# Analysis of Heat Transfer Enhancement of a Heated Plate with Rectangle Perforated Fins

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***Abstract*- The fins are often used to enhance the rate of heat transfer from the heated surfaces to the environment. In this paper rectangular longitudinal fins with and without perforated were compared using experimental and numerical Analyses. The base plate is kept at a temperature of 100 ºC and Reynolds number varies between 5.93×104 and 2.96×105. Such fins shall find its applications in heat transfer through solar air heaters, refrigeration systems, etc. Here it is observed that at an air velocity of 20, 15, 10, 5 and 0 m/s the heat transfer rate using rectangular perforated fins is more than that of rectangular solid fins by 8.62%, 3.34%, 2.24%, 1.53%, and 1.2%, respectively. Thus, for higher air velocity the use of rectangular perforated longitudinal fins is justified for a higher rate of heat transfer in the engineering applications.**

## I. INTRODUCTION

The removal of excessive heat from system components is essential to avoid damaging effects of overheating. Therefore, the enhancement of heat transfer is an important subject of engineering application. Two types of cooling we can provide on the heated surface, namely active cooling and passive cooling. In active cooling, some external source such as a fan and blower are required, this type of cooling also known as forced convection cooling. But in passive types of cooling will do with the help of natural convection like air. Extended surfaces (fins) are frequently used in heat exchanging devices for the purpose of increasing the heat transfer between a primary surface and the surrounding fluid. Silva M.J. et.al. [1] Investigated experimentally and numerically the heat transfer coefficient from the cast iron plate with different Reynolds number. They studied that the heat transfer coefficient can be improved if the spacing between the fins can nullify the boundary layer formation. Sahin B. and Demir A. [2] Stated that the performance of the heat transfers from fins can be enhanced if using perforations, porosity or slots. They studied that the heat transfer improvement can be achieved either by increasing the heat transfer surface area or the heat transfer coefficients or by both. Due to high demand for compact, lightweight, and economical fins, the optimization of fin size is of great importance. Shaeri M.R. and Yaghoubi M. [3] Investigated numerically to determine the number of perforations is required along the longitudinal direction fin array for turbulent heat transfer, fluid flow and pressure drop in the longitudinal rectangular fin array. Heat transfer equipment is required to be much more compact in size and light in weight because of space limitation. While the solid rectangular fins attached to the duct wall enhances heat transfer, rectangular perforated fins attached to one of the methods to take away heat transfer from the surface area of the thermal device is extended surface (fins). In our experiment, we are using the material of fins and plate is aluminum because the thermal conductivity of aluminum is more than other metallic material. The thermal conductivity of aluminum at 100℃ is 237 W/mK, and in this analysis, two types of fins are using, Rectangular Perforated fin, and rectangular solid fin. The parameter fin effectiveness is used to determine fin performance. One can find that rectangular perforated fins have higher heat transfer performance and can exchange more heat between primary surface and the ambient air. It is observable that solid fins have the largest average Nusselt number in comparison with rectangular perforated fins, but rectangular perforated fins have a large heat transfer area compared with solid fin and by an increase of perforations, the heat transfer area becomes larger. Due to the high surface force and higher surface roughness, the flow characteristics through the rectangular perforated fins are quite high as compared to the rectangular solid fins. The pressure drag co-efficient continues to decrease with the increase of Reynolds number. Throughout the range of velocities, rectangular fins have the highest pressure drag coefficient as these fins have maximum frontal surface area. Rectangular fins have higher pressure drag co-efficient than rectangular perforated fins. So, rectangular fins require more power to circulate the coolant than the rectangular perforated fins. The wake behind the solid fin is more whereas in the case of the perforated fin very small wake is composed attached to the base plate and the flow in the channels of perforation eliminates wake formation. In fact, for the reason of the perforation, a part of flow goes in the perforations like the flow in a duct and for Fins with more perforations this part increases. For this reason, the formed wakes are negligible for fins with perforations but in the case of the solid Fin, fluid interacts with the front surface of the fin and separation occurs. Due to air flow from the inside heat transfer will be enhanced. So its other advantage is to enhance the heat transfer coefficient from the fins by the heated body. All studies in this experiment done in a steady state condition.

