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Effect of Perforation Shapes on the Heat Transfer Characteristic of Perforated Fins

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***Abstract:** A large number of engineering applications required rapid heat dissipation from its surface. This is achieved by the use of the fins i.e. increasing the surface area. Enhancement of heat transfer and reduction in the weight is the major criteria for designing the fins. The main objective of this project is to enhance the heat transfer through the use of perforated fin. A large number of study have been conducted on shape modification by cutting some material from fins to make holes, cavity, slots, groves or channel through the fin body to increase flow area. A rectangular fin of dimension 100 mm. x 200 mm. x 2 mm. and area of perforation is 100 mm^2 was selected. The number of perforation was varied from 20, 28, 36 and 44. It was found that maximum temperature drop occurred with 44 perforations. With the same fin with 44 perforation, temperature drop and heat transfer was analysed for different shapes (circular, square, oriented square, pentagon and elliptical) of perforation. I was found that in case of different shape of perforation with same cross sectional area, weight is nearly reduced by 28.42 % for elliptical perforation (a/b>3) was most effective in which 32.20 % more temperature drop and maximum average heat flux as compared to other perforation shape.*

***Keywords:** FEM, Heat transfer, perforated fin.*

I. INTRODUCTION

In so many numbers of applications such as engine cylinders, led lights, extruder cooling, air craft engine, generator cooling, transformer, computer processor and other electronic and mechanical equipment produces heat during operation. The production of excess heat in system is unavoidable [1]. The heat production in thermal equipment depends on the various factors. So it is essential to overcome heat quickly from the system to surrounding for best performance of the system [2]. To reduce the overheating problems of equipment is essential to enhance the heat transfer from the surface. This can be achieving either by increasing convective heat transfer coefficient or the surface area. Let a plane that is on a fixed temperature, there are three ways in which heat transfer may increase, by increasing heat transfer coefficient (h), reduced fluid temperature (T_∞) and increasing surface area.

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Heat transfer coefficient (h) could be increased by increasing the fluid velocity. In many situations in which increasing value of h is not sufficient to obtained desired heat transfer and the associated costs are expensive. Costs are related to blower or pump power requirements needed to increase h through
increased fluid motion. The second option of reducing fluid temperature (T_∞) is often impractical. So we see the third option that is heat transfer may be increased by increasing the surface area across which convection occurs. This may be done by using fins that extend from the wall in to surrounding fluid [3]. Heat transfer enhancement through various types of fins was studied by different researchers, Mhamuad.M.A *et, al.* studied about the temperature distribution along the perforated rectangular fins under natural convection and concluded that rate of temperature drop along the fin length was consistently high than that for the equivalent non perforated fin and heat transfer coefficient was decreased on reducing the perforation dimensions. [4]. Pujari.S. *et,al.* Investigated the effect of geometry and orientation of pin fin under natural convection. Upward and sideward two orientation and circular pin fin and conical cone two geometry were chosen and concluded that at same heat input conical cone fins show better result.[5]. Dhanadhya.V.R. *et, al* investigated the augmentation of heat transfer through rectangular fins with circular embossing under natural convection. In the present study finite element analysis had been done using ANSYS 11 and concluded that maximum heat transfer rate was found with fins having 12 perforations. [6]. Abdullah.H.M. *et, al.* was experimentally verified heat transfer enhancement from a horizontal rectangular fins with triangular perforation under natural convection. He reported that for certain values of perforation dimension the perforated fin can enhance heat transfer. [7]. Vyas.A. *et, al.* investigated the effect of shape factor on perforated fins by using computational fluid dynamics as a tool. The result showed that the shape has lower eccentricity showed good heat removal capacity. [8]. Patil.H.M. *et, al.* studied the effect of percentage perforation on heat transfer through fin array. Investigation had been done experimentally as well as CFD with 10%, 20%, and 30% perforation and concluded that total heat transfer was increased as the percentage of perforation increases and total heat transfer was maximum for 30% perforated fin array [9]. Similar trend in heat transfer with Rectangular, Trapezoidal, Triangular and Circular geometry was reported by different scientists [10-11].Present study was designed to investigate the temperature variation along fin length for number of perforations and various shapes of perforations.

