# Performance Evaluation of Rectangular Fin Array - A Comparative Study of Fin with various Perforated Designs

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*Abstract*— Heat transfer from the heat sink plays major role on the performance on various components in Automobile, Air conditioning, Heat treatment, Electronic Industries. In this heat transfer process, material type, shape, length plays a vital role. It is very important to dissipate unwanted heat generated in devices such as IC engines, radiators, electronic IC's etc. to the atmosphere. Extended surfaces are widely used for this purpose in many engineering applications because of easy construction, requires less space, light weight. This study examines heat transfer augmentation from a rectangular fin embedded with circular perforation under natural convection compared to the equivalent solid fin using Computational Fluid Dynamics analysis on the rectangular fin arrays by natural convection heat transfer process. Parameters varied in this work are space length and thickness of fins. Circular, Elliptical and Rectangular fins are compared for better heat transfer rate. The output parameters like Nusselt number, Reynolds number, Heat Transfer rate are increased indicating better cooling for the modified fin with low aspect ratio. These output parameters are increased with the perforations on the fin also maximum heat transfer rate is observed for circular fin. However the heat transfer coefficient is found to be Maximum for original model because of low temperature differences due to slow cooling.

***Key words:*** Element Analysis, ANSYS, Heat Transfer Enhancement, Natural Convection, Perforated Fin

## I. INTRODUCTION

Many engineering systems during their operation generate heat. If this generated heat is not dissipated rapidly to surrounding atmosphere, this may cause rise in temperature of the system components. This by-product cause serious overheating problems in system and leads to system failure, so the generated heat within the system must be rejected to its surroundings to maintain the system at recommended temperature for its efficient working. The techniques used in the cooling of high power density electronic devices vary widely, depending on the application and the required cooling capacity. The heat generated by the electronic components has to pass through a complex network of thermal resistances to the environment.

Passive cooling techniques found more efficient and economic for electronics component. Using fins is one of the most inexpensive and common ways to dissipate unwanted heat and it has been successfully used for many engineering applications are perforated.

Fins as heat transfer enhancement devices have been quite common. The different materials like Mild steel, Stainless Steel, Aluminum, Silver and Copper *etc.* are used for making fins. As the extended surface technology continues to grow, new design ideas have been emerged including fins made of anisotropic composites, porous media, interrupted and perforated plates. Due to the high demand for lightweight, compact, and economical fins, the optimization of fin size is of great importance. Therefore, fins must be designed to achieve maximum heat removal with minimum material expenditure taking into account the ease of the fin manufacturing. Rectangular fins are the most popular fin type because of their low production costs and high thermal effectiveness.

### A. *Previous Work*

Abdullah H. AlEssa [1] compared Heat transfer dissipation from a horizontal rectangular fin embedded with equilateral triangular perforations numerically using one-dimensional finite element technique. The heat dissipation of the perforated fin is computed and compared with that of the solid one of the same dimensions and same thermal properties. The comparison refers to acceptable results and heat dissipation enhancement due to certain perforations.

Abdullah H. AlEssa et al. [2] has studied the heat transfer enhancement from a horizontal rectangular fin embedded with triangular perforations (their bases parallel and toward the fin tip) under natural convection. They considered geometrical dimensions and thermal properties as parameter of the fin and the perforations. The temperature drop is studied for perforation dimension and space between them. The experimentation results shows that gain in heat transfer enhancement for certain values of triangular dimensions is increase with its dimensions and is proportional to the fin thickness and its thermal conductivity. They state that the gain in the heat dissipation rate for the perforated fin is a strong function of both the perforation diameter and lateral spacing which attain maximum at optimum perforation dimension and spacing respectively. With perforation it reduces the fin material cost.

Shaeri.M.R.et al. [3] conducted experimentation fluid flow and conjugate conduction-convective heat transfer from a three-dimensional array of rectangular perforated fins with square windows that are arranged in lateral surface of fins are studied numerically. Results show that perforated fins have higher total heat transfer and considerable weight reduction in comparison with solid fins.