## 2. EXPERIMENT SETUP

A schematic of the Experiment setup is shown in Fig. 1. The experimental setup consists mainly of a heated bed, wind tunnel, Pitot tube, flow control valve and a multi-thermometer. The cross section area of the wind tunnel 300×300 mm2. The material of the fins and the base plate is aluminum because the thermal conductivity of the aluminum is more than other metals and it is easily available with less cost and the weight of aluminum is less than other metals. Table 1 approaches all properties of aluminium.

Table 1 Properties of aluminium

| S.NO. | Properties of aluminum | |
|---|---|---|
| I. | Density | 2700 Kg/m$^3$ |
| II. | Thermal conductivity (k) | 237 W/mK |
| III. | Elasticity (E) | 70 Gpa |
| IV. | Bulk modulus (K) | 76 Gpa |
| V. | Modulus of rigidity (G) | 26 Gpa |
| VI. | Poisson ratio (υ) | 0.35 |

The flow of air is considered steady and turbulent. Blowing air dominant forced convection for heat transfer mechanism from fin to ambient. The initial velocity of the air 5 m/s in wind tunnel, but when the flow control valve gradually opens it will increase till 20 m/s. From the high velocity of air more turbulence occurred in surrounding the fin plate. Table 2 presents the all geometric parameters of a rectangular plate with or without fins. In this experimental setup, we have studied of heat transfer from a rectangular plate without fins, a rectangular perforated fins channel, and rectangular solid fins channel.

Table 2 Geometric Parameters of a rectangular plate with or without fins.

| S. NO | Parameter | Rectangular plate without fins | Rectangular solid fins | Rectangular perforated fins |
|---|---|---|---|---|
| I. | Base area | 300×250 mm$^2$ | 300×250 mm$^2$ | 300×250 mm$^2$ |
| II. | Base plate thickness | 1 mm | 1 mm | 1 mm |
| III. | Length of fin | - | 250 mm | 250 mm |
| IV. | Height of fin | - | 25mm | 24 mm |
| V. | Thickness of fin | - | 2 mm | 2.2 mm |
| VI. | Area of fin | - | 50 mm$^2$ | 48.2 mm$^2$ |
| VII. | Perimeter of fin | - | 54 mm | 52.4 mm |
| VIII. | Pitch of fins | - | 28.20 mm | 28.02 mm |
| IX. | Volume of fin | - | 12500 mm$^3$ | 12050 mm$^3$ |

Table 3 presents a description of heated bed. The work of the heated bed to provide uniform heating in a bottom rectangular plate with or without fins in a wind tunnel. The minimum temperature range of heated bed is 100℃ and maximum range is 180℃ which obtained 12V and 24V. But in this analysis, we have taken 100℃.

Table 3 Description of heated bed

| S.NO. | Parameter | Heated bed |
|---|---|---|
| I. | Power input | 120W |
| II. | Voltage | 12/24V |
| III. | Resistance | 1.2/4.8Ω |
| IV. | Base area | 214×214 mm2 |
| V. | Minimum temperature | 100℃ |
| VI. | Maximum temperature | 180℃ |

## VI. MAXIMUM TEMPERATURE 180℃

### 2.1 Rectangular plate with rectangular perforated fins

Shown in fig. 1 Experiment setup of a wind tunnel with rectangular perforated fins. Rectangular plate with attached rectangular perforated fins situated in the middle of the test section in a wind tunnel.

