Design and Analysis of Porous Rectangular Fins for Experimental Investigation under Forced Convection

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Abstract-*In design and analysis of porous rectangular fins for experimental investigation under forced convection, designing and analysis of rectangular fin array is carried out under forced convection, modification of the same array is done to increase effectiveness. The sole purpose is to verify increase in effectiveness of fin due to the modification like mini holes. These are drilled on the designed fins. The Experimental analysis is to be carried out on a setup which is also designed considering the required parameters. Finally, the experimental calculations are done by varying air flow and temperature at various conditions to obtain result which is likely to be increase in effectiveness by 7% to 9%.*

Keywords:-Fin Effectiveness, Fin Design, Porous Fins, Forced Convection, Heat Transfer Coefficient.

I. INTRODUCTION

There is large number of engineering equipment where the unutilised heat energy is required to be dissipated to the atmosphere. If this heat is not dissipated, the system will fail to due to overheating. Examples of engineering systems needing the heat dissipation are the cooling of internal combustion engines, heat removal from nuclear reactors, cooling of electronic components/integrated circuits, transformers, motors, compressors, refrigerators etc. In most of these cases the heat transfer takes place by conduction and convection. Heat is conducted in solid material up to its surface and finally the heat is rejected by convection from its surface to the surroundings. Thus the aim is to increase the heat transfer rates from the surface so that the temperature of solid surface is maintained within desired limits to avoid failure of system. The fins are normally thin strips of high conducting materials. This are surfaces which extends from an object to increase the rate of heat transfer to or from the environment by increasing convection.

A. Fin Effectiveness*:*

It is defined as ratio of heat transfer rate from the surface with fin to the heat transfer rate that would be obtained without fins. Conductivity should be high as possible. Aluminium is preferred because of low cost, less weight and resistance to corrosion (as in our case)

$$n_{fin} = \frac{Q_{fin}}{Q_{\ fin\ max}}$$

There are three cases of fin effectiveness

1. When there is no effect on the heat transfer rate of a body.
2. When < 1 then fins act as insulation of heat transfer.
3. When > 1 then there is enhancement in heat transfer.

B. Fin Efficiency:

It is defined as the ratio of actual heat transfer rate from the fin to ideal heat transfer rate from the fin if entire fin were at base temperature. In limiting case of zero thermal resistance or infinite thermal conductivity, the temperature of the fin will be uniform at base value.

$$n_{fin} = \frac{Q_{fin}}{Q_{\ fin\ max}}$$

C. Material Used For Fin Manufacturing

Aluminium and Copper are the main materials used for the manufacturing of fins because of their high thermal conductivity, corrosive resistance and strength. But in most of the application aluminium is used because of low cost and low weight than copper. Some material and their prices are given in Table 1. Rectangular fins are a type of longitudinal fins that have rectangular cross section. The rectangular fin array made of Aluminium is used to carry out the project. This array is perforated with micro laser holes and is subjected to forced convection. Heat dissipation due to the modification is to be calculated; also optimum angle for maximum heat dissipation is to be found.The types of fins we are using to conduct the experiment are porous fins the pores will be made using laser cutting along the thickness of the fins the pores will be of minute diameter.

Table1: Material for fin

MATERIAL	CONDUCTIVITY(K) (W/mK)	PRICE PER KG (INR)
Copper	385	350
Aluminium	205	280
Cast Iron	79.5	48
Mild Steel	50.2	44

D. Manufacturing Methods

Base Plate: Most common method used for making the base plate is stamping. Other methods include cold forging.

Fins: Fins can be manufactured by various methods such as sheet metal cutting, cold forging etc.
Porous Fin: The fins are manufactured as stated and the pores are made onto the fin by punching, drilling, laser drilling.

E. Problem Statement:

The problem arising in the fin related machine is about heat dissipation. The heat dissipation rate of such machines is relatively average. The experimental project aims to increase effectiveness of the fins i.e. increasing heat dissipation rate of fins. Hence, it is expected that the heat dissipation rate of fins increases due to the micro channels made on the fins through thickness.