Solid Works Model for Square and Elliptical shape perforation having 44 in numbers was designed and imported in ANSYS 19.2 Work bench for steady state thermal analysis. Best mesh size was determined by convergence test then thermal load was assigned as boundary condition for perforated fins. FEM suggested, those fins having elliptical shape with 44 numbers are best fit in terms of temperature drop and average heat flux.

II. EXPERIMENTAL SETUP AND METHODOLOGY

A. Experimental conditions

In the present work, the five aluminium rectangular fin (104.5 mm. long, 200 mm. wide and 2 mm. thick) were selected. One non perforated fin and four perforated fins were attached. 20,28,36,44 perforations were present per fin having dimension 10 mm. X 10 mm. The fins used in this study were assembled radially on an aluminium cylinder of 50 mm. diameter and 200 mm (Figure 2(a)) length. In the aluminium cylinder one hole was drilled, one heating element was fitted in the cylinder as shown in figure 1. The heat produced within the cylinder with the help of one heating element power of 500 Watt.

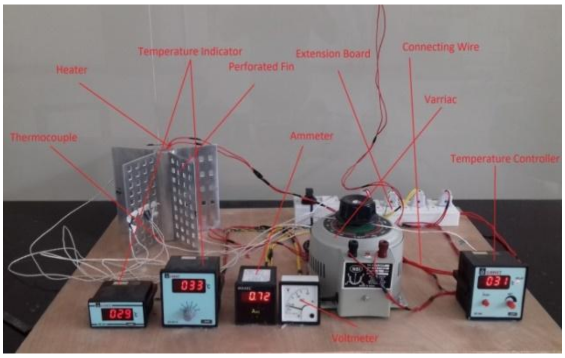

Fig.1.Photograph of experimental set up.

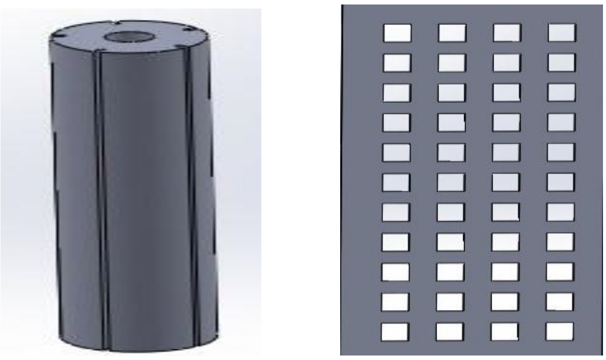

Fig.2. (a) Aluminium Cylinder. (b) Perforated Fin.

To regulate the voltage supplied to the heater a varriac of type 2PI with input 220 V and 50 Hz and output 0-240 V, 4 A and 1.0 kVA were used. A hole of size 15.8 mm. was bored in the cylinder and five numbers of slots (2.0×4.5mm.) were cut on the outer surface of the cylinder. Figure 2(a) and 2(b) shows the design of Aluminium plate Fin in the Solid Works software. The length and height of the plate was 100 mm. and 200 mm. respectively. Square shape hole of size (10 mm. X 10 mm.) was punched in the plate. The number of perforation in the plate was varying from 20 to 44 to investigate the effect of perforations on heat transfer rate from the fin.

B. Methodology

Eight K-type calibrated thermocouples were used to measure the testing fin temperature. Out of these five thermocouples were used to measure the temperature of perforated fin at uniform distance of 20 mm. across the length of fin. Two thermocouples were attached to the outside of the aluminium cylinder for measurement of base temperature and one thermocouple was used for environmental temperature. The voltage of 80 V was supplied. Steady state conditions were maintained for measuring required data.

III. MATHEMATICAL ANALYSIS

Mathematical modelling was carried out for a rectangular fin which geometry mentioned with dimension is shown in the Fig.3.

Heat transfer analysis was based upon following assumptions:

1- Heat transfer through fin is one dimensional.
2- No internal heat generation within.
3- Material is homogenous and isotropic with constant thermal conductivity.
4- Uniform cross sectional area of fin along fin length.
5- Base and ambient temperature are constant.

On the basis of the above assumptions in case of rectangular fin the governing differential equation for conservation of energy is given below.

