International Research Journal of Engineering and Management Studies (IRJEMS)
Volume: 03 Issue: 05 | May -2019 ISSN: 2395-0126

Experimental Investigation of Heat Transfer enhancement on Rectangular fins using Perforations

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Abstract

In the present research, an experimental investigation is carried out for analysing the heat transfer performance by designing the fin with rectangular cross-section. The heat transfer performance of fin with same geometry having perforations and without perforations is compared. Approximately 3% to 5% more heat transfer rate can be achieved with perforated fin as compared with same geometry of fin without perforations.

In thermal analysis, variation of temperature with respect to the distance at which heat flow occur through the fin is analyzed. Extension surfaces with perforations is used to increases the surface area of the fin in contact with the fluid flowing around it. When the surface area increases, more fluid comes in contact with surface which increases the rate of heat transfer.

Here the mode of heat transfer is forced convection and it can be accomplished by using the blower with regulator and the flow analysis can be analysed by calculating Reynolds number, Nusselt number for the fin with perforations and without perforations.

***Key Words*:** Forced convection, heat transfer enhancement, straight rectangular fin, Reynolds number, Nusselt number.

1.INTRODUCTION

In the study of heat transfer, fins are surfaces that extend from an object to increase the rate of heat transfer to or from the environment by increasing convection. By slightly increasing the convection heat transfer coefficient, or slightly increasing the surface area of the fin configuration of the object increases the rate of heat transfer [1].

Adding a fin configuration to the object, however, slightly increases the surface area and can sometimes be economical solution to heat transfer problems [2].

Circumferential fins around the cylinder, square and rectangular shape of a motor cycle engine and fins attached to condenser tubes of a refrigerator are a few familiar examples only occurs when there is a temperature difference, Flows faster when this difference is higher, always flows from high to low temperature, Is greater with greater surface area

There are various types of fins but rectangular plate fins are commonly used for the reason of simplicity in manufacturing. It is easy and effective way to make perforations in rectangular fin and hence the performance investigation of rectangular fin with perforations is considered [3].

Heat transfer rate from fins can be improved by employing perforations, porosity or slots and also heat transfer improvement may be achieved by either increasing the heat transfer co efficient or the heat transfer surface area or by both [4].

1.1 Heat transfer through fins

Convection heat transfer between a hot solid surface and the surrounding colder fluid is governed by the Newton's cooling law which states that "the rate of convection heat transfer is directly proportional to the temperature difference between the hot surface and the surrounding fluid and is also directly proportional to the area of contact or exposure between them". Newton's law of cooling can be expressed as

$$Q = h\,A\,(dT)$$

Where,

h = convection heat transfer coefficient
T_s = Hot surface temperature
T_a= Fluid temperature
A = Area of contact or exposure

Therefore, convection heat transfer can be increased by either of the following ways

1. Increasing the temperature difference (T_s) between the surface and the fluid.
2. Increasing the convection heat transfer coefficient by enhancing the fluid flow or flow velocity over the body.
3. Increasing the area of contact or exposure between the surface and the fluid. Most of the times, to control the temperature difference is not feasible and increase of heat transfer coefficient may require installation of a pump or a fan or replacing the existing one with a new one having higher capacity, the alternative is to increase the effective surface area by extended surfaces or fins. [5]

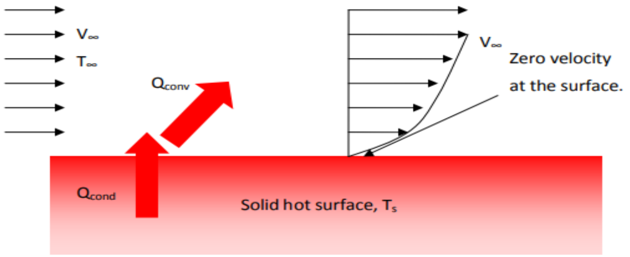


Fig -1: Forced convection heat transfer

Convection heat transfer is complicated since it involves fluid motion as well as heat conduction. The fluid motion enhances heat transfer (the higher the velocity the higher the heat transfer rate).
The rate of convection heat transfer is expressed by Newton's law of cooling:

The forced convective heat transfer coefficient strongly depends on the fluid properties and roughness of the solid surface, and the type of the fluid flow (laminar or turbulent) [6].