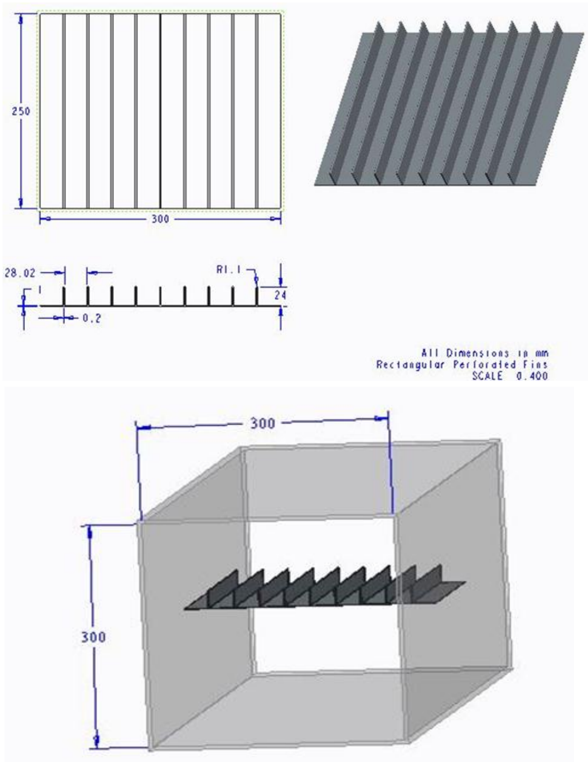



Fig. 1. Schematic diagram of the Experiment set-up of a wind tunnel with rectangular perforated fins

A pitot tube established near parallel with a plate which measures the velocity of flowing air. A heated bed attached the bottom of channel fins, which uniform heating of base of channel fins. When the temperature of a heated bed, reached 100℃ uniformly then after wind tunnel started. In this analysis, the pitch distance between rectangular perforated fins is taken 28.02 mm, and the length of the fins is 250 mm. For enhancement of heat transfer provides a 0.2 mm perforation. Due to perforation boundary layer formation occurred in between the fins, then pressure drop also increased, but the heat transfer have enhancement, and checked all results with different velocities like 20 m/s, 15 m/s, 10 m/s, 5m/s and checked also result of the base temperature of the plate without velocity used of the wind tunnel.

2.2 Rectangular plate with rectangular fins

Fig. 2 Show rectangular solid fins which attached with rectangular plate. A rectangular solid fins channel situated in a middle of the test section in the wind tunnel, and Pitot tube attached with near to the plate so that we can find the velocity of air. The pitch of the fins taken 28.20mm and, the length and thickness are 250 mm, and 2mm. In this rectangular solid fins channel 9 fins are attached in parallel longitudinal with equidistance.

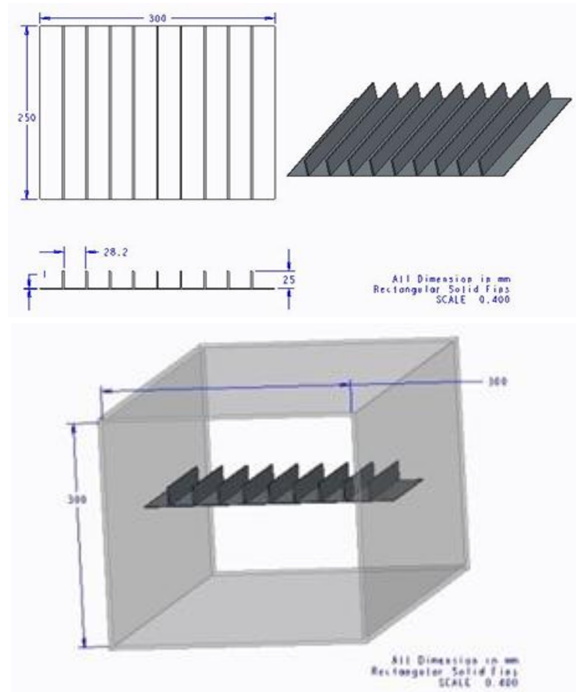
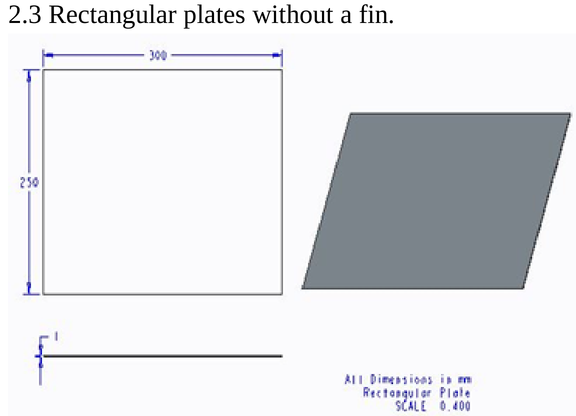



Fig. 2. Experimental setup of a wind tunnel with rectangular fins

Air is flowing along the longitudinal direction of the fins. Manometric fluid is taken alcohol and its density is 789 kg/m3, and when high-velocity air passes through the test section around the rectangular channel some boundary layer formation occurred. From manometric deflection in a U-tube manometer, we can find pressure difference.