Temperature distribution along the fin based on these assumptions-

$$\frac{T_x - T\infty}{T_b - T\infty} = \frac{\cosh\,[m(L-x)] + \left[\frac{h}{km}\right]\sinh[m(L-x)]}{\cosh\,(mL) + \left[\frac{h}{km}\right]\sinh\,(mL)} \ldots\ldots\ldots\ldots(2).[12]$$

Dissipation of heat from tip is given by-

$$Q = k.m.(T_b - T\infty)Ac.\frac{\sinh\,(mL) + \left[\frac{h}{km}\right]\cosh(mL)}{\cosh\,(mL) + \left[\frac{h}{km}\right]\sinh\,(mL)} \ldots\ldots(3)$$

Where $m = \sqrt{\frac{hP}{kA_c}}$

T_x = temperature at a distance x.
$T\infty$ = Ambient Temperature.
T_b = Base Temperature.

IV. FINITE ELEMENT ANALYSIS

A. Physical models

Numerical analysis of the geometry, a steady state thermal analysis was used. In the first step model of perforated and without perforated fins were developed by SOLIDWORKS 2013 X 64 Edition.

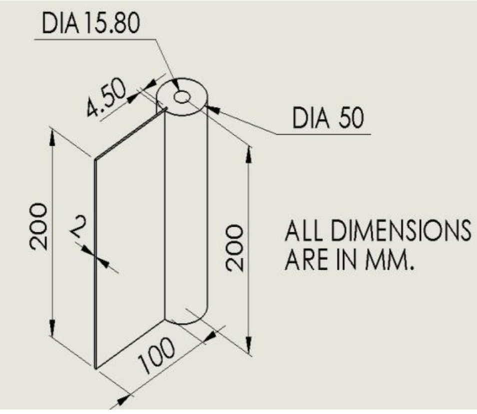

Fig.3.Rectangular fin.

B. Mesh generation

Quadtratic mesh and two types of element TET10 and HEX20. Tetrahedral elements were choosen, accuracy of result depends on mesh size, number of elements, types of mesh and grid dependency test etc.We select high quality due to their connection between base and fin. HEX type of mesh is used for plane geometry. Size of mesh was 3 mm. Fig.4 and fig.5 shows the meshed structure for 44 square and 44 elliptical peroration.

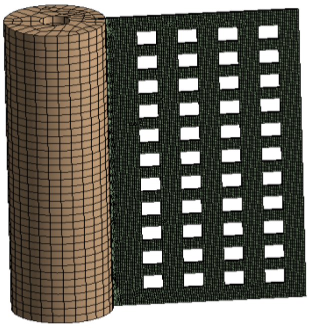

Fig.4. Meshed fin with 44 square perforation.

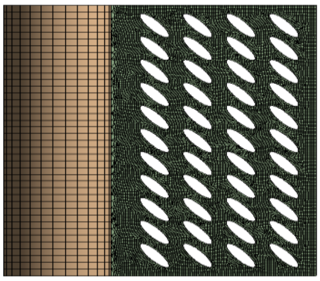

Fig.5. Meshed fin with 44 elliptical perforation.

Fig. 4 shows the meshed models of square perforated fin have total numbers of element 35404 and total numbers of nodes 187532 and Fig. 5 shows the meshed models of elliptical perforated fin have total numbers of element 62239 and total numbers of node 241561.

C. Boundary condition

Due to light weight Aluminium has selected as material for model, heat transfer rate is high in this material. Temperature of cylinder surface at wich fin base is attached (T_0). All material property and boundary conditions are shown in table I. and Fig. 6.

Table I: Important property and boundary condition .

Parameter	Value
Material	Aluminium
Conductivity	237 W/ m ^{0}C
Specific Heat capicity	0.896 J/g ^{0}C.
Density	2700kg/m^3
Base temperature	T_0
Convective heat transfer cofficient	15 W/m^2 ^{0}C
Ambient temperature	22 ^{0}C

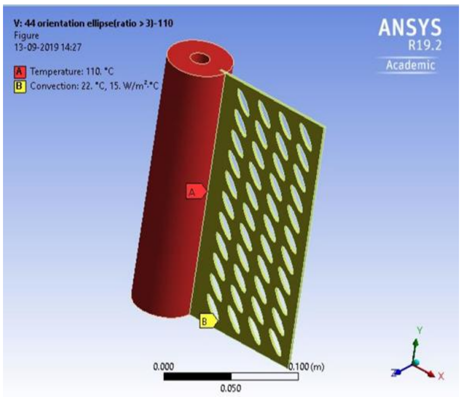

Fig. 6. Boundary condition apply to the geometry.