Wadhah Hussein Abdul Razzaq Al- Doori et al. [4] has studied and investigate heat transfer rate from rectangular fin with circular perforation. The pattern of perforation including 24 circular perforations with increment of 8 from first fin until 56 no of perforation which is distributed in 14 Columns and 4 rows. Experiments were carried through in an experimental facility that was specifically design and constructed for this purpose. The study shows that temperature along the perforated fin length higher than that for the equivalent non perforated fin. The gain in heat dissipation rate for the perforated fin is a strong function of the perforation dimension and lateral spacing. Decreasing the perforation dimension reduces the rate of temperature drop along the perforated fin.

 

Kumbhar D.G. et al. [5] has observed that heat transfer rate increases with perforations as compared to fins of similar dimensions without perforations. It is noted that in case of triangular perforations optimum heat transfer is achieved. They also concluded that heat transfer rate is different for different materials or heat transfer rate changes with change in thermal conductivity. The perforation of fins enhances the heat dissipation rates and at the same time decreases the expenditure for fin materials also. Results obtained by ANSYS and experimentation support each other.

Rupali V. et al. [6] examined the heat transfer augmentation from horizontal rectangular fins with circular perforations under natural convection compared with solid fins and Fins with different thickness keeping length constant are also examined. They use Finite element analysis using ANSYS 11 to find out heat transfer rate. Study found that as the number of perforations increases heat transfer rate increases. Heat transfer rate is found maximum in fin with 12 perforations.

## II. SYSTEM MODEL

Fins are used to enhance convective heat transfer in a wide range of engineering applications and offer a practical means for achieving a large total heat transfer surface area without the use of an excessive amount of primary surface area. Fins are commonly applied for heat management in electrical appliances such as computer power supplies or substation transformers.

In this work two fins of different lengths and thickness are considered to determine the influence of aspect ratio on heat transfer hence cooling a fin is considered as and designed it using Pro-Engineering software and later imported into ANSYS software and analyzed it using CFD. Three different perforation patterns on fin viz., Circular, Elliptical and Rectangular fins are compared for better heat transfer rate.

The geometrical details including the aspect ratio of original fin and modified fin are given in the table 1. Development of 2D model of the solid, circular, elliptical and rectangular fins of original and modified are obtained using CAD software.

| | Length (Mm) | Width (Mm) | Thickness (Mm) | Aspect Ratio |
|---|---|---|---|---|
| Original Model | 120 | 62 | 3 | 1.94 |
| Modified Model | 100 | 62 | 2 | 1.61 |

Table 1: The geometrical details of aspect ratio in original and modified fins

The CAD drawing of original and modified solid fins are shown in Fig 1(a) and Fig 2(a) while solid modeling of the same is obtained by pro-E as shown in Fig 2(a) and 2(b) respectively. The circular, elliptical and rectangular profiles are obtained by perforation.

