Enhancement of Heat Transfer of Fins with Different Geometrical Perforation for Natural Convection

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Abstract- *The importance of heat transfer by natural convection in enclosures can be found in many engineering applications, such as energy transfer in buildings, solar collectors, nuclear reactors and electronic packaging. An experimental study was conducted to investigate heat transfer by natural convection in a rectangular fin plate with circular and rectangular perforations as heat sinks. The experiment is carried out for different aspect ratios of 1, 2 and 3. The perforated fin is compared with its equivalent solid one. The parameters considered are geometrical dimensions and thermal properties of the fin and that of the perforations. The study considered the gain in fin area and of heat transfer coefficients due to perforations. The results showed that, for certain values of rectangular perforation dimension, the perforations lead to an augmentation in heat dissipation of the perforated fin over that of the equivalent solid one. The magnitude of heat dissipation enhancement depends upon the fin thickness, its thermal conductivity, the perforation dimension. Finally, the study showed that, the perforating of the fins enhances heat dissipation rates and at the same time decreases the weight of the fin. The research summarized in this paper presents the experimental investigation of fins with different geometric profile of temperature profile.*

Keywords- Thermal conductivity, Heat transfer coefficient, Reynolds number, Aspect ratio

I. INTRODUCTION

For a number of industrial applications, heat generation can cause overheating which occasionally leads to system failure. To overcome this problem, efficient heat sinks are essential. Free convection from these devices is a commonly used cooling technique and plays an important function in preserving proper operation. Extended surfaces, known as fins, are typically used to enhance heat transfer in many industries. The performance of heat exchanging devices can be increased by applying extended surfaces. Practical applications of this technique are found in some heat exchangers used for cooling combustion chambers and electronic devices. Using fins as extended surfaces increases the weight and volume of the device and also increases the cost of production. As a result, in recent years, much care has been taken in optimizing fin geometry. Advanced technologies need superior heat transfer equipment. Processes for improving heat transfer are classified into two families: active and passive methods. Active methods need an external power source to enhance heat transfer, but passive methods do not need an external power source. Fins are a good example of a passive method, and they are typically applied in an assortment of industrial applications to enhance the rate of heat transfer between the primary surface and the ambient fluid. Wadhah Hussein Abdul Razzaq Al- Doori[1] presented a paper on “Enhancement of natural convection heat transfer from rectangular fins by circular perforations” in this paperan experimental study was conducted to investigate heat transfer by natural convection in a rectangular fin plate with circular perforations as heat sinks. The patterns of the perforations included 24 circular perforations (holes) for the first fin, the number of perforations increased by eight for each fin to 56 in the fifth fin. These perforations were distributed in 6-14 rows and four columns. Experiments were carried out in an experimental facility that was specifically designed and constructed for this purpose. It was observed that the temperature along the non-perforated fin dropped from 30 to 25°C, but the temperature drop for the perforated fins was from 30 to 23.7°C at low power (6 W). The drop in temperature between the fin base and the tip increased as the diameter of the perforations increased. The temperature drop at the highest power (220 W) was from 250 to 49°C for the non-perforated fin and from 250 to 36°C for the perforated fins. The heat transfer rate and the coefficient of heat transfer increased with an increased number of perforations. Laxmikant Chavan et al.[2] presented a paper on “Thermal Analysis of Pin Fin using Different Materials and Forms” in this paper the main aim of this study is to find out the most effective fin from a series of selected fins of different materials and geometries. Trials were conducted for varying Reynolds number and results were found out respectively for each fin**,** from the results obtained, we can conclude that as Reynolds number increases, the efficiency and effectiveness of the pin fin decreases. While material wise Aluminium is the most effective material. Abdullah H. AlEssa et al.[3] presented a research paper on “Enhancement of natural convection heat transfer from a fin by rectangular perforations with aspect ratio of two” in this study, the enhancement of natural convection heat transfer from a horizontal rectangular fin embedded with rectangular perforations of aspect ratio of two has been examined using finite element technique. The results for perforated fin have been compared with its equivalent solid one. It was found that for certain values of rectangular perforation dimension, the perforated fin enhances heat transfer. The magnitude of enhancement is proportional to the fin thickness and its thermal conductivity. Also, the extent of heat dissipation rate enhancement for perforated fins is a function of the fin dimensions, the perforation geometry and the fin thermo-physical properties. Furthermore, the gain in heat dissipation rate for the Perforated fin is a strong relation of both, the perforation dimension and the lateral spacing. This function attains a maximum value at given perforation dimension and spacing, which are called the optimum perforation dimension, and the optimum lateral spacing respectively. Finally, not only the perforation of fins enhances heat dissipation but also decreases the weight of the fin.