D. **Solution:**

In the present study steady state thermal analysis, SPARSE MATRIX DIRECT SOLVER is used.

V. RESULT AND DISCUSSION

A. Validation

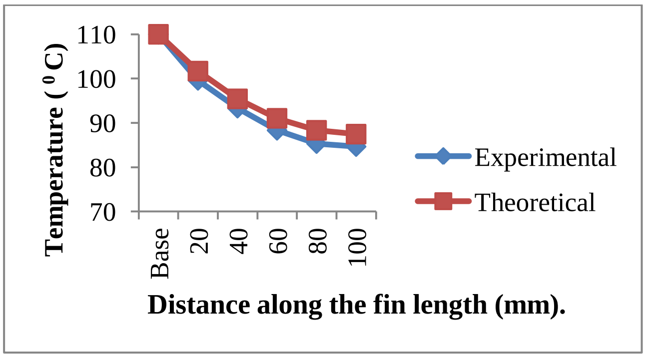

Fig.7.Validation of theoretical and experimental result

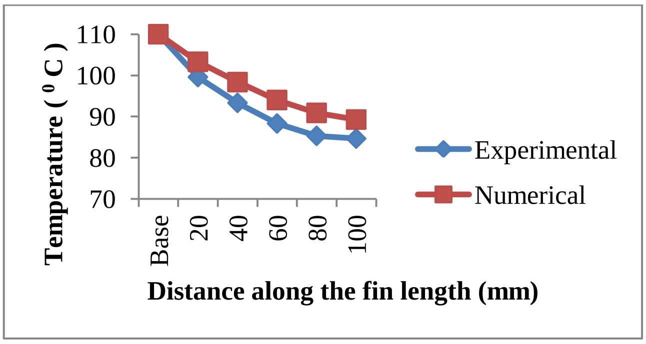

Fig.8.Validation of experimental and numerical result

Fig.7 and Fig.8 shows the validation between experimental and theoretical results and between experimental and FEA results. In case of without perforated fin, it was noted that the results obtained from experiment are very close to theoretical result and maximum percentage deviation is 3.4 %, between experiment and FEA was 5.12 %.

B. Effect of number of perforation.

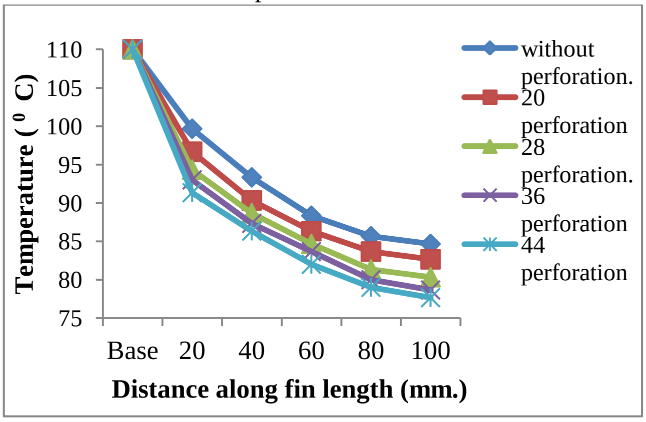

Fig.9. Distribution of temperature Vs. distance along fin, base at 110 ^{0} C.

It is clear from Fig.9, that temperature drops from base towards tip at 110^0 C base temperature and concluded the effect of number of perforations on temperature distribution on the length of perforated and non-perforated fin. It was also observed from the Fig.9, that the temperature decreases along length of the fin for different perforation numbers. The highest drop in temperature was found at 44 perforation number and it was recorded as 29.4 % as compared to without perforated fin. The temperature drop may be due to high thermal conduction resistance in perforated fin.