2.3 Rectangular plates without a fin.



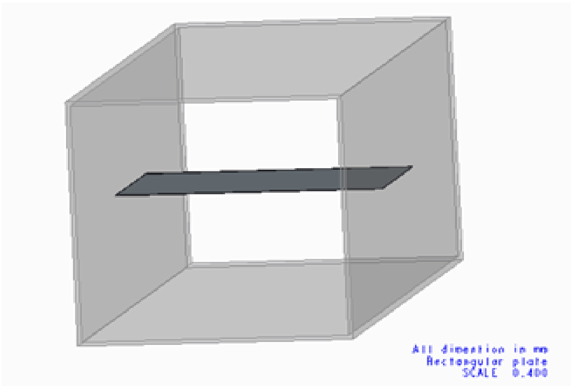



Fig. 3. Experimental setup of a wind tunnel with rectangular plate

Fig. 3 Show the rectangular plate without fins in a wind tunnel. A rectangular plate 300 ×250 mm² cross-section is situated in test section in the wind tunnel, and a Pitot tube is attached to the parallel with a plate to find the velocity of flowing air. The thickness of the aluminum plate taken in this analysis 1 mm.

When the air flow on the surface of the heated plate, it became too cool, but the base temperature of the plate is becoming more than the perforated rectangular fins channel and rectangular fins channel. But the whole body was direct contact with flowing air. The heat transfer rate with 20 m/s is more than another velocity for perforated fins and the flow of fluids (air) have turbulence in the rectangular channel of a wind tunnel. The temperature of the heated rectangular plate calculating with the help of a multi - thermometer.

## 3. NUMERICAL ANALYSIS

The steady state heat transfer through fins surface described in this analysis if h is the heat transfer coefficient of air and $A_{tot}$ is the total surface area of the surface and fins, then Bilen K. et. al. [8] Investigation of the air passes through heated plate, the heat transferred from the finned surface expressed as,

$$Q = hA_{tot}[T_{sur} - (\frac{T_{out} + T_{in}}{2})] \qquad (1)$$

$$Q = \sqrt{hpkA}\, \Delta T \frac{\sin hmL + \left(\frac{h}{mk}\right)\cos hmL}{\cos hmL + \left(\frac{h}{mk}\right)\sin hmL} = hA\Delta T \qquad (2)$$

Where; $T_{sur}$ = base temperature of fin or surface temperature of plate

$T_{out}$ = outlet temperature of air flow

$T_{in}$ = inlet temperature of air flow

Where; $\Delta T$ = Temperature difference between air fin surface and ambient

h = Heat transfer coefficient of air

$A_c$ = cross section area of the fin

m = slope of heat transfer in $m^{-1}$ = $\sqrt{hp/kAc}$

But heat transfer coefficients have varied with temperature. So in this analysis temperature of the base plate is 100°C. The inlet temperature of air assumed to be 27°C, and the inlet velocity of the wind tunnel is constant, where steady flow condition is considered for all variables using $U_{in} = U\infty$, and $T_{in} = T\infty$. The effect of radiation heat transfer neglected in this analysis. The heat transfer rate over the surface due to convection or conduction may be found with the help of the Nusselt number ($N_u$). Shaeri M.R and Yaghoubi M. [4] Studied if air blowing over the surface of the heated plate in this place heat transfer from convection and conduction both, but the predominance of convection or conduction find with the help of Nusselt number. Nusselt number is defined as it is the ratio of heat transfer through convection to the heat transfer to conduction.