II. PROBLEM DEFINATION

Heat rejection is one of the major task associated with all the heat transfer components. If it is not taken proper care it would result in overheating. Overheating in components could result in failure of device and also reduces the effectiveness of the component, therefore one of the active method to reduce heat is by using blower or radiator, which requires energy. The passive method eliminates the use of energy by the use of fins. Fins are a powerful tool to increase heat dissipating from primary surface to surrounding fluid to avoid the burning or overheating the system. Various types of fins such as rectangular fins, square fins, tapered or pin fins are used for both natural and forced convection heat transfer. These fins protrude from either a rectangular or cylindrical base. Many attempts have been made to optimize fin design. To dissipate more heats from these fins slots, grooves, interruptions or perforation are made to the body of fins. In this study we consider aspect ratio 1, 2 & 3, which is defined as the ratio of height of the fin to its width. The heat transfer through solid fin is compared with circular and square perforated fins. The entire process is carried out in Free/Natural Convection. The work is carried out in the following three methods. 1. Analytical Calculation. 2. Experimentation.

III. EXPERIMENTAL PROCEDURE

1) The heater along with fins is connected to electric supply by means of thermostat regulator as shown in the fig 3.1

Fig 3.1: Experimental set up

2) Thermostat is set to desired voltage and waited till the heater reach steady state temperature.

3) Temperature at different points of the fin is found using IR Thermometer (IR GUN) starting from the base of the fin till the top most tip of the fin for equal interval distance over the fin length.

4) For aspect ratio 1, temperature at points at distance 0,25,50,75,100mm respectively are measured and tabulated

5) For aspect ratio 2, temperature at points at distance 0,50,100,150,200mm respectively are measured and tabulated

6) For aspect ratio 3, temperature at points 0,75,150,225,300mm respectively are measured and tabulated

Fig 3.2: Experimental specimens

IV. CALUCALATIONS

A. ASSUMPTIONS

1. Steady state one-dimension heat conduction.
2. Homogeneous and isotropic fin material with constant thermal conductivity.
3. No heat sources/sinks in the fin body.
4. Uniform base and ambient temperatures.
5. Uniform heat transfer coefficient over the whole fin solid surface (perforated or solid)
6. Uniform heat transfer coefficient within the perforation
7. Thermal conductivity of fin material is constant
8. Negligible radiation effect

B. ASPECT RATIO

Aspect ratio: It is the ratio of height of the fin to its width.
Aspect ratio = length of the fin/width of the fin
Aspect ratio 1: For aspect ratio 1 length of the fin considered is 100mm and width of the fin considered is 100mm.
Aspect ratio 2: For aspect ratio 2 length of the fin considered is 200mm and width of the fin considered is 100mm.
Aspect ratio 3: For aspect ratio 3 length of the fin considered is 300mm and width of the fin considered is 100mm.
Biot number is a dimensionless quantity used in heat transfer calculations. The transverse Biot number in (z) direction (B_{iz}) can be calculated by (B_{iz}= ht/k) and the transverse Biot number in (y) direction (B_{iy}) can be calculated by (B_{iy} = hL/k). If the values of (B_{iz}) and (B_{iy}) are less than 0.01 then the heat transfer in (z) and (y) directions can be assumed lumped and one dimension solution can be considered. If the values of (B_{iz}) and (B_{iy}) is greater than 0.01 then the heat transfer solution should be two or three dimensions. In this study the parameters of the perforated fin are restricted as they lead to values of (B_{iz}) and (B_{iy}) smaller than 0.01.
For aspect ratio 1:
L=100mm
K=167 W/mK
h = 8.5358 W/m^{2}K
$B_{iy} = h\times LK = 8.5358 \times 0.1167 = 5.111\times10^{-3}$
$B_{iy} = h\times tK = 8.5358 \times 3\times 10-3167 = 1.533\times10^{-3}$
For aspect ratio 2:
L=200mm
K=167W/mK
h = 7.1776 W/m^{2}K
$B_{iy} = h\times LK = 7.1776 \times 0.2167 = 9.179\times10^{-3}$
$B_{iy} = h\times tK = 7.1776 \times 3\times 10-3167 = 1.2893\times10^{-4}$
For aspect ratio 3:
L=300mm
K=167W/mK
h = 6.4857 W/m^{2}K
$B_{iy} = h\times LK = 6.4857\times 0.1167 = 0.01$
$B_{iy} = h\times tK = 6.4857 \times 3\times 10-3167 = 1.165\times10^{-4}$
Since from the above calculations we find that biot number is less than 0.01, the calculations in this study are based on assuming steady state one dimension heat conduction, uniform heat transfer coefficient over the whole fin solid surface (perforated or solid) and uniform heat transfer coefficient within the perforation, neglecting radiation effects, no heat sources/sinks in the fin body with uniform base and ambient temperatures homogeneous and isotropic fin material with constant thermal conductivity and the side area of the fin is much smaller than that of its surface area.

C. CALCULATION OF HEAT TRANSFER COEFFICIENT

(H) Heat transfer coefficient is calculated for fins of different aspect ratios (i.e., 1, 2 and 3) and for different base temperatures, for which the base of fins are heated (i.e., 100, 125, 150, 175 and 200^{0}c). Heat transfer coefficient can be determined by calculating Nusselt number.