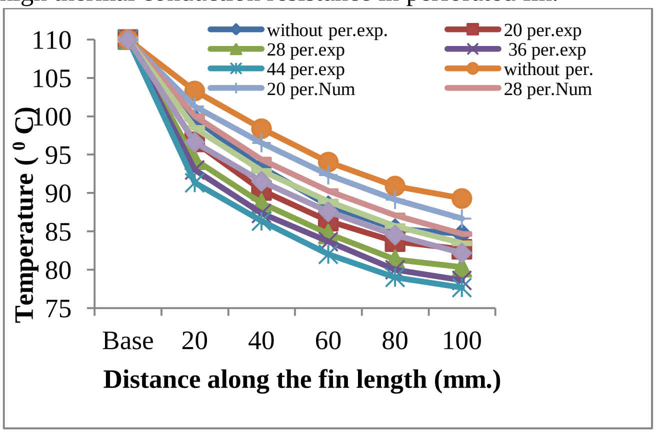

Fig.10. Comparison between experimental and numerical result, base at 110 ^{0} C.

According to Fig. 10 the difference between experimental and numerical results is visible in case of square perforated fin. The maximum difference between experimental and numerical result was 5.75 % in fin having 20 perforations. This is due to the fact that radiation effect has not been considered.

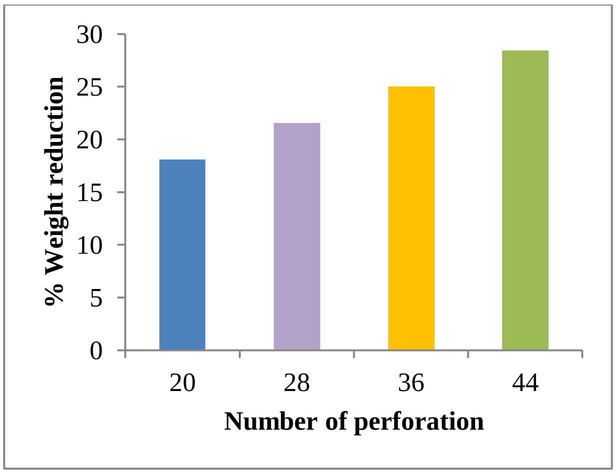

Fig.11. Reduction in weight (%) vs. number of perforation.

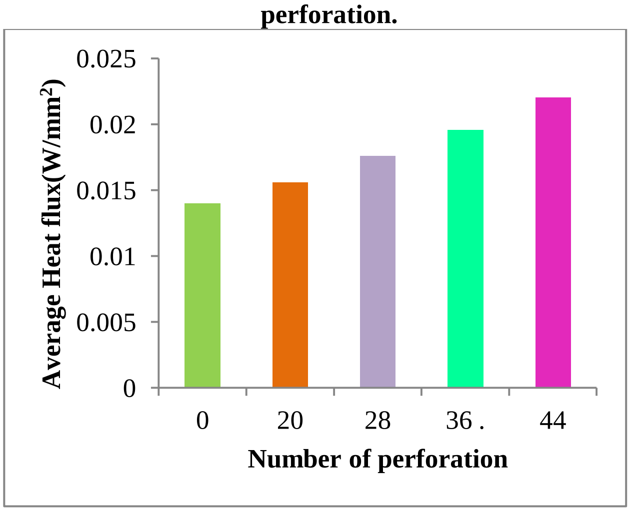

Fig.12. Average heat flux vs. number of perforation.

Fig. 11 shows increase in average heat flux by increasing the number of perforation. Higher number of perforation in fin provides more surface area for air flow which may ultimately enhance the heat flux. Fig. 12 shows the effect the number of perforation on weight reduction. By making the perforation, performance of fin increase as well as weight also reduced by 28.42 %, which makes our system lighter in weight.Experimental and numerical results confirmed that maximum temperature drop and maximum average heat flux was obtained at 110 ^{0} C base temperature and 44 number square shape perforation. On the basis of the result, it was decided to study effect of different shape of perforation with same cross sectional area and same number of perforation. For further investigation following dimensions of different shape perforation was decided and showed in Table II.

Table II: Dimensions of various perforation.