II. LITERATURE SURVEY

Ethesham et al. (2015) have worked on thermal and hydraulic analysis of rectangular fin array with perforation size and numbers and have found out about the effect on heat transfer by making perforation on the rectangular fin array. They have varied the diameter and number of perforations made on the fins.

Roy et al. (2015) have worked on decomposition method for convective–radiative fin with heat generation studying the effect of environmental temperature such as radiation sink temperature, convection sink temperature and heat generation number on the temperature distribution and efficiency of a convective–radiative stationary fin. They have used many mathematical Equations and methods to study the effect of the above described temperature on a long fin also considering a static current also flowing through the filaments due to its atomic properties. The mathematical equations they used are The Adomian Decomposition Method (ADM) being one of the efficient numerical methods for highly non-linear equations, the local temperature field and efficiencies are obtained using ADM in which Newton–Raphson method is used to estimate the fin temperature for insulated boundary conditions. And other equations like Least Square Method (LSM) and fourth-order Runge–Kutta Method. Differential Transformation Method (DTM), Collocation Method (CM).The analysis is carried out to study the variation of local fin temperature of the fin materials and fin efficiency with different controlling parameters, such as dimensionless thermal conductivity parameters, dimensionless sink temperatures and heat generation number. The present results obtained are compared with the results of Galerkin Method (GM) and Boundary Value problem Method (BVP) and a good agreement is observed.

Singh et al. (2014) have worked on convective-radiative fin with temperature dependent thermal conductivity, heat transfer coefficient and wavelength dependent surface emissivity and they found about the variation of heat transfer coefficient (HTC) with temperature and variation of surface emissivity with temperature and wavelength. The Heat Transfer Coefficient is assumed to be power law type form where the exponentials represent different types of convection, nucleate boiling, condensation, radiation etc. Here thermal conductivity is assumed to be linear and quadratic function of temperature. There is comparison between solutions obtained in case of temperature independent thermal conductivity and in absence of radiation conduction parameter with those obtained by present methods up to 10 decimal points. Presented analysis is in dimensionless form. Parameters as in convection-conduction, radiation-conduction, thermal conductivity, emissivity, convections in k temperature, radiations in k temperature and exponent on the temperature distribution in fin and surface heat loss are studied descriptively. They concluded that the comparison proves to be exactly same up to 4 decimal points after which there is slight variation. Cooling is more efficient when thermal conductivity is of quadratic type. For higher values of exponent, convection and radiation sink temperature, heat releases fast from fin. Cooling process is fast in nucleate boiling. For Highwave- length, temperature in fin decreases consequently cooling becomes more effective. It has been observed that as dependency of emissivity increases with wavelength, the temperature of fin decreases.

Sengupta and Chakraborty (2014) have worked on assessment of thermal performance of semi-circular fin under forced air convection: application to air-preheater and performance of semi-circular fin is studied for use in air preheater under forced convection. In this the different condition are studied which effect the efficiency of fin. The effects of various parameters on the heat transfer coefficient and the exit air temperature have been determined for semi-circular finned air preheater.

Bhanja et al. (2013) have work on thermal analysis of porous pin fin used for electronic cooling they observed that rate of heat transfer from the fin decreases with the increase of fin length and hence, the entire heat transfer surface of a fin may not be equally utilized. For this reason designers have to determine the optimum length of fin that will maximize the rate of heat transfer for a specified fin volume. This study is based on finite-length fin with insulated tip. They observed that the porosity decreases the thermal conductivity and heat transfer rate due to decrease in solid material but this will not influenced when Nu is low. The fin having smallest length have better heat transfer rate because large length of fin will increase the conductive resistance.

Ismail et al. (2013) have worked on numerical investigation of turbulent heat convection from solid and longitudinally perforated rectangular fins and in this experiment different shapes of perforation in fins are studied. The result shoes that the perforation fin has higher contact surface area hence the heat transfer is increase due do this the efficiency of the perforated fin increases than the solid fin. They concluded analytically that the heat transfer rate is higher in perforated fin than solid fin so have better efficiency.

