosh mL}{\cosh mL + \left(\frac{h}{mk}\right) \sinh mL} \right]$$

- Fin efficiency

$$\eta = \frac{Q}{h A_t (T_0 - T_{\infty})}$$

- Fin effectiveness

$$\epsilon = \frac{Q}{h A_{fin\ base} (T_0 - T_{\infty})}$$

IV. DESIGN AND ANALYSIS OF FIN WITH GROOVE

Geometric dimension of the fin is expressed in 3-D views with the help of application, ANSYS design modeller. Unit of dimension is in millimetre.

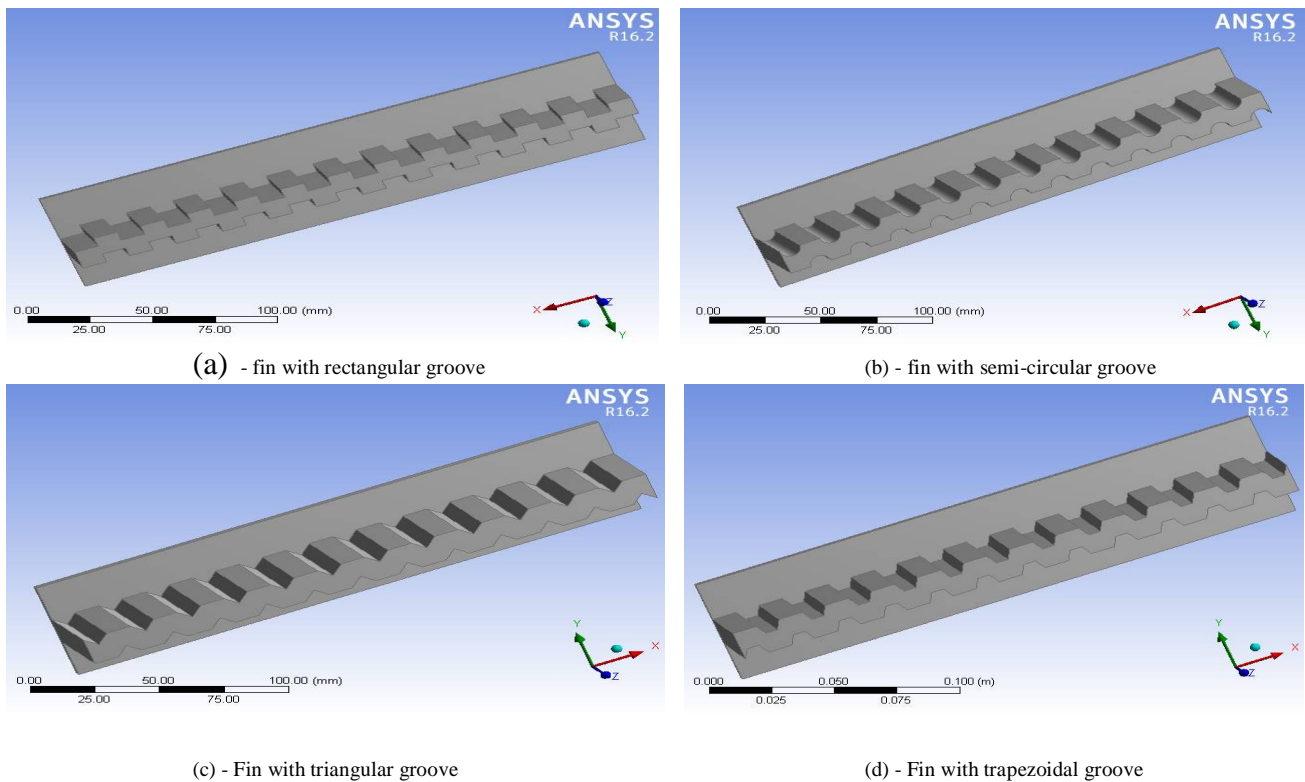


Fig 1.2

The Fig 1.1 and 1.2 shows the 3D views of all five designs which have been considered for analysis

V. RESULTS AND DISCUSSION

The temperature distribution is generated along the length of fin for a fixed base plate temperature. After that, with the help of analytical equation heat transfer is calculated. Validation of temperature distribution is carried out using the analytical equation of fin. Validation of temperature distribution is carried out using the analytical equation of fin presented in the heat and mass transfer data book. For different values of load condition (such as different heat transfer coefficient, the different fixed temperature of the base plate, etc.) values of heat transfer is calculated and tabulated accordingly. Different performance parameter such as fin effectiveness and fin efficiency has been calculated with the help of analytical equation.

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TABLE I: HEAT TRANSFER AT BASE PLATE TEMPERATURE = 500K.