Shape of perforation	Dimensions(mm.)
Square	Length =10, width =10
Oriented square	Length =10, width =10
Circle	Diameter =11.28
Pentagon	Sides =7.624
Oriented pentagon	Sides =7.624
Ellipitical (a/b=2)	Major axis(a)=7.978, minor axis(b)=3.99
Ellipitical (a/b>3)	Major axis(a)=10.61, minor axis(b)=3.00
Number of perforation	44

C. Effect of change of shape on temperature distribution

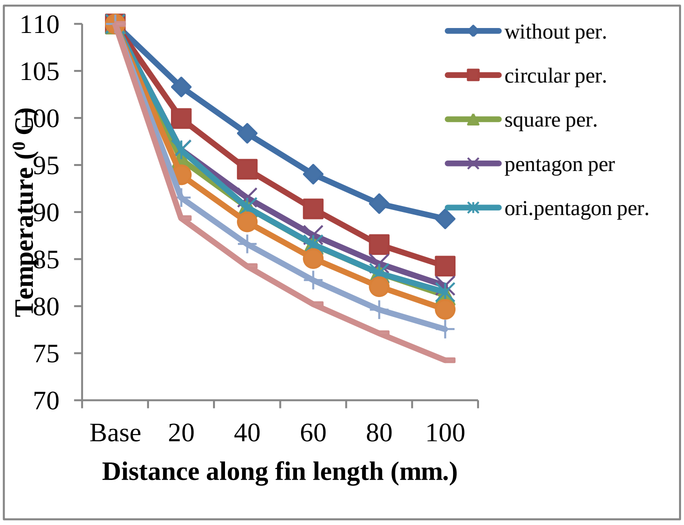

Fig. 13.Temperature vs. distance.

Fig.13 shows the temperature distributions along the length of the fin having 44 perforations of different shape at base temperature 110 ^{0}C. It was found that temperature at the tip of the fin for shapes drop for fin with no perforations 89.282^0 C in without perforation and 84.258 ^{0}C, 81.168 ^{0}C, 79.665 ^{0}C, 82.183 ^{0}C, 81.458 ^{0}C, 77.566 ^{0}C, 74.251 ^{0}C for circular, square, oriented square, pentagon, oriented pentagon, elliptical (a/b=2) and elliptical (a/b>3) respectively. From the above figure we can conclude that maximum temperature drops occur in elliptical (a/b>3) perforation. The present study focussed on creating more surface area by increasing the number and shape of perforation by maintaining constant cross sectional area of each perforation shape. Improvement of heat transfer may be achieved in the situation of vertical fins because whole surface of fin is opened to the air flowing stream. Turbulence may be generated as air travels along the surface of fin. The various shape of perforation provides more effective area for turbulence. Shape as well as geometry of perforation is responsible for the turbulence intensity. As air travels across the fin having perforation, the thermal boundary layer disturbs. The continuous breaking and formation of thermal boundary layer at each and every perforation interruption, which ultimately reduces the overall thickness of thermal boundary layer. This phenomenon may be responsible for enhancement in heat transfer.

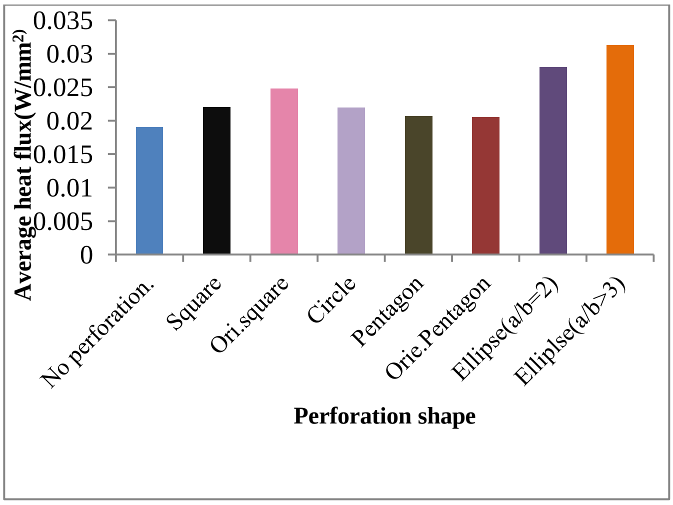

Fig.14. Average heat flux vs. shape of perforation.

The above Fig.14 shows the average heat flux for different perforation shape and it is found that maximum average heat flux observed in Elliptical (a/b>3) perforation.