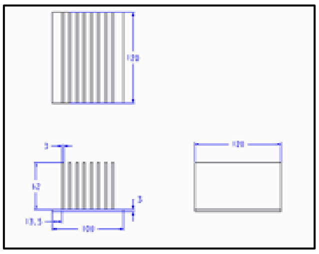

Fig. 1(a): CAD model Original Fin

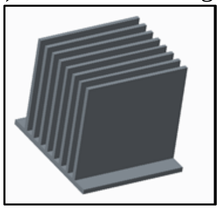

Fig. 1(b): PRO-E model OriginalFin

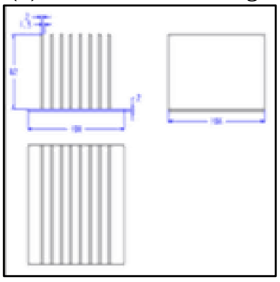

Fig. 2(a): CAD model Original Fin

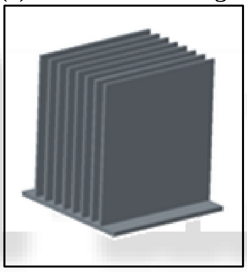

Fig. 2(b): PRO-E model Modified Fin

## III. COMPUTATIONAL FLUID ANALYSIS

Computational fluid dynamics, usually abbreviated as CFD, is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. The study of the effect of aspect ratio on the Nusselt number, Reynolds number, Heat transfer coefficient, Heat transfer rate using CFD analysis is made Various types of 3D models of fins viz., Solid, circular, elliptical and rectangular are exported to CFD software.

Various outputs of CFD are explained

### A. *Nusselt Number*

It is a non dimensional heat transfer coefficient. It gives the comparison between the conduction and convection heat transfer rate. As the Nusselt number increases heat transfer by conduction will be more than by convective mode. It is given by the following equation.

Nusselt number ($N_UL$) =Total heat transfer/conductive heat transfer = $h_L/K$

### B. *Reynolds Number*

It provides a measure of the conditions or range of conditions at which a boundary layer becomes turbulent depending on the density, heat transfer increases because of turbulence of the fluid as Reynolds no. increases. It is given by the following equation

$R_e$= Inertial Force / Viscous Force =V L/ μ

*C. Heat Transfer Coefficient*

h=amount of heat transfer (heat flux)/temperature difference =q/ΔT W/($m^2$/K)

It is used to find the heat transfer between simple elements such as walls in buildings or across heat exchangers

*D. Heat Transfer Rate*

ΔQ/Δt =rate of heat flow/temperature difference=thermal conductivity X surface area X temperature gradient
= -K×A×ΔT/x (KW)

It used in calculating the heat transfer, typically by convection or phase transition between a fluid and a solid

The models are imported from Pro-Engineer software and CFD analysis is performed

*1) CFD Analysis of Solid Fin*

Table 1 gives the output parameters obtained from CFD analysis for solid original and modified fins

| Sl. No | Output | Original model | Modified model |
|---|---|---|---|
| 1 | Nusselt number | 101 | 499 |
| 2 | Reynolds number | 112 | 197 |
| 3 | Heat transfer coefficient (kW/$m^2$-K ) | 380 | 169 |
| 4 | Heat transfer rate (kW) | 9.56 | 167.33 |

Table 1: The output parameters obtained from CFD analysis for solid original and modified fins

The Nusselt number is obtained from CFD analysis and it is found that Nusselt number for original model is 101 and for the reduced aspect ratio in case of modified fin it is 499.On comparing the Fig 3(a) and Fig 3(b) the heat transfer in modified fin is maximum because of increased conduction.

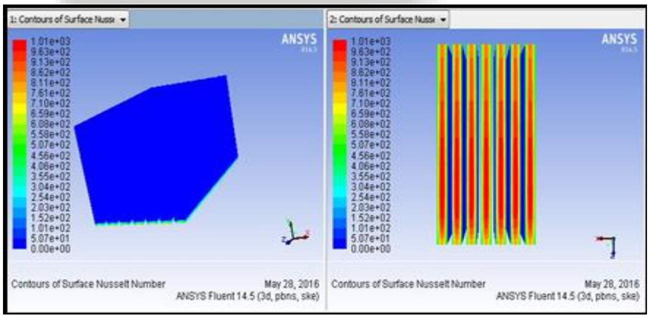

Fig. 3(a): Nusselt number for original solid model

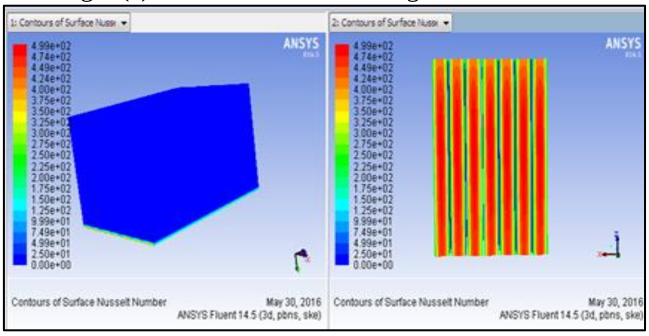

Fig. 3(b): Nusselt number for modified solid model

The Reynolds number is obtained from CFD analysis and it is found that Reynolds number for original model is 112 while for the reduced aspect ratio in case of modified fin it is 197. The heat transfer by the conduction in modified fin is maximum because the turbulence of the fluid is increased in conduction