$$N_u = \frac{Q_{conv}}{Q_{cond}} \qquad (3)$$

Heat transfer coefficient of air in laminar flow we can find by Nusselt number, it is defined by in equation [3],

$$Nu = \frac{hLc}{k} = 0.664\ (Re)^{1/2}\ (Pr)^{1/3} \qquad (4)$$

Where; h = heat transfer coefficient of fluid (air),

Lc = characteristic length,

k = thermal conductivity of flowing fluid (air),

P.K. Nag [20] to find if the ideal gas (air) flowing through the channel, the density will be varied with pressure and temperature;

$$þ = \frac{P}{RT} \qquad (5)$$

Where; P = atm. air pressure generally its value is = 1.01325 bar

R = gas (air) constant = 287 J/kg-k

T = atm. Temperature = 300k

If all value put in equation (a) we can find the density of flowing fluid (air)

$$þ = \frac{101325}{287 \times 300}$$

$$= 1.1768\ kg/m^3$$

Kong Y.Q. and Yang L.J and Du X.Z and Yang Y.P. [5] investigation flow behaviors of air when it flows different channel, if v is the velocity of air and υ is the dynamic viscosity of air then flow behavior find from '$R_e$'. The flow over the plate is laminar or turbulent we can find by Reynolds number; "it can be defined as a ratio of Inertia force to the viscous force".

$$R_e = \frac{\text{þ}vLc}{\upsilon} \quad (6)$$

Where; þ = density of flowing fluid (air) at 300k,
= 1.1768 kg/$m^3$
v = velocity of flowing fluid (air),
Lc = characteristic length,
υ = viscosity of flowing fluid (air) at 300k,
= 1.983 x $10^{-5}$ Pa-s

## 4. RESULT AND DISCUSSION

In a horizontal channel under the bottom wall at constant heat flux conditions the convection heat transfer with longitudinal fins has been investigated. A Reynolds number calculated by using equation [4]. The present analysis of the rectangular perforated fins and rectangular solid fins is done with Re = $5.93\times10^4$ to $2.96\times10^5$. According to Table.4, all value of the Reynolds numbers with different velocities showing the behaviour of the flowing fluid is turbulent. Due to more momentum transfer in turbulent flow to enhance the heat transfer rate through the heated plate.

Table 4 presents the variation of Reynolds number with different velocities. By adjusting the flow control valve the fluid velocity at the inlet of the test section obtained at 5 < $V_{in}$ < 20 m/s. with increase the velocity of air Reynolds number will also increase. At higher Reynolds number turbulence of air increased that's by heat transfer coefficient from the heated plate also increased. Due to perforations some portions of the flow passes through the channels and thus the air velocity reduces.

Table 4 The range of Reynolds number studied for steady state flow.

| S.NO. | Velocity (m/s) | Reynolds number ($R_e$) |
|---|---|---|
| I. | 5 | $5.93\times10^4$ |
| II. | 10 | $1.48\times10^5$ |
| III. | 15 | $2.22\times10^5$ |
| IV. | 20 | $2.96\times10^5$ |

Fig.4 illustrates the variation of the heat transfer coefficient with velocity. The Initial value of heat transfer coefficient for air at 0 m/s taken in this analysis 10 W/m2K. Due to perforation more air will be contacted with fins so the heat transfer coefficient of rectangular perforated fins will be more than rectangular solid fins. To increase the speed of air turbulence will be increased at that point heat transfer coefficient from the heated plate with fins increased. It's found that when the inlet air temperature and the heat transfer are kept constant, the thermal resistance decreases with increasing the Reynolds number. This is because of the heat transfer rate increases as the air flow rate increases. Rectangular perforated fins have slightly higher thermal resistances than that of rectangular fins.

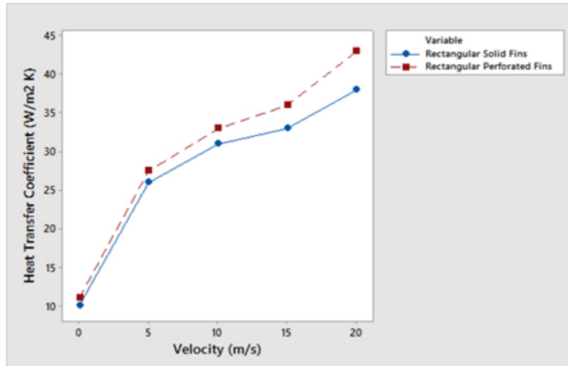



Fig.4 Comparisons between rectangular perforated fins and rectangular solid fins of heat transfer coefficient with velocity.

Table 5 Show the temperature variation of a rectangular plate, rectangular perforated fins and rectangular solid with temperature are kept at 100℃. After some time at working time the base temperature of rectangular perforated fins slightly decreased and less then rectangular solid fins and rectangular plate that means the cooling rate of rectangular perforated fins are more than rectangular solid fins because due to perforation heat transfer coefficient increased.