Table 4.1: Calculation of rate heat transfer for aspect ratio 1

Base Temp.(^{0}c) To	**h (W/m^2 K)**	**Ө0 =(T0-Ta) (0c)**	**m(m^{-1})**	**Q_{fin} (W)**
100	7.6649	70	5.6319	10.14
125	8.1982	95	5.8059	14.623
150	8.6151	120	5.9180	19.314
175	8.9567	145	6.0686	24.164
200	9.244	170	6.1651	29.138

Table 4.2: Calculation of rate heat transfer for aspect ratio 2

Base Temp.(^{0}c) To	**h (W/m^2 K)**	**Ө0 =(T0-Ta) (0c)**	**m(m^{-1})**	**Q_{fin} (W)**
100	6.445	70	5.1478	14.022
125	6.8938	95	5.324	20.028
150	7.244	120	5.4579	26.261
175	7.5317	145	5.5649	32.662
200	7.773	176	5.6534	39.196

Table 4.3: Calculation of rate heat transfer for aspect ratio 3

Base Temp.(^{0}c) To	**h (W/m^2 K)**	**Ө0 =(T0-Ta) (0c)**	**m(m^{-1})**	**Q_{fin} (W)**
100	5.8245	70	4.8935	15.455
125	6.2293	95	5.0609	21.911
150	6.5463	120	5.1881	28.387
175	6.8056	145	5.2899	35.387
200	7.0245	170	5.3741	42.321

From the table 4.1, 4.2 & 4.3 calculation of rate heat transfer we can infer that heat transfer of fins increases with increase in aspect ratio, i.e., heat transfer thorough fins of aspect ratio 3 is more than that of aspect ratio 2 and 1.
Heat transfer through: aspect ratio 3 > aspect ratio 2 > aspect ratio 1

D. CALCULATION OF FIN EFFICIENCY (ε_{Fin}) AND FIN EFFECTIVENESS (η_{Fin})

Fin efficiency is defined as the amount of heat actually transferred by a given fin to the ideal amount of heat that would be transferred if the entire fin where at its base temperature.
Fin efficiency is given by η_f=tanh (m×L)/m×L
Fin effectiveness is defined as the ratio of heat transfer rate with the fin in place, to the heat transfer that would occur if the fin where not there, from the area of the base surface where the fin was originally fixed.

V. RESULT

In this chapter, following tables shows temperature distribution in fins along it's length which are obtained from experimentation, theoretical calculations for different base temperatures 100, 125, 150, 175 and 2000c respectively and also for different aspect ratio and shapes of perforations.

A. FOR ASPECT RATIO 1:

Solid fin:

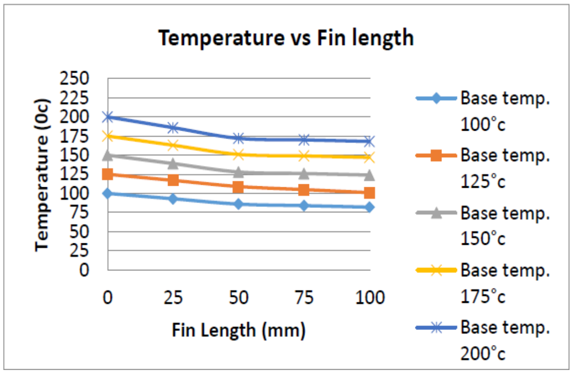

Fig 5.1: Graph of temperature v/s fin length for solid fin of aspect ratio 1(experimental)

Fin with circular perforation:

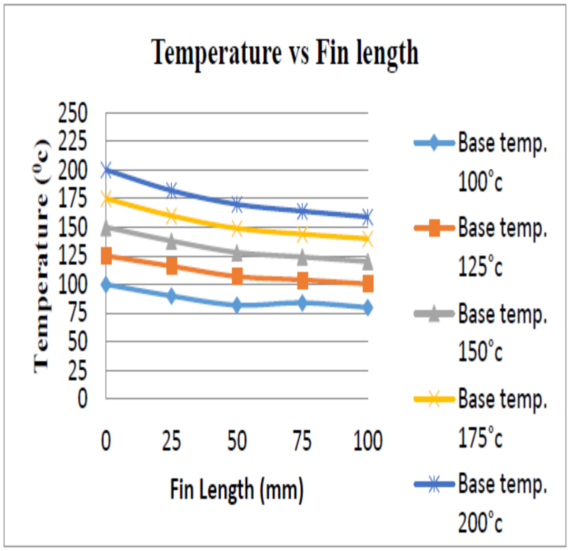

Fig 5.2: Graph of temperature v/s fin length for fins with circular perforations of aspect ratio 1 (experimental)

Fin with square perforation:

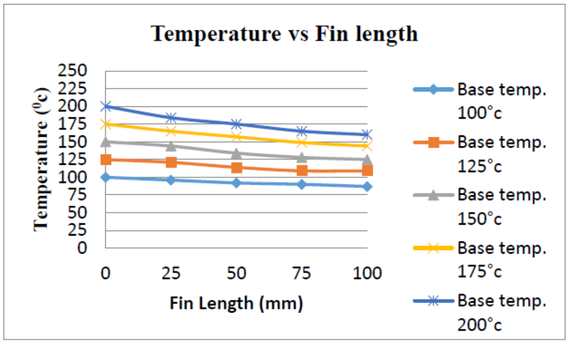

Fig 5.3**:** Graph of temperature v/s fin length for fins with square perforations of aspect ratio 1(experimental)

From the fig 5.1, 5.2 & 5.3 for aspect ratio1, increase in fin length decrease in temperature. Maximum heat dissipation occurs in square perforation fin compare to circular perforation and solid fins.