The heat transfer coefficient is obtained from CFD analysis and it is found that the heat transfer coefficient for original model is 380 for the reducing aspect ratio in case of modified fin it is 169. The heat transfer by the conduction in modified fin is maximum because the heat transfer between simple elements (such as walls in heat exchangers) is decreased in conduction. It is attributed to the minimum heat transfer in original fin and is maximum in modified fin.

Heat content in the inlet air is 33.4 W and in the wall is 7.14 W while it is 40.54 W for the outlet air. The net heat extracted is 0.009 W however for the modified model, heat extracted from the body is 1.67W. These figures indicate that the heat transfer rate is increased considerably with reducing the fin thickness. This is attributed to the increase in the number of fins on the same body with reduction in thickness from 3mm to 2mm.

The figure 4 Shows output parameters of CFD analysis of the original and modified models of solid fin. As explained above, these graphs explain that the output parameters of CFD analysis are better for modified fin with reduced aspect ratio except heat transfer coefficient. Heat transfer coefficient depends upon area of cross section which is high for original fin.

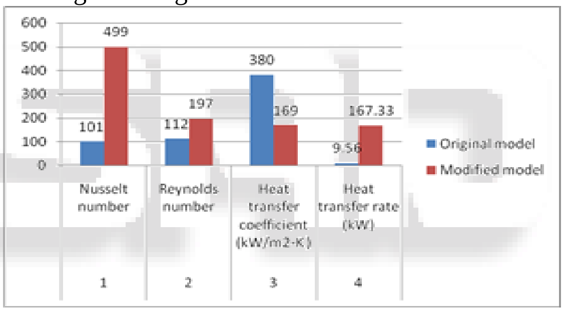


Fig. 4: Comparison of CFD analysis output parameters of original and modified models of solid fin.

*2) CFD analysis of elliptical fin*

TABLE 2 gives the output parameters obtained from CFD analysis for elliptical original and modified fins.

| Sl. No | Output | original model | modified model |
|---|---|---|---|
| 1 | Nusselt number | 237 | 477 |
| 2 | Reynolds number | 109 | 220 |
| 3 | Heat transfer coefficient (kW/$m^2$-K ) | 925 | 613 |
| 4 | Heat transfer rate (kW) | 218.7 | 475.20 |

Table 2: The output parameters obtained from CFD analysis for elliptical original and modified fins.

The Nusselt number is obtained from CFD analysis and it is found that Nusselt number for original model is 237 while for the reducing aspect ratio in case of modified fin it is 477. The heat transfer in modified fin is maximum because of increased conduction.

The Reynolds number is obtained from CFD analysis and it is found that Reynolds number for original model is 109 while for the reducing aspect ratio in case of modified fin it is 220. On comparing the Fig 5(a) and Fig 5(b) the heat transfer in modified fin is maximum because turbulence of the fluid is increased in conduction.