$T_b=500K, h=12W/m^2K, T_\infty=300K$			
Types of Groove	Heat Transfer (W)	Increase in Heat Transfer (W)	% increase in Heat Transfer
Without Groove	57.29	---	---
Rectangular	74.81	17.52	30.59
Triangular	65.17	5.88	13.75
Trapezoidal	69.13	11.84	20.66
Semi-Circular	67.94	10.73	18.74

In above table I, at base plate temperature $T_b=500K$, heat transfer is calculated analytically. We can observe that rectangular fin with rectangular groove have a high value of heat transfer and increase in heat transfer as compared to other types of design consideration. With the help of above tabular column, a graph has been plotted between heat transfer and different grooves and also increase in heat transfer v/s different grooves. We can observe the increase in heat transfer linearly by increasing the base plate temperature. Graph of heat transfer v/s groove is shown in figure 1.3

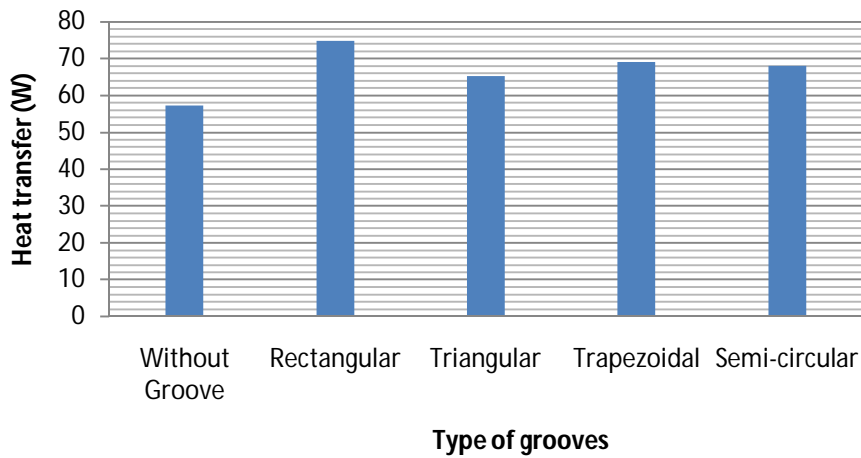


Fig. 1.3: Heat Transfer v/s Grooves

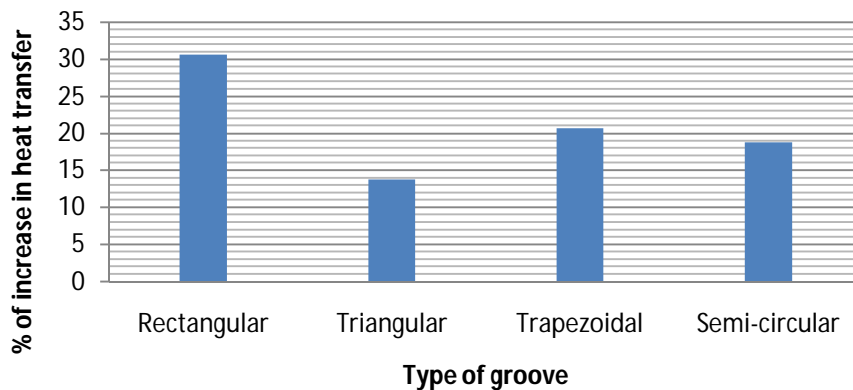


Fig. 1.4: Percentage increase in heat transfer v/s groove

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By analysing the graph, we can observe that at particular base plate temperature, rectangular fin with rectangular groove have the highest heat transfer as compared to any other fin with or without the groove.

A. Performance

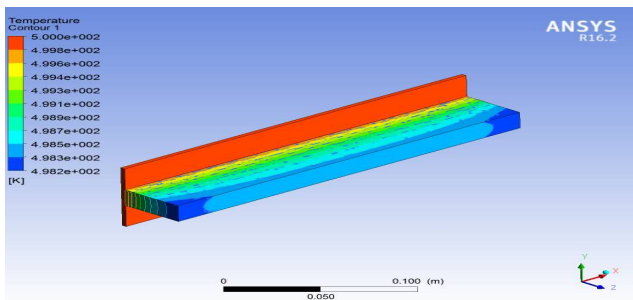
Effectiveness and efficiency have been calculated. Percentage decrement in weight has been calculated for different design consideration as explained below the table II and the result is tabulated. Rectangular fin with rectangular groove design has the highest value of effectiveness as compared to other types of design. It also shows highest percentage decrement in weight which tends to reduce the cost of material.

TABLE II: PERFORMANCE PARAMETER OF DIFFERENT DESIGN CONSIDERATION

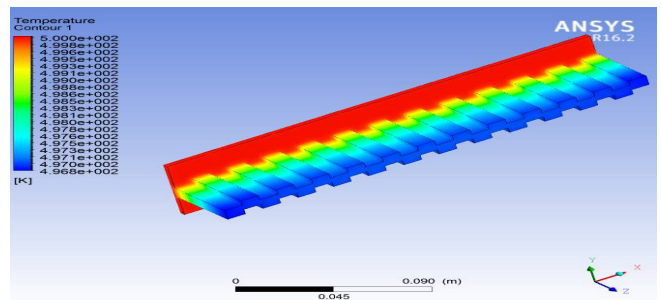
$T_b=500K, h=12W/m^2K, T_\infty=300K$				
Parameter	Fin with different types of groove			
	Rectangular	Semi-circular	Triangular	Trapezoidal
Effectiveness	12.98	10.65	9.05	10.66
Efficiency (%)	98.64	98.06	98	98.10
Weight (kg)	0.36612	0.39395	0.43092	0.39852
% Decrease in Weight	12.96	10.17	6.48	9.72