Shih et al. (2013) have worked on time-accurate CFD conjugate analysis of transient measurements of the heat-transfer coefficient in a channel with pin fins about the measuring technique of Heat Transfer Coefficient (HTC) when exposed to convection environment. Also, there is use of CFD conjugate analysis to determine the error that may arise due to various assumptions made while performing the problem. There is a channel with 11 rows of pin fin located at certain distances along the length of channel. Two plates of certain thickness are also placed with adiabatic surfaces acting as adiabatic walls. The pin fins are made of Aluminium and the plates are made of Plexiglass. There are two operating conditions; one is time accurate version used for determining the errors occurring during the transient technique and the other is steady state version used for determining the relationship version to study the connection between transient measurements of the HTC and steady-state values of the HTC with isothermal walls. They concluded that CFD analysis shows that the HTC obtained is accurate for the transient technique with relative error less than 5%. Also it can be seen that HTC obtained under transient condition may considerably differ from the HTC obtained under steady state condition with the isothermal walls.

Kundu et al. (2012) have worked on a model on the basis of analytics for computing maximum heat transfer in porous fins and have found about the performance and optimum design analysis for porous fin of various profiles operating in convection environment. They found that the effectiveness of porous fins is better than solid fins.

kumar et al. (2012) have worked on modification and analysis of compressor Intercooler fin in Turbocharger using FEM this study to increase the amount of hot air when it is passed through the liquid intercooler. This is accomplished by making modifications in the existing fin of the tubes in intercooler. The best design for maximum heat transfer is chosen by varying the parameters such as material, shape and size of the fin using Taguchi's design of Experiments (Doe). The material for the intercooler fin is selected based on the parameters such as thermal conductivity, density heat transfer coefficient and specific heat. The materials which selected are aluminium, copper and brass. The different shapes and thickens also can be chosen by this technique the chosen shapes are Rectangular, Triangular and Conical and thickness are 0.5mm,1mm and 1.5mm.The analysis is carried out by using ANSYS software. The analysis is carried out and the output response parameters are analyzed by signal-to-noise ratio. AFEM validation is performed to determine output response parameters heat flux and temperature distribution based on the individual optimum conditions.

Gorla and Bakier (2011) have worked on thermal analysis of natural convection and radiation in porous fins and find about natural convection and radiation in porous fin. They found that increasing CT has minor effect on heat transfer rate for all values of Biot number. In addition, increasing the radiation parameter G also increases heat transfer from fin for small values of Biot numbers.

III. CALCULATIONS

A. Fin calculations*:*

For designing the fin for heat transfer rate of 90W the following assumptions were made:

1. Thickness = 3mm,
2. length of fin = 100mm
3. Distance between 2 fins (d) = 8 mm = 0.008 m

Given:

L= Length of fins = 100 mm = 0.1 m
t= Thickness of fin = 3 mm = 0.003 m
v= velocity of air = 36 km/hr = 10 m/s
p = perimeter = (100+3)*2 = 206 mm = 0.206 m
k= conductive heat transfer co-efficient = 205 $\frac{W}{mk}$
A= Area of fin = 3*100 = 300 mm^2 = 3*10^{-4} m^2
ΔT= Temperature Gradient =423-303= 120 K
Q_{Total}= 90W

To Find:

l= Height of fins

Calculation:

h= convective heat transfer co-efficient

$$= \left[10.45 - v + 10 * v^{\frac{1}{2}}\right] = 32.072 \frac{W}{m^2 k}$$

Area required for heat transfer

$q = h * A * \Delta T$
$A_{Theo} = 0.0234 m^2$

Calculations for fin array

$Q_{base} = h * A * \Delta T$
$Q_{base} = 9.216\, W$

$Q_{remaining} = Q_{Total} - Q_{base}$
$Q_{remaining} = 80.784 W$

$Q_{per\ fin} = 20.196 \frac{W}{m^2}$

Assuming short fins $q = \sqrt{hpkA} Q_0 \left[\frac{\tanh(ml)+\left(\frac{h}{mk}\right)}{1+\tanh(ml)*\left(\frac{h}{mk}\right)}\right]$

$46.16 = 127.343 * \left[\frac{\tanh(10.3531*l)+0.01507}{1+\tanh(10.3531*l)*0.01507}\right]$
$m = \sqrt{\frac{ph}{kA}} = 10.3531$

$l = 0.0261$m

Area of fin array

$single fin Area$

$= [2 * (26.1572 * 100)] + [3 * 100] + [2 * (3 * 26.1572)]$
$= 5688.3832\, mm^2$

$All fin Area$

$= 5688.3832 * 4$
$= 22753.5328\, mm^2$
$Total Area = All fin Area + Base Area$
$= 22753.5328 + (3 * 8 * 100)$
$= 25153.5328\ mm^2$

The total area is slightly more than the practical area. Hence, we can say that the design is safe.