B. FOR ASPECT RATIO 2:

Solid fin:

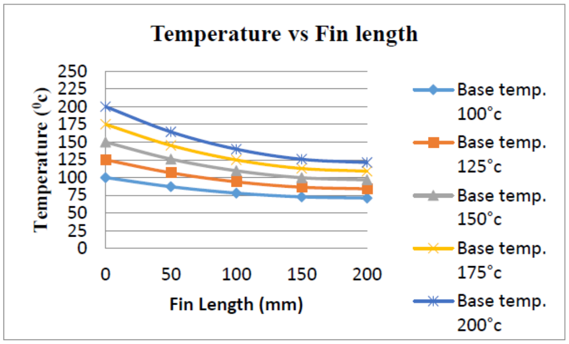

Fig 5.4: Graph of temperature v/s fin length for solid fin of aspect ratio 2 (experimental)

Fin with circular perforation:

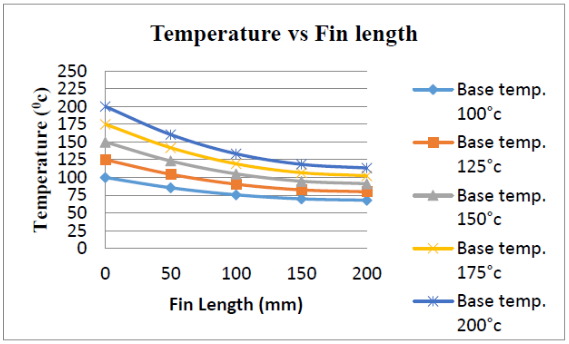

Fig 5.5: Graph of temperature v/s fin length for fins with circular perforations of aspect ratio 2 (experimental)

Fin with square perforation:

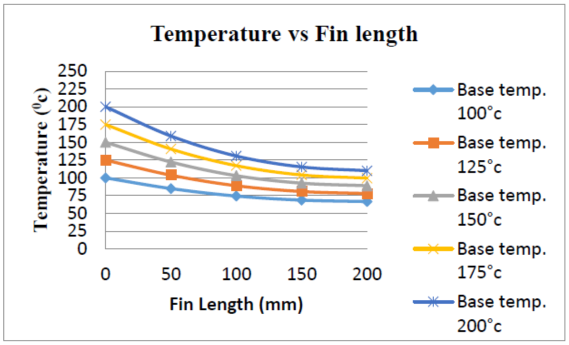

Fig 5.6**:** Graph of temperature v/s fin length for fins with square perforations of aspect ratio 2(experimental)

From the fig 5.4, 5.5 & 5.6 for aspect ratio2, increase in fin length decrease in temperature. Maximum heat dissipation occurs in square perforation fin compare to circular perforation and solid fins. Heat dissipation in circular perforation fin is greater than solid fin.

C. FOR ASPECT RATIO 3:

Solid fin:

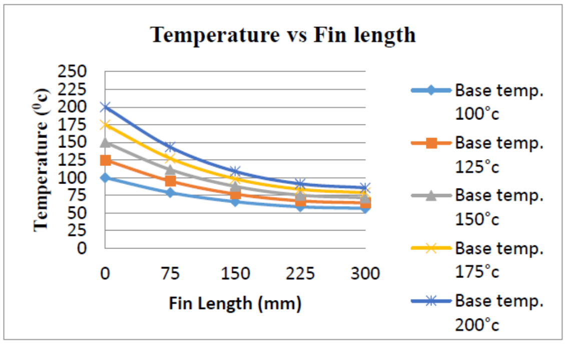

Fig 5.7: Graph of temperature v/s fin length for solid fin of aspect ratio 3 (experimental)

Fin with circular perforation

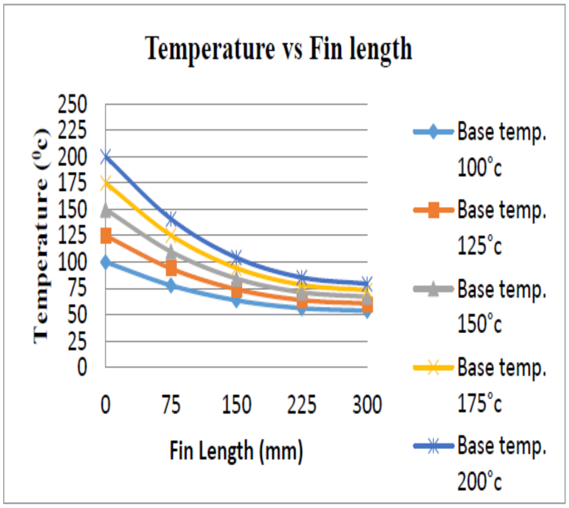

Fig 5.8: Graph of temperature v/s fin length for circular perforations of aspect ratio 3 (experimental)

Fin with square perforation:

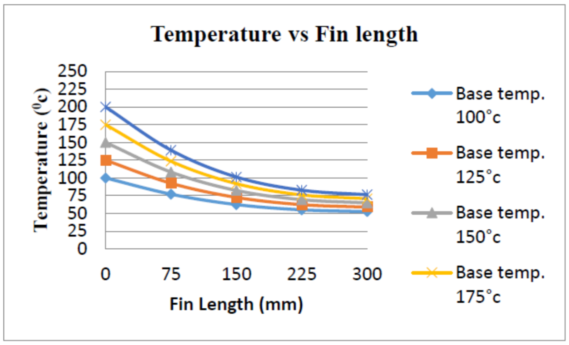

Fig 5.9: Graph of temperature v/s fin length for square perforations of aspect ratio 3 (experimental)

From the fig 5.7, 5.8 & 5.9 for aspect ratio2, increase in fin length decrease in temperature. Maximum heat dissipation occurs in square perforation fin compare to circular perforation and solid fins.

D.COMPARISON OF SOLID FIN WITH CIRCULAR AND SQUARE PERFORATED FIN (EXPERIMENTAL):

Comparison of solid fins with circular and square perforated fins is made for different aspect ratios at different base temperature (100, 125, 150, 175 and 200^{0}c), following graphs shows the comparison.

E. FOR ASPECT RATIO 1:

At base temperature 100^0 C

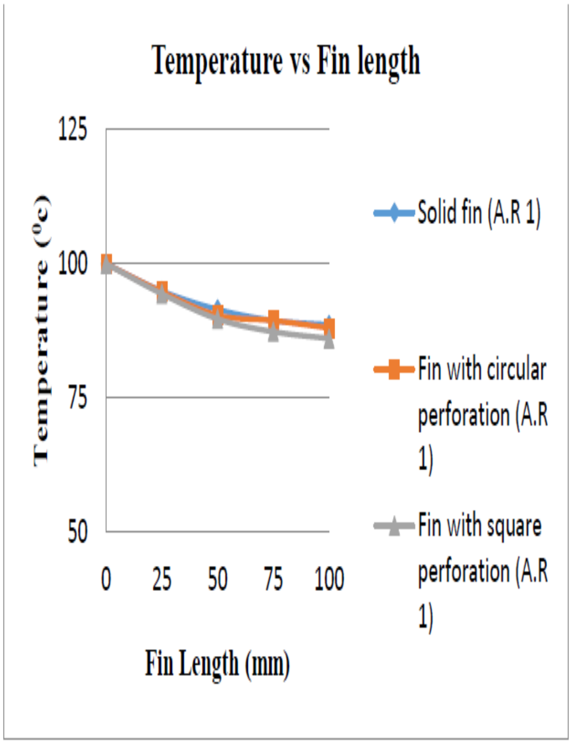

Fig 5.10: graph of temperature v/s fin length to compare solid and perforated fins of aspect ratio 1 at base temperature 100^{0}c

At base temperature 125^0 C

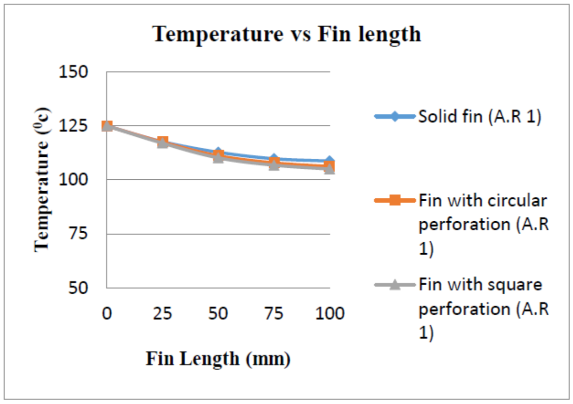

Fig 5.11: graph of temperature v/s fin length to compare solid and perforated fins of aspect ratio 1 at base temperature 125^0c

At base temperature 150^0 C

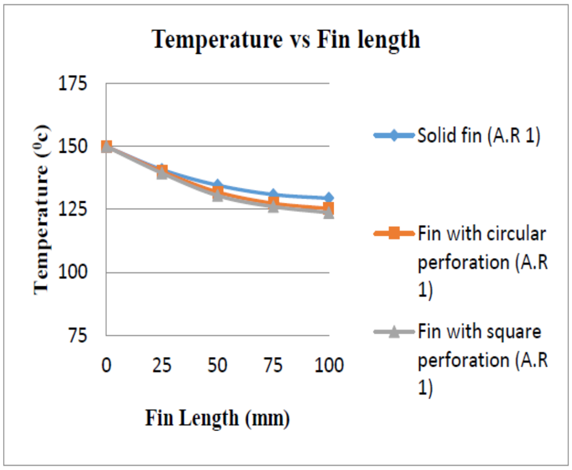

Fig 5.12: graph of temperature v/s fin length to compare solid and perforated fins of aspect ratio 1 at base temperature 150^0c