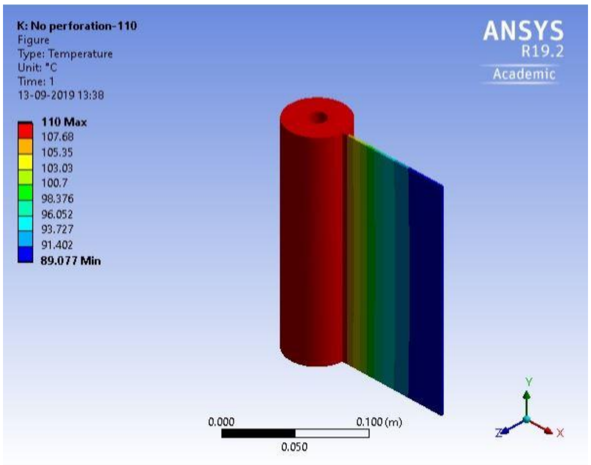

Fig.15. Temperature contour in without perforated fin.

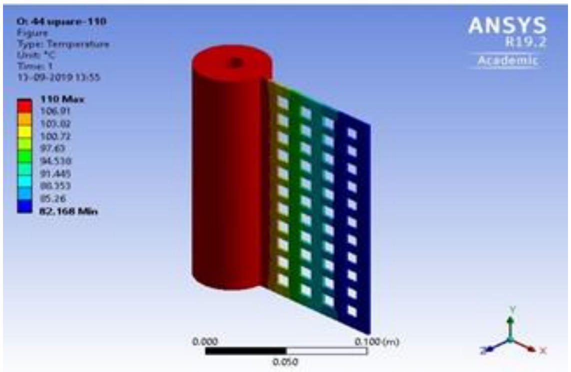

Fig. 16. Temperature contour in square perforated fin.

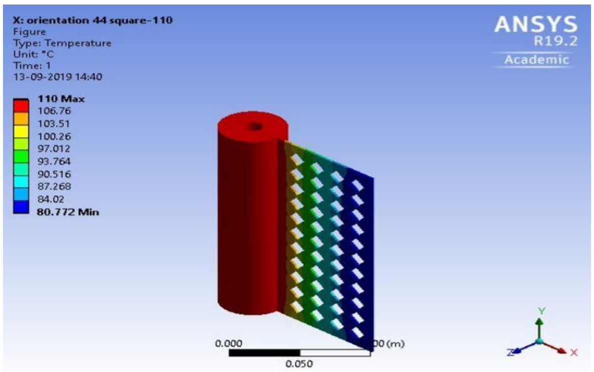

Fig.17.Temperature contour in oriented square perforated fin

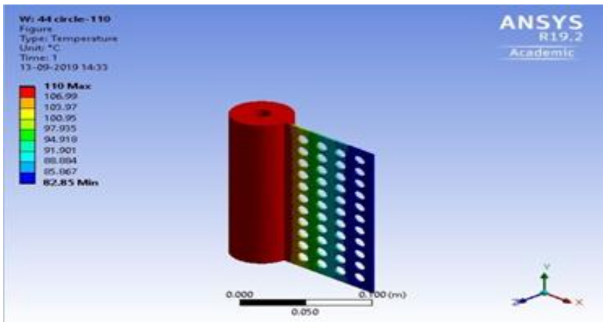

Fig.18.Temperature contour in circular perforated fin.

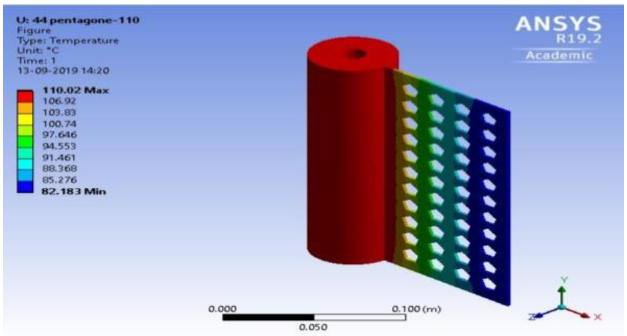

Fig. 19. Temperature contour in pentagon perforated fin.