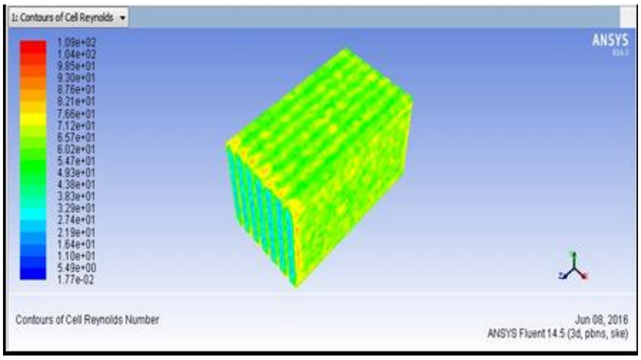


Fig. 5(a): Reynolds number for Original elliptical model

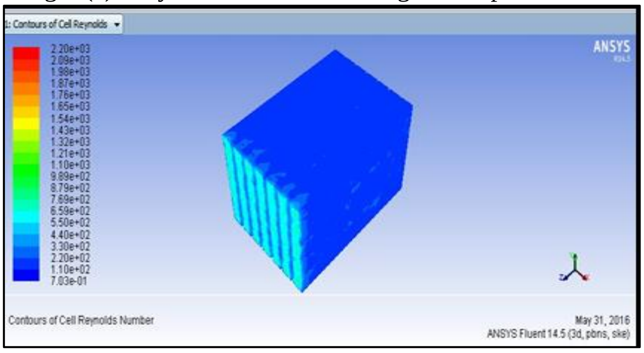


Fig. 5(b): Reynolds number for Modified elliptical model

The heat transfer coefficient is obtained from CFD analysis and it is found that the heat transfer coefficient for original model 925 and for the reducing aspect ratio in case of modified fin it is 613. The heat transfer by the conduction in modified fin is maximum because the heat transfer between simple elements (such as walls in heat exchangers) is decreased in conduction. It is attributed to the minimum heat transfer in original fin and is maximum in modified fin.

Heat content in the inlet air is 33.4 W and in the wall is 9.42 W while it is 43.09 W for the outlet air. The net heat extracted is 0.218 W however for the modified model, heat extracted from the body is 4.75 W. These numbers indicate that the heat transfer rate is increased considerably with reducing the fin thickness. This is attributed to the increase in the number of fins on the same body with reduction in thickness from 3mm to 2mm.

The graph 6 shows the original and modified models of elliptical fin. As explained above these, graphs explain that the output parameters of CFD analysis are better for modified fin with reduced aspect ratio for except Heat transfer coefficient. Heat transfer coefficient depends upon area of cross section which is high for original fin.

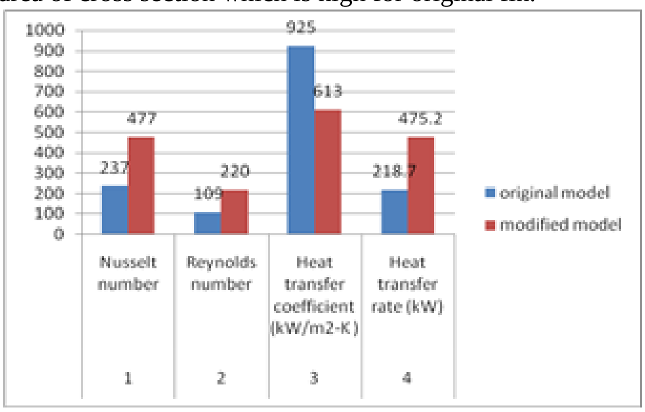


Fig. 6: Comparison of CFD analysis output parameters of original and modified models of elliptical fin.

### 3) CFD Analysis of Circular Fin

TABLE 3 gives the output parameters obtained from CFD analysis for circular original and modified fins.

| Sl. No | Output | original model | modified model |
|---|---|---|---|
| 1 | Nusselt number | 104 | 241 |
| 2 | Reynolds number | 142 | 914 |
| 3 | Heat transfer coefficient ($kW/m^2$-K ) | 256 | 101 |
| 4 | Heat transfer rate (kW) | 19.17 | 756.7 |

Table 3: The output parameters obtained from CFD analysis for circular original and modified fins.