At base temperature 175^0 c

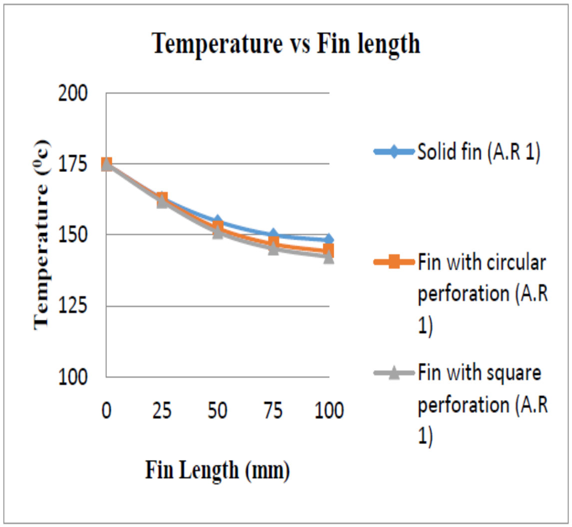

Fig 5.13: graph of temperature v/s fin length to compare solid and perforated fins of aspect ratio 1 at base temperature 175^0c

At base temperature 200^0 C

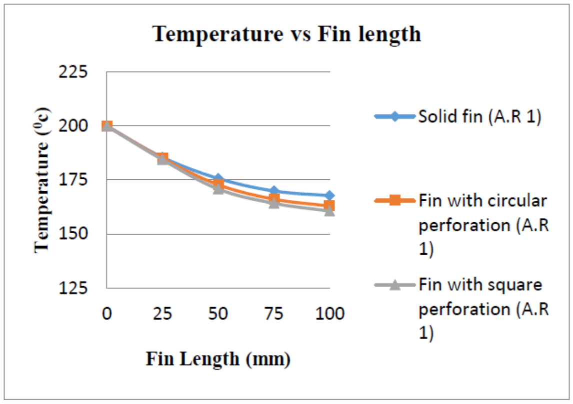

Fig 5.14: graph of temperature v/s fin length to compare solid and perforated fins of aspect ratio 1 at base temperature 200^0c.

F.FOR ASPECT RATIO 2:

At base temperature 100^0 C

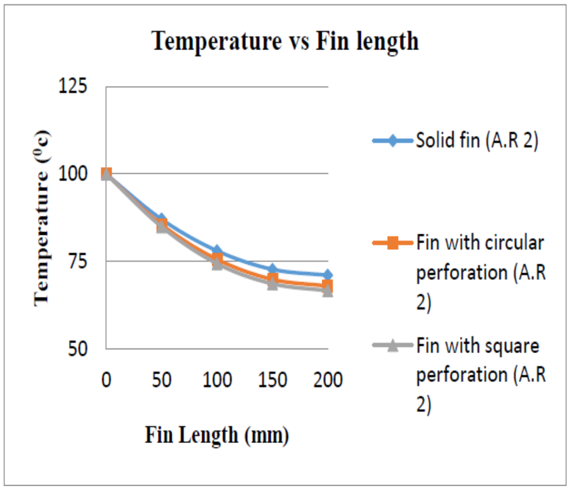

Fig 5.15: graph of temperature v/s fin length to compare solid and perforated fins of aspect ratio 2 at base temperature 100^0c

At base temperature 125^0 C

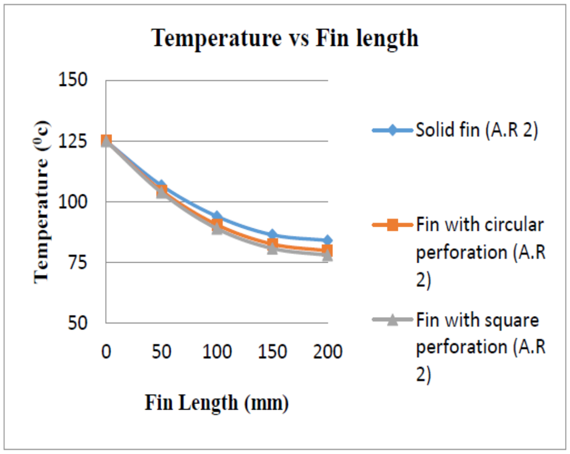

Fig 5.16: graph of temperature v/s fin length to compare solid and perforated fins of aspect ratio 2 at base temperature 1250c

At base temperature 150^0 C

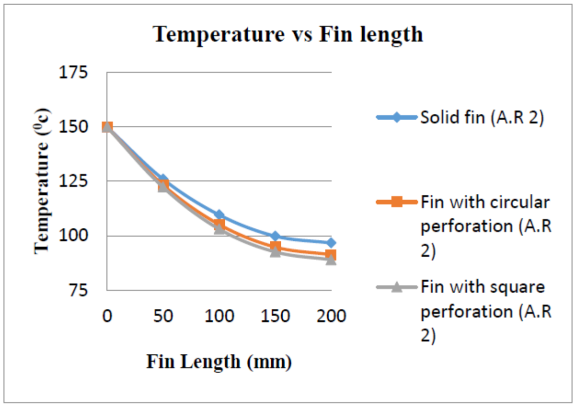

Fig 5.17: graph of temperature v/s fin length to compare solid and perforated fins *of* aspect ratio 2 at base temperature 150^{0}c