The type of fluid flow can be determined by Reynolds number (Re) which is a Non-dimensional Number and it is a ratio of inertia force to the viscous forces in the fluid. At large Re numbers, the inertia forces, which are proportional to the density and the velocity of the fluid, are large relative to the viscous forces; thus the viscous forces cannot prevent the random and rapid fluctuations of the fluid (turbulent regime).

The Reynolds number at which the flow becomes turbulent is called the critical Reynolds number. For flat plate the critical Re is experimentally determined to be approximately Re critical = 5 x10^5

2. Literature Review

G. D. Gosavi studied and investigated the concept of heat transfer through perforated material is one of the methods of improving the heat transfer characteristic in the natural convection. A perforated and solid material of brass, aluminum and copper was selected for the experimentation. As the review was concerned it was found that, the heat transfer through perforated fins was much greater than 50-60% than the solid one.

U. V. Awasarmol and A. T. Pise studied experimentally natural convective heat transfer enhancement of perforated fin array with perforation diameter ranging from 4 mm to 12 mm inline. They tested the four configurations from 0^0C to 90^0C inclination angle from which they found optimum perforation diameter as 12mm at 45^0.

A. H. AlEssa and M. Q. Al-odat used several methods to increase the effective heat transfer surface area of fin specified.

They investigated the natural heat transfer enhancement from a horizontal rectangular fin embedded with equilateral triangular perforations numerically and concluded that magnitude of enhancement is directly proportional to fin thickness and thermal conductivity of material.

3. Design of rectangular fin considerations:

The design of fins is considered to be optimum when the fins offer

1. Minimum resistance to flow of fluid,
2. Are easy to manufacture,
3. Require minimum cost of manufacture, and
4. Are light in weight.

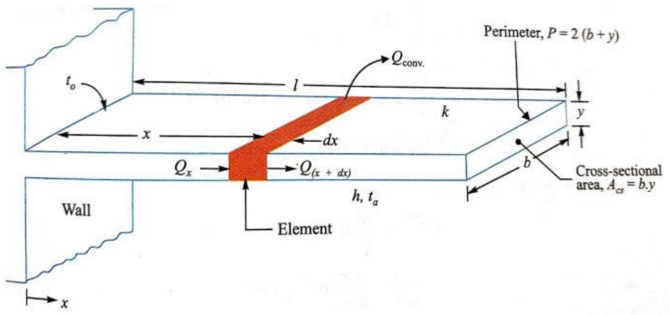


Fig -2: Rectangular fin geometry

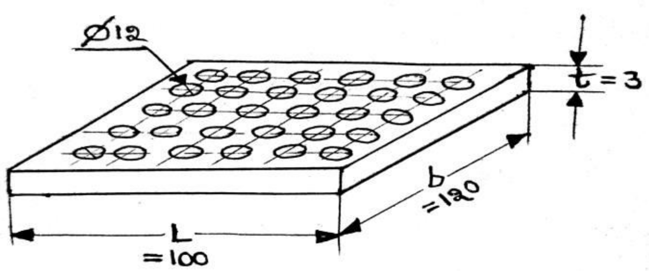
The other boundary condition depends on physical situation. The following cases may be considered:

Case 1: The fin is infinitely long and the temperature at the end of the fin is ambient fluid.

Case 2: The end of the fin is insulated.