The Nusselt number is obtained from CFD analysis and it is found that Nusselt number for original model is 104 while for the reducing aspect ratio in case of modified fin it is 241. The heat transfer by the conduction in modified fin is maximum because of increased conduction

The Reynolds number is obtained from CFD analysis and it is found that Reynolds number for original model is 142 while for the reducing aspect ratio in case of modified fin it is 914. The heat transfer by the conduction in modified fin is maximum because turbulence of the fluid is increased in conduction

The heat transfer coefficient is obtained from CFD analysis and it is found that the heat transfer for original model is 256 and for the reducing aspect ratio in case of modified fin it is 101. On comparing the figures Fig 7(a) and Fig 7(b) the heat transfer by the conduction in modified fin is maximum because the heat transfer between simple elements (such as walls in heat exchangers) is decreased in conduction. It is attributed to the minimum heat transfer in original fin and is maximum in modified fin.

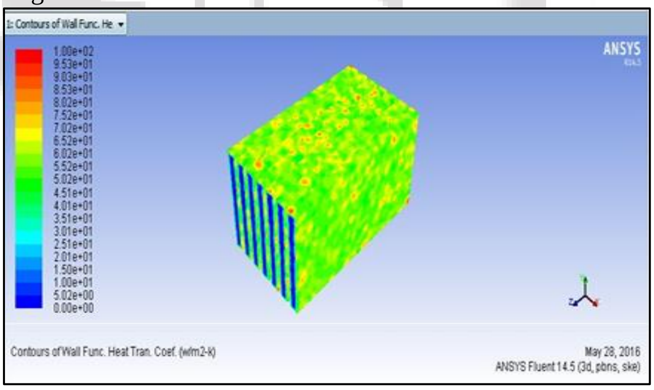


Fig. 7(a): Heat Transfer Coefficient For Original Model

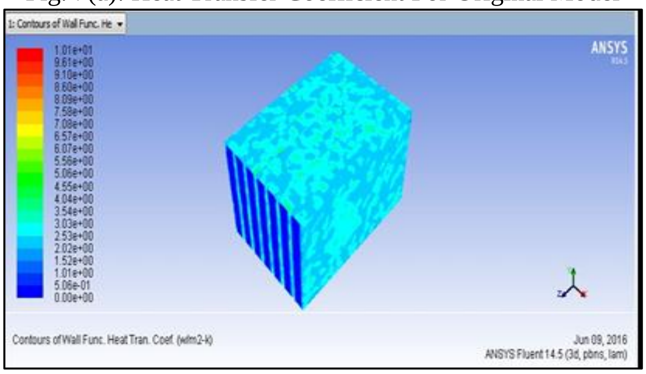


Fig. 7(b): Heat Transfer Coefficients for Modified Model

Heat content in the inlet air is 33.4 W and in the wall is 9.10 W while it is 42.52 W for the outlet air. The net heat extracted is 0.019 W however for the modified model, heat extracted from the body is 7.56 W these figures indicate that the heat transfer rate is increased considerably with reducing the fin thickness .this is attributed to the increase in the number of fins on the same body with reduction in thickness from 3mm to 2mm.

The figure 8. shows the original and modified models of circular fin. As explained above these, graphs explain that the output parameters of CFD analysis are better for modified fin with reduced aspect ratio for except Heat transfer coefficient. Heat transfer coefficient depends upon area of cross section which is high for original fin.

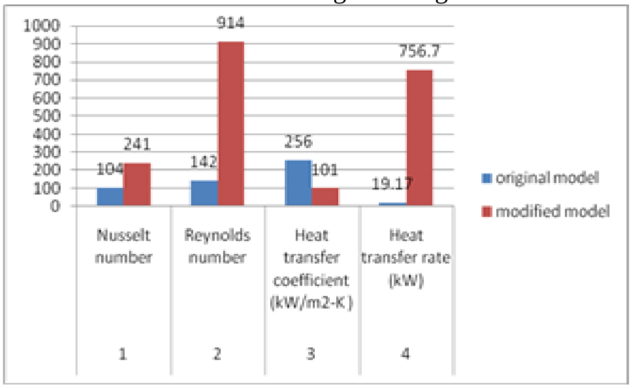


Fig. 8: Comparison of CFD analysis output parameters of original and modified models of circular fin.