Table 5 The temperature variation with or without fins plate with a different velocity.

| S. NO | Velocity of air (m/s) | Base temperature of rectangular plate | Base temperature of rectangular fins | Base temperature of rectangular perforated fins |
|---|---|---|---|---|
| I. | 20 | 58℃ | 52.40℃ | 50.20℃ |
| II. | 15 | 62℃ | 55.60℃ | 53.80℃ |
| III. | 10 | 69℃ | 59.30℃ | 58℃ |
| IV. | 5 | 79℃ | 73.2℃ | 72.1℃ |
| V. | 0 | 84.10℃ | 90.95℃ | 89.90℃ |

Fig.4 show heat transfer with different velocities to increase the velocity of air the heat transfer will be increase because the heat transfer coefficient from surrounding heated plate with fins increase. At 20 m/s rectangular perforated fins showing 8.62% more heat transfer rate than rectangular fins. That means rectangular perforated fins cooling capacity more than rectangular fins with decrease the magnitude of velocity the heat transfer slightly decrease. At 15, 10, 5 m/s heat transfer rate of rectangular perforated fins found 3.34%, 2.24%, 1.53% more than rectangular solid fins. Without surrounding velocity the heat transfer rate of perforated fins 1.2% more than the rectangular fins. For more heat transfer rectangular perforated fins have better heat transfer Then rectangular fins.

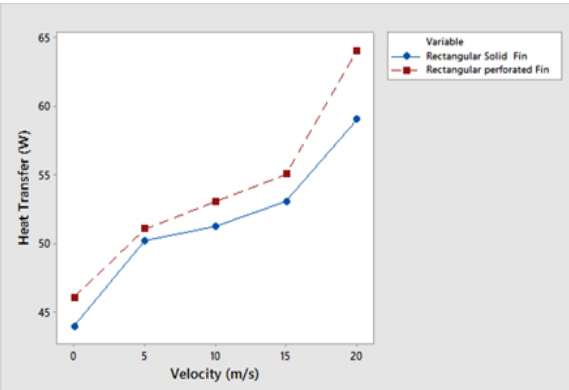



Fig.5 Comparisons of heat transfer in rectangular perforated fins and rectangular solid fins with velocity

## 5. CONCLUSION

Thermal performance of rectangular perforated fins, and rectangular fins is experimentally investigated in this analysis. Generally, optimization of fins is focused on to maximize heat dissipation rate and to minimize pressure drop for a given mass or volume of the heat sink. Rectangular perforated fins have a large contact surface with the air than rectangular fins. Thus the rectangular perforated fins have higher effectively than the rectangular fins.

- Rectangular Perforated fins have a higher contact area with air than rectangular fin. In rectangular perforated fins the average friction drag higher compared to rectangular solid fin, and it will also increase with perforations.
- The temperature drops from fin base to the top surface increases with addition of perforations.
- Rectangular perforated fins have higher fin effectiveness than solid fins. With increase in effectiveness shows the enhancement of heat transfer from perforated fin with respect to solid fin in the range of the present investigation.
- With increase of perforations weight reduction is also considerable and Economical gain along with more enhancement of heat transfer rate.
- One of the most important benefits of the utilization of perforated fins to reduction of fins weight. Low weight certifies saving material of fins and related equipment such as heat sinks.
- In this experiment we have achieved base temperatures of rectangular perforated fins is less than rectangular fins with different velocity of air.

## 6. FUTURE SCOPE

In this experiment analysis we find heat transfer rate through rectangular fins, rectangular perforated fins, and rectangular plate. Heat transfer rate through rectangular perforated fins is more than rectangular solid fins because of contact of fluid (air) in rectangular perforated fins more than the rectangular solid fins so heat transfer rate through heated body will be increased. These types of Fins are more suitable in a solar application like solar air heaters, solar water heater, and refrigeration etc. At working time in solar system more internal heat generation occur and it can be reduce to attach the fin on the bottom surface. But these fins are also suitable in statically system but less efficient than the dynamic system. Because in dynamic system due to velocity phenomenon heat transfer rate increase then static system.

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