Case 3: The fin is of finite length and loses heat by conduction

3.1 considerations for Perforations



All the dimensions are in 'mm'

Fig -3: Perforated fin

Perforations can be analyzed by considering 10% area

L= 90 mm, W=120 mm

Area = L*W= 90*120 = 10800 mm^2

Considering, 8*11 =88 holes

10800 = $\pi r^2 * 88$

Therefore, r = 6 mm

4. Experimental setup

In this experiment, we are using two types of fins one is without perforation and another one is perforated. Fins have 100mm length, 120mm width and 3mm thickness. One fin is perforated with 6mm diameter of circular hole. Fins are made of pure aluminum with thermal conductivity of 237 W/m K. Fins are heated by electrical heater which is made up of ceramic with thermal conductivity 150 W/m K and of rectangular shape. Heater works on 230V, 50Hz and 600 watts' single phase. Readings of heater measured in the form of voltage and current by digital voltmeter and digital ammeter. The heat transfer rate is calculated by multiplying the voltage and current. Blower is a device used to increase the velocity and pressure of air and it is used in forced convection heat transfer to increase the convective heat transfer rate. It is operated on suction mode. Speed of blower is 13500 rpm and discharge can be varied by using regulator and it is attached with a blower. Blower is fitted to the left side of the fins at a distance of 50cm and forced air is passed through fins. Hence forced convection takes place and heat is dissipated. Five thermocouples are used to measure the surface temperature of each fins and one is used for measuring ambient temperature and temperature readings are displayed on digital temperature indicators. Manometer is a device used for measuring the pressure difference at a point in a fluid by balancing the column of fluid by another column of fluid. It is used to measure the pressure in pipes and channels. A duct of rectangular shape dimension of 15cm width, 16cm height and length 50cm is placed on the table and fins with thermocouples are placed inside the duct

Fig -4: Experimental setup

4.1 Experimental procedure

1. First of all, switch on the power supply and adjust the voltage to 40v by using dimmer stat for required heat input to fins.
2. Then adjust the speed of the blower with regulator to force the ambient air on to the heated fin which is having certain surface temperature.
3. Next note down the readings of the experiment (i.e., voltage, current and fin surface temperatures).
4. Note down the readings of the experiment until the equipment reaches steady state.
5. Repeat the experiment for different heat input values (50V, 60V, 70V).
6. Tabulate the final readings of the experiment for different heat inputs.
7. Finally set the voltage and fan speed to zero position and switch off the power supply.

4.2 Experimental Calculations

Find the average surface temperature (T_s)

$$T_s = (T1 + T2) / 2$$

And using the chamber temperature (T_c), surface area of the plate and with the heat input given to the base plate of the fin, we can calculate the heat transfer coefficient using this formula

$$\text{Heat transfer rate } (Q) = h\ A\ dT$$

4.3 Theoretical calculations

Here the discharge of air can be analyzed by calculating the head difference of air flowing through the pipe using an orifice meter connected with u-tube manometer and velocity of air is determined using continuity equation.

$$Q = A * v$$

Where

Q = Discharge of air through the pipe in m^3/sec.
A = Cross sectional area of the pipe in m^2
v = Velocity of air in m/sec.

After determining the velocity, flow analysis is done and for the flow analysis Reynolds number which is used to calculated the type of flow (i.e., laminar or turbulent).

$$Re = \rho\, \nu\, l / \mu$$

Where

ρ = standard density of atmospheric air.
ν = velocity of the air flowing over the plate.
l = length of the plate.
μ = dynamic viscosity of the air.

By using Nusselt number (Nu), Reynolds number (Re) and prandtl number (Pr), calculate the heat transfer coefficient of the air by taking properties of air at film temperature from the standard heat transfer data book. Once the heat transfer coefficient is found, find the rate of heat transfer using the formulae

$$Q_{fin} = \sqrt{hPkAcs}\,(T_0 - T_a)\left[\frac{\tanh(ml) + \frac{h}{km}}{1 + \frac{h}{km}\tanh(ml)}\right]$$

Where

h = Heat transfer coefficient of air.
P = Perimeter of the plate.
k = Thermal conductivity of the plate.
A_{CS} = Cross sectional area of the plate.
T_0 = Base temperature of the plate.
T_a = Ambient temperature of air.
l = Length of the plate.
m = Constant = $\sqrt{\frac{hP}{kA}}$.