At base temperature 175^0 C

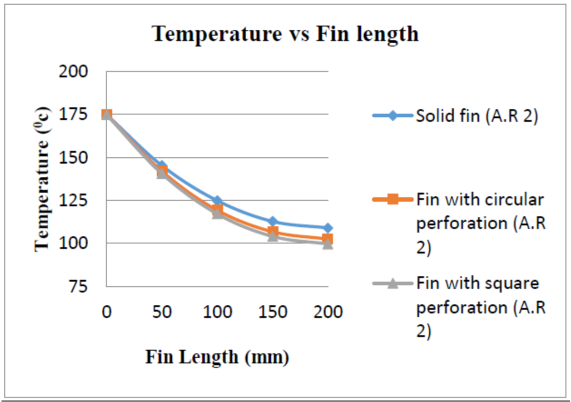

Fig 5.18: graph of temperature v/s fin length to compare solid and perforated fins of aspect ratio 2 at base temperature 175^{0}c

At base temperature 200^0 C

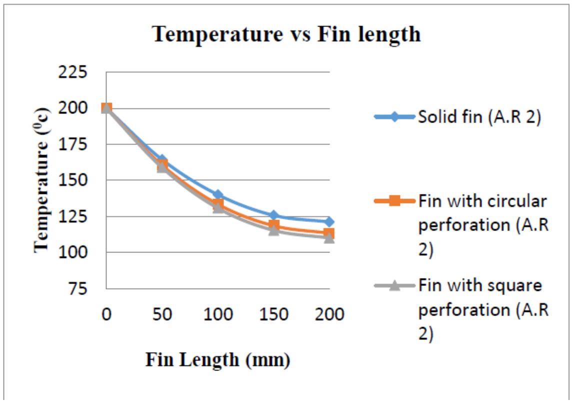

Fig 5.19: graph of temperature v/s fin length to compare solid and perforated fins of aspect ratio 2 at base temperature 200^{0}c

F.FOR ASPECT RATIO 3:

At base temperature 100^0 C

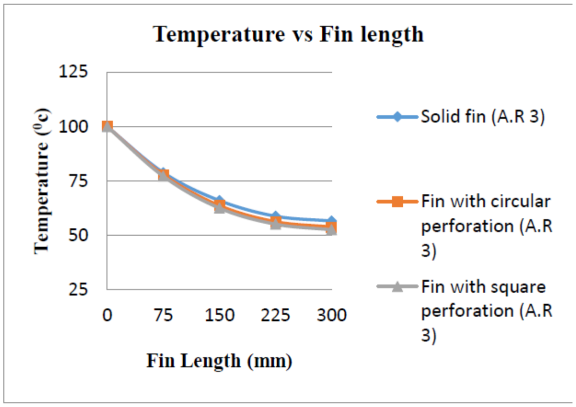

Fig 5.20: graph of temperature v/s fin length to compare solid and perforated fins of aspect ratio 3 at base temperature 100^{0}c

At base temperature 125^0 C

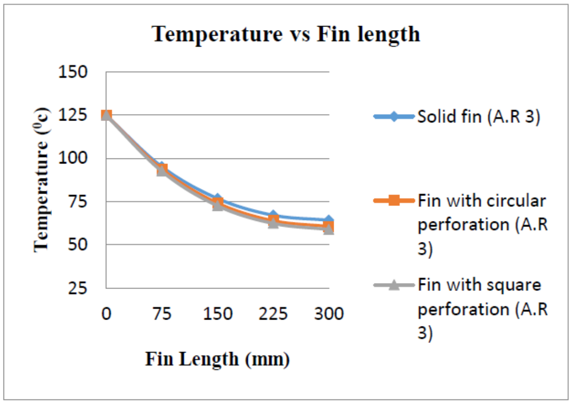

Fig 5.21: graph of temperature v/s fin length to compare solid and perforated fins of aspect ratio 3 at base temperature 125^{0}c

At base temperature 150^0 C

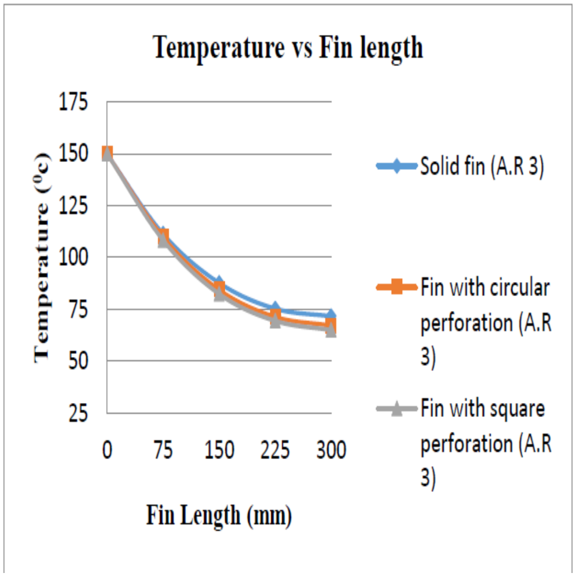

Fig 5.22: graph of temperature v/s fin length to compare solid and perforated fins of aspect ratio 3 at base temperature 150^{0}c