*4) CFD Analysis of Rectangular Fin*

TABLE 4 gives the output parameters for obtained from CFD analysis for circular original and modified fins rectangular original and modified fin

| Sl. No | Output | original model | modified model |
|---|---|---|---|
| 1 | Nusselt number | 226 | 496 |
| 2 | Reynolds number | 111 | 894 |
| 3 | Heat transfer coefficient ($kW/m^2$-K ) | 311 | 100 |
| 4 | Heat transfer rate (kW) | 29.04 | 120.69 |

Table 4: The output parameters obtained from CFD analysis for rectangular original and modified fins.

The Nusselt number is obtained from CFD analysis and it is found for original model is 226 and for the reducing aspect ratio in case of modified fin it is 496. The heat transfer by the conduction in modified fin is maximum because of increased conduction.

The Reynolds number is obtained from CFD analysis and it is found for original model is 111 and for the reducing aspect ratio in case of modified fin it is 894. The heat transfer by the conduction in modified fin is maximum because turbulence of the fluid is increased in conduction.

The heat transfer coefficient is obtained from CFD analysis and it is found for original model is 311 and for the reducing aspect ratio in case of modified fin it is 100. The heat transfer by the conduction in modified fin is maximum because the heat transfer between simple elements to the increased surface area due to reduction in fin thickness (such as walls in heat exchangers) is decreased in conduction. . It is attributed to the minimum heat transfer in original fin is maximum in modified fin.

Heat content in the inlet air is 33.4 W and in the wall is 9.11 W while it is 42.53 W for the outlet air. The net heat extracted is 0.029 W however for the modified model, heat extracted from the body is 12.06 W these figures indicate that the heat transfer rate is increased considerably with reducing the fin thickness. This is attributed to the increase in the number of fins on the same body with reduction in thickness from 3mm to 2mm.

The figure 9 shows the original and modified models of rectangular fins. As explained above these, graphs explain that the output parameters of CFD analysis are better for modified fin with reduced aspect ratio. Heat transfer coefficient depends upon area of cross section which is high for original fin.

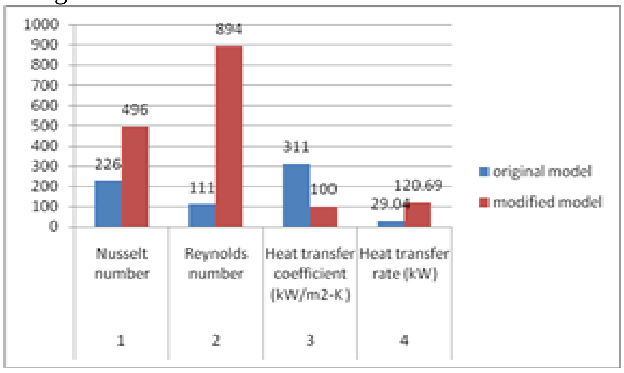


Fig. 9: Comparison of CFD analysis output parameters of original and modified models of rectangular fins.

## IV. Conclusions

CFD analysis of the fins is done; various heat transfer output parameters are evaluated

1) Increase in the Reynolds number and Nusselt number for the modified fin with low aspect ratio is indicate that the heat transfer is maximum for the modified fin.
2) The heat transfer rate in the modified model is found to be 0.009watts and for the modified model with fin thickness is reduced from 3mm to 2mm the heat transfer rate is increased to 1.67 watts. The increase in the heat transfer rate is attributed to the increase in the surface area as the fin thickness is reduced from 3mm in the original model to 2mm for the modified model. Overall the heat transfer rate is maximum for circular modified fin profile.
3) Heat transfer coefficient is reduced numerical for the modified fin on comparison with original fin. These may be attributed to the increased surface area due to reduction in fin thickness

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