5. Results and Discussions

After completing the experimentation process the results obtained are as follows.

Results shows that the variation of temperatures of perforated fin and without perforated fin along with voltages (40V, 50V & 60V) and the rate of heat transfer rate along with the voltage.

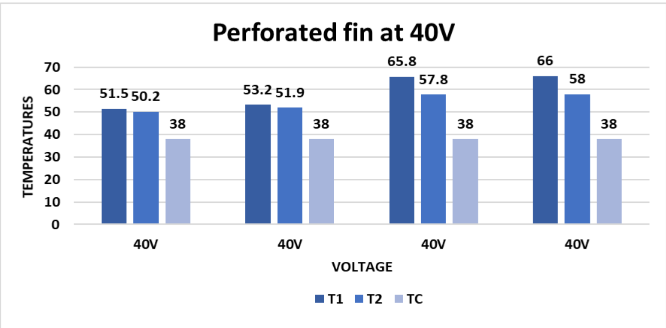


Chart -1: Perforated fin temperature variation at 40V

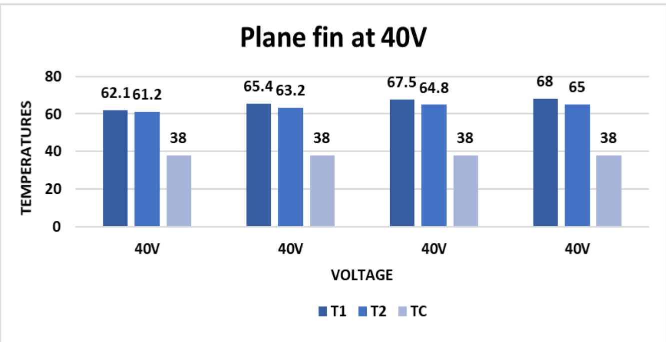


Chart -2: Plane fin temperature variation at 40V

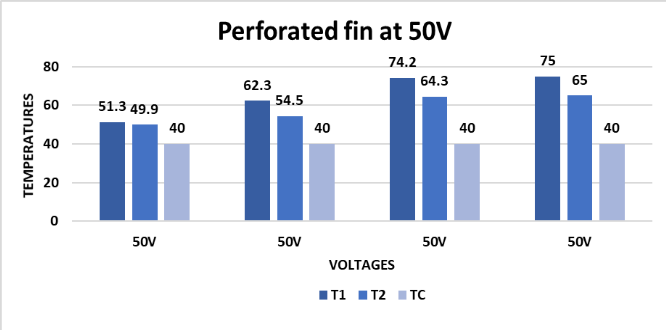


Chart -3: Perforated fin temperature variation at 50V

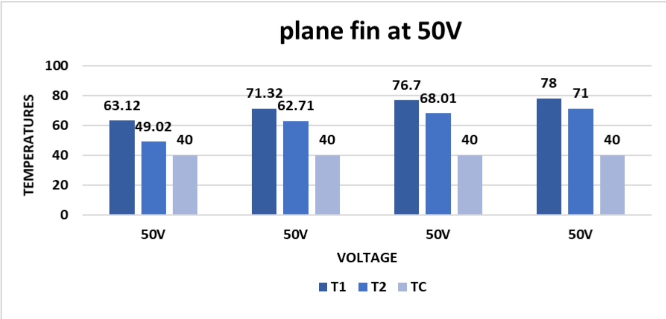


Chart -4: Plane fin temperature variation at 50V

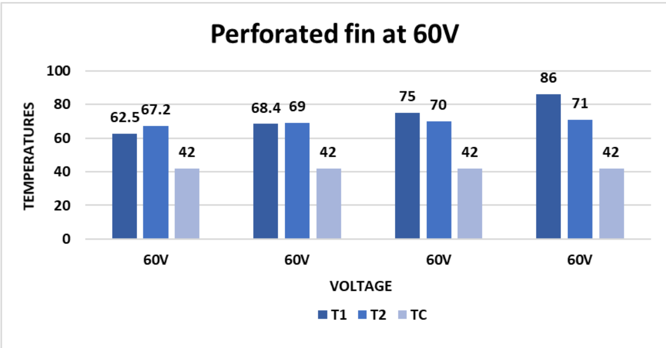


Chart -5: Perforated fin temperature variation at 60V

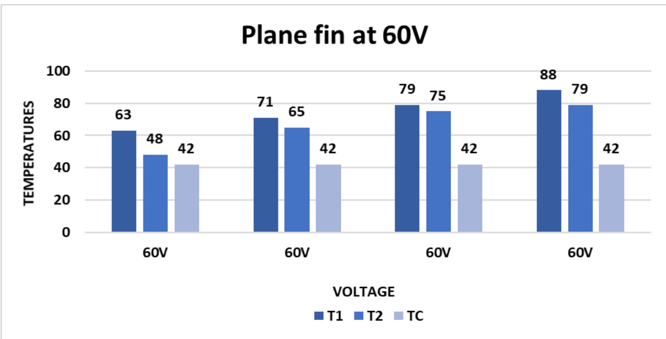


Chart -6: Plane fin temperature variation at 60V

5.1 Variations of Heat Transfer Rate for different types of fins

S.NO	TYPE OF FIN	VOLTAGE(V)	HEAT TRANSFER RATE(W)
1.	Plane Fin	40	94.9
		50	179.37
		60	195.8
2.	Perforated Fin	40	98.2
		50	185.35
		60	203.3

Table -1: variation of heat transfer rates with voltages

Here the perforated fin at each and every voltage is having greater heat transfer rates when compared with fin without perforations.