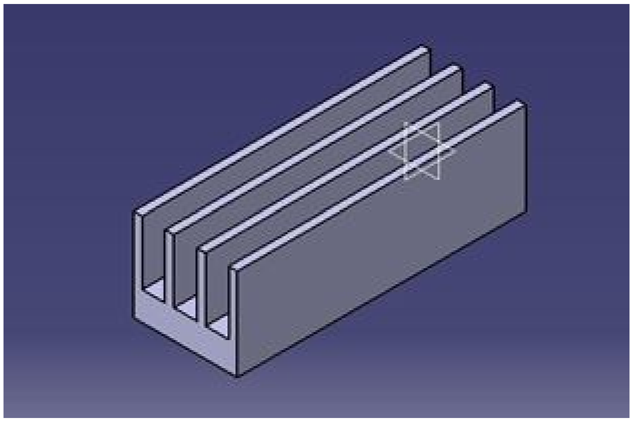

Fig. 1: Fin Array

B. Number of holes:

The total numbers of holes that can be made on fin by removal of certain amount of area are calculated below. The holes are the modification that is required for checking the change in heat dissipation rate of fins.

$Total area of fin = l * h = 2615.2 mm^2$

$No. of holes = H$
$Diameter of hole = 1 mm$

$r = 1.5$ mm

For 10% Area $H = 148$, For 6% Area $H = 89$
For 3% Area H = 44.

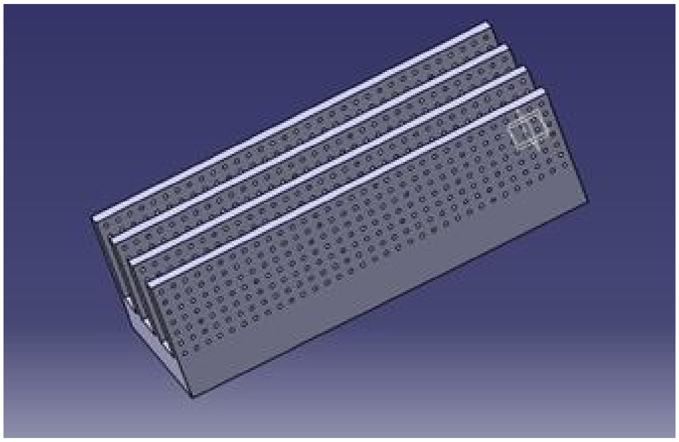

Fig.2: Fin array with holes

C. Duct dimensions and Blower Capacity

Duct: Height = 12cm or 0.12 m
Width = 7cm or 0.07m
Length = 50cm or 0.5 m

Blower capacity:

Cross section area for air passage = 0.0049 m^2
At speed 36km/hr blower capacity is 2.94 m^3/min.

D.Parts of Experiment Setup

1. Blower: it is used to vary the velocity of air used for analysis by forced convection.
2. Air supply pipe: The air from the blower is carried up to the ducts with help of this pipe.
3. Duct: The duct used in the setup is a rectangular duct; air from the pipe is forced on to the fin array kept in the duct. As shown in Fig 5.
4. Fin array: the fin array used for the experiment is of both perforated and non perforated type.
5. Clamping assembly: The clamping assembly will consist of the heater box on which the array will be mounted. As shown in Fig.4.
6. Heater box: it is designed to inhibit the plate heater onto which fin array will be mounted. As shown in Fig.3.