B. Temperature distribution for different types of groove by Simulation

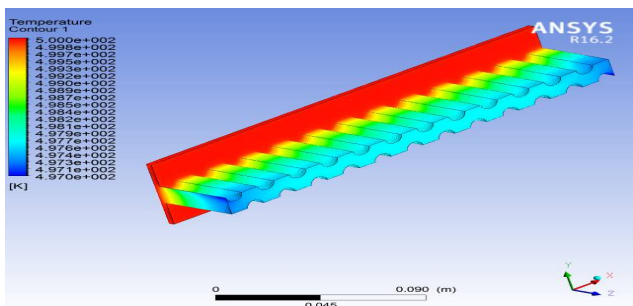
On a rectangular fin, different shapes of groove have been designed and simulated with the help of CFX. In CFX postprocessor, temperature contour tool is used to get the desired temperature distribution along the length of the fin. Temperature distributions of different shapes of fins are shown in figure 1.5



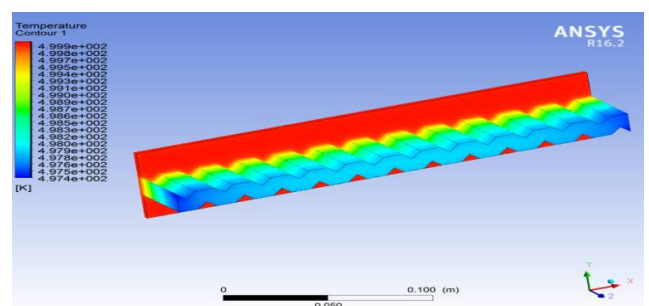
(a) - Rectangular fin without groove



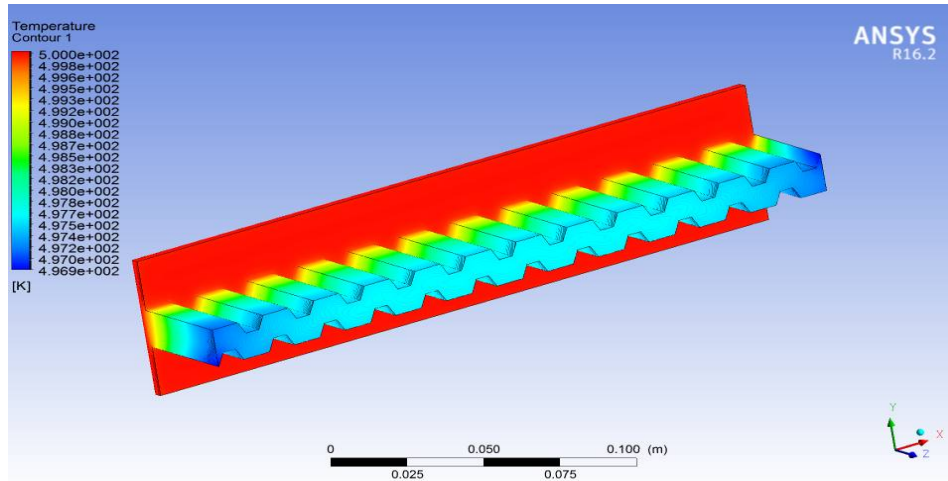
(b) - Fin with rectangular groove



(c) - Fin with semicircular groove



(d) - Fin with Triangular Groove



(e) – Fin with Trapezoidal groove
Fig 1.5: Temperature distribution along the fin

Temperature distribution along the length of fin is tabulated for different types of design consideration

TABLE III: TEMPERATURE DISTRIBUTION ALONG THE LENGTH OF FIN

$T_b=500K, h=12W/m^2K, T_\infty=300K, L = 0.04m$	
Type of Groove	Temperature at the Tip of Fin (K)
Without grove	498.157
Rectangle	496.758
Triangle	497.375
Trapezoidal	496.872
Semi-Circular	496.954

From the above table III, we can observe that rectangular fin with arectangular groove has less temperature at different length as compared to other types of design consideration. At different length, thetemperature is noted down with the help of probe tool present in ANSYS/CFX 16.2 post processor.

VI. CONCLUSION

Different fin configuration was designed and analysed with the help CFX. Fin with groove provides almost 13 to 30% of heat transfer enhancement as compared to fin without grove. Fin with rectangular grooves gave a higher heat transfer upto a maximum of 30% compared to other types of grooves. The effectiveness of rectangular fin with rectangular groove was more when compared to another type of grooves. Use of grooves on fin reduces the weight of material thus there will be a decrement in the cost of manufacturing of fin.

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