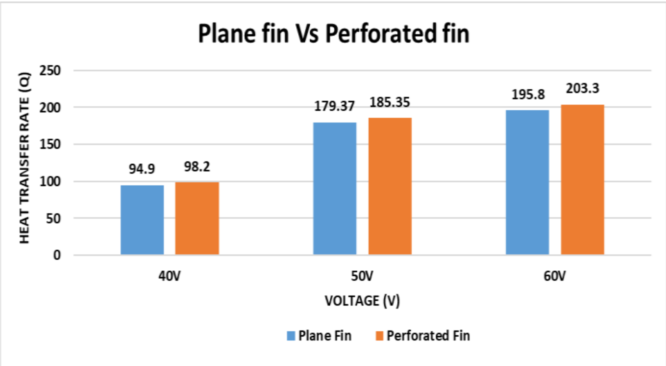


Chart -7: Plane fin Vs Perforated fin heat transfer rate

And in each and every voltage (40V, 50V, 60V), the percentage increase in heat transfer rate are 3.47 %, 3.33 % & 3.83 % respectively.
Therefore, the overall percentage increase in heat transfer rate of perforated fin is 3.54% when compared with fin without perforations.

6. CONCLUSIONS

In this study, the heat transfer rate for a rectangular fin with perforation and without perforation were investigated experimentally and the effect of the fluid flow on the heat transfer rate were studied.

The average heat transfer rate increased by **3.54 %** for perforated fin compared to plane fin at different heat inputs. Hence we can conclude that perforating a fin gives more heat transfer rate.

7. FUTURE SCOPE

1. In future the analysis can be done with the help of computational fluid dynamics and hence better results will emerge.
2. Analysis can also be done on the compound geometry [cylindrical & square] fins.
3. Analysis can also be done on the fin with inline &staggered arrangement of perforations for different materials and geometries.
4. Analysis can also be done on the fins with different inclinations of perforations.

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