At base temperature 175^0 C

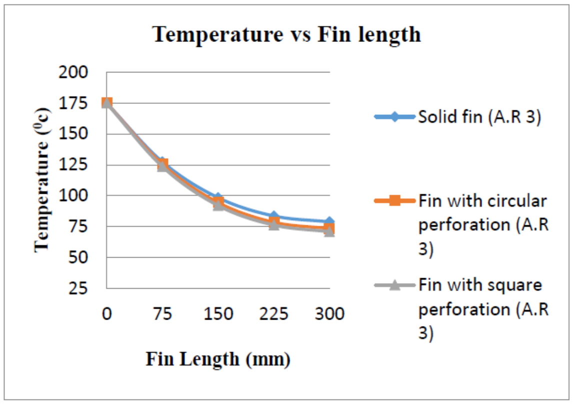

Fig 5.23: graph of temperature v/s fin length to compare solid and perforated fins of aspect ratio 3 at base temperature 175^{0}c

At base temperature 200^0 C

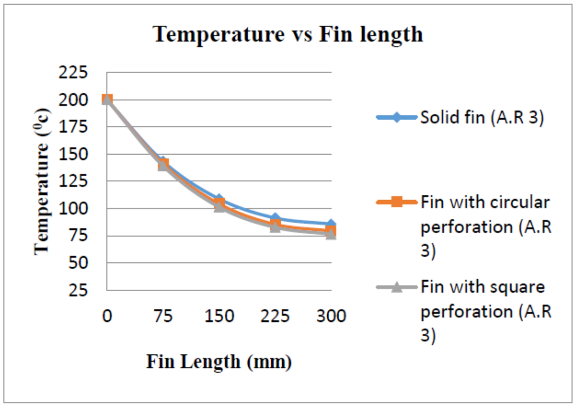

Fig 5.24: graph of temperature v/s fin length to compare solid and perforated fins of aspect ratio 3 at base temperature 200^{0}c

From the above graphs (Fig 5.10 to 5.24) we can observe that the tip temperature of solid fin is more than the tip temperature of circular and square perforated fins. Hence we can say that heat transfer in perforated fins is more than that of solid fins.

This is due to the fact that an interruption in the form of perforations aims at promoting surface turbulence that is intended mainly to increase the heat transfer coefficient rather than the surface area. Hence this results in increased heat transfer in perforated fins.

VI. CONCLUSION

From this study after conducting series of experiments, calculation and simulation of fins we can draw following conclusions.

1. The perforation increases the drop in temperature between the fin base and the tip. Which means more heat transfer takes place in perforated fins (i.e circular and square perforation) than a solid fin.
2. For a same base temperature the heat transfer coefficient decreases with increase in aspect ratio.
3. Irrespective of shape of perforation almost same amount of heat dissipation takes place for same exposed area of fin. That is, for fins with circular perforations almost same amount of heat dissipation takes place as that of fins with square perforations provide the area of both circular and square perforations are same.
4. The heat transfer coefficient increases with increase in base temperature.
5. For a same base temperature Nusselt number increases with increase in aspect ratio.
6. The rate of heat transfer increases with increase in aspect ratio (length of fin).
7. The fin efficiency decreases with increase in aspect ratio while fin effectiveness increases with increase in aspect ratio.
8. The perforated fin is light in weight, saves material and extracts heat quickly from heated surface compared to solid fin.

REFERENCES

[1] Wadhah Hussein Abdul Razzaq Al- Doori “Enhancement of natural convection heat transfer from rectangular fins by circular perforations” International Journal of Automotive and Mechanical Engineering (IJAME) Volume 4, July-December 2011

[2] Laxmikant Chavan, Niranjan Purane“ Thermal Analysis of Pin Fin using Different Materials and Forms” International Journal of Science and Research (IJSR)Volume 4 Issue 12, December 2015.

[3] Abdullah H. AlEssa, Ayman M. Maqableh and Shatha Ammourah“Enhancement of natural convection heat transfer from a fin by rectangular perforations with aspect ratio of two” International Journal of Physical Sciences Vol. 4 (10), October, 2009

[4] D. Abdullah H. AlEssa “Augmentation of Heat Transfer of a Fin by Rectangular Perforations with Aspect Ratio of Three” International Journal of Mechanics and Applications 2012, Volume2(1)

[5] Nalkande S.A, Shiriramshasri “Experimental Investigation of Fins With Different Geometric Profile” International Engineering Research Journal (IERJ) Special Issue Page 1169-1175, June 2016

[6] P. Mathiazhagan, S. Jayabharathy “Heat transfer and temperature Distribution of different fin geometry Using numerical method” JP Journal of Heat and Mass Transfer Volume 6, Number 3, 2012.

[7] Abbas Jassem Jubear and Ali A. F. Al- Hamadani “The effect of fin height on free convection heat transfer from rectangular fin array” International Journal of Recent Scientific Research Vol. 6, Issue, 7, July, 2015.

[8] A.V. Zoman and D. D. Palande “Heat transfer enhancement using fins with perforation: a review” International Journal of Engineering Sciences & Research Technology volume 5(7). July 2016.

[9] C P Kothandaraman, S Subramanyan “Heat and Mass transfer data book”, new age international publishers, 8th edition 2014

[10] M.Tirumaleshwar, “Fundamentals of heat & mass transfer” Pearson Publication,first edition 2006