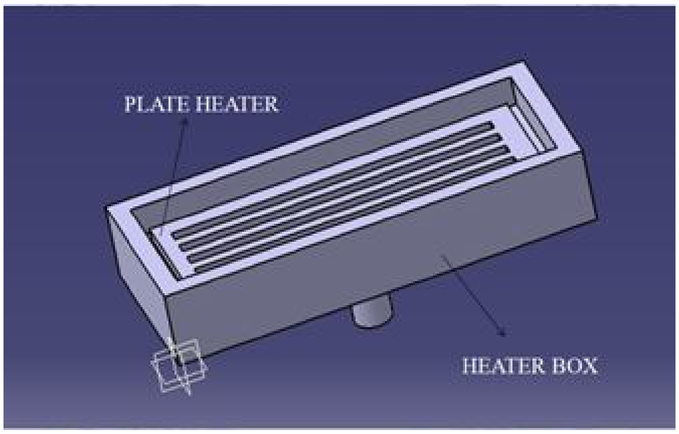

Fig.3: Heater box

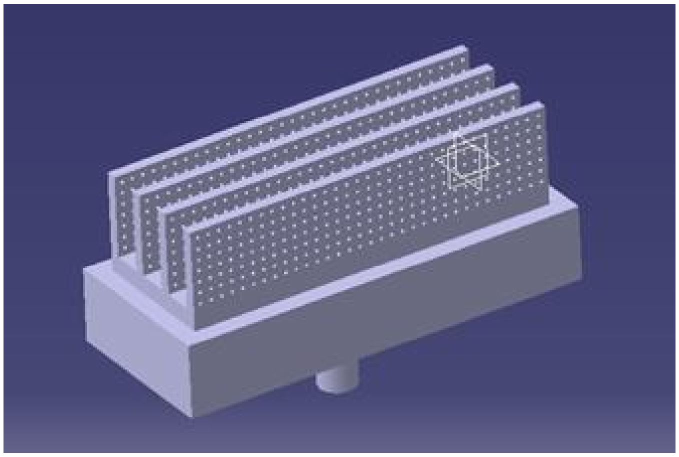
Fig.4: Assembly of fin array and heater box

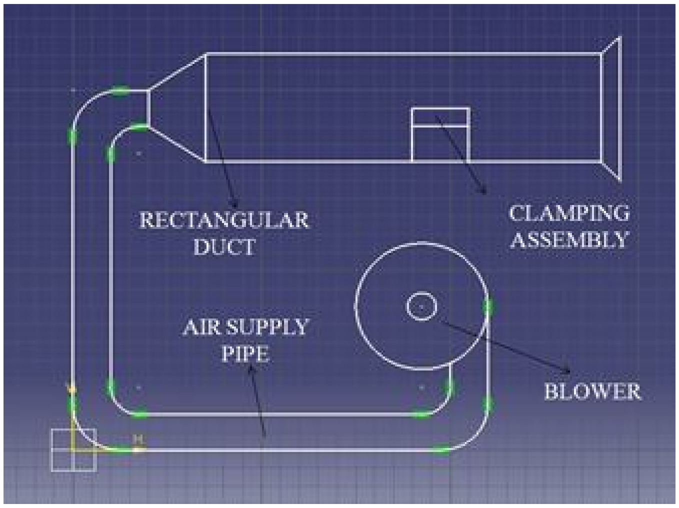

Fig.5: Experimental Setup

IV. CONCLUSION

In this study certain assumptions were made for conducting the experiment on fins to check if the efficiency of the fins can be increased. The conditions that are taken for conducting the experiment are based on the base plate temperature for the experimentation and calculation by theoretical methods. Also heat flux and Air flow are varied to check if there is any change on the values of the heat distribution of the fins .The change in length of fin arrays can also result in change of the heat distribution. The types of fin arrays used are porous and normal fins the pores are made by drilling along the thickness of the fins. The pores will be very minute in diameter so as only 10% of the part from all of the fins volume is removed. In this method we are also going to use CFD analysis in ANSYS to check the variations of heat and other parameters in normal and porous fins. And compare it with the theoretical values which were manually calculated earlier in the process of designing the fins. The porous fins allow more surface are to be exposed to the surrounding for the heat distribution the normal fins will have less surface area to be exposed for the heat distribution or convective heat transfer. The convective heat transfer in normal and porous fins will be further compared to see if the assumed results are obtained or not for the various processes which are conducted. The results which are assumed to be obtained are that the efficiency of the fins would increase due to mini holes on fins.

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