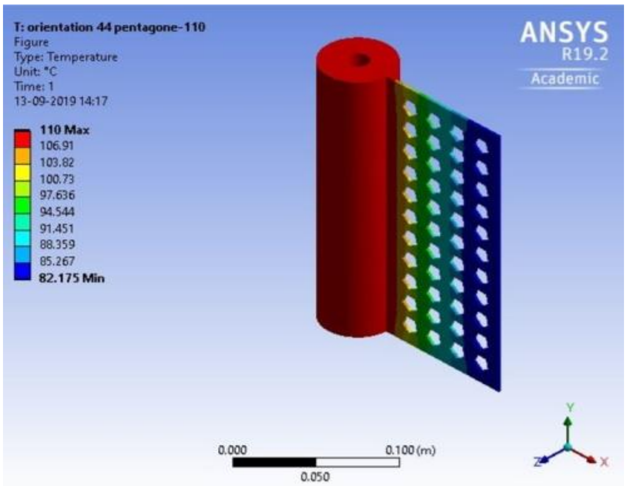

Fig. 20. Temperature contour in oriented pentagon perforated fin.

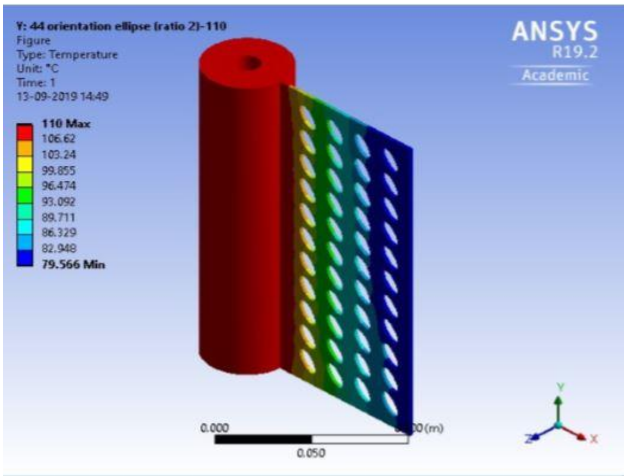

Fig.21.Temperature contour in elliptical (a/b=2) perforated fin

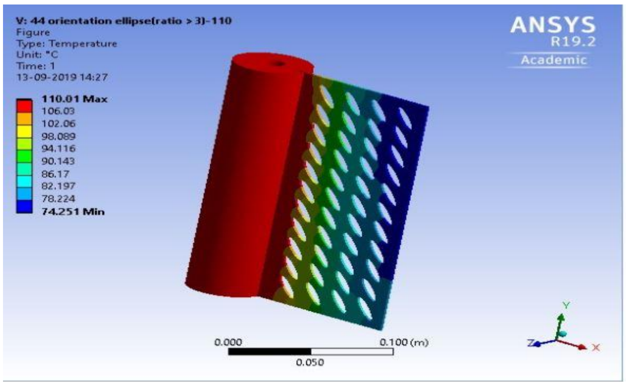

Fig.22.Temperature contour in elliptical (a/b>3) perforated fin

Fig.15 to Fig. 22 shows the temperature contour of diffeent types of perforated fin.

VI. CONCLUSION

The above study finally concluded that increase of temperature drop between the base and tip was observed by increasing amount of perforation. In order to dissipate more heat from source to medium the number of perforations was increased and shape was varied. The present work concluded,

1. The results also correlated that rate of heat dissipation in fin having perforation depends on the number of perforation, perforation dimension as well as perforation shape.
2. It was found that perforation reduced the material weight in the range of 18.1% to 28.42 % as the number of perforation changed from 20 to 44 and reduced the cost also.
3. In case of elliptical perforation (a/b>3) maximum temperature drop 32.2% and Maximum average heat flux i.e. 68.42% more than fin without perforation was found.

The result of this study concluded that elliptical perforation (a/b>3) was most effective perforation shape.

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REFERENCES

1. Umesh V. Awsarmol, Ashok T. Pise, "An experimental investigation of natural convection heat transfer enhancement from perforated rectangular fins array at different inclinations". Experimental Thermal and Fluid Science, Vol. 68, pp. 145–154, 2015.
2. M. Shudheer, Ashwani Shetty, Shashiraj Somayaji, "Finite element investigations of temperature distribution in fins with circular perforations". American journal of material science, Vol. 5, pp. 157–161, 2015.
3. Sahivasheesh Kaushik, Vinay Sati, Anirudh Gupta, Kavita Puri, "Experimental analysis between rectangular solid fins with different circular perforated rectangular fins under natural convection". International Journal of Engineering Research and Sciences, Vol. 4(05), pp. 1299-1306, 2015.
4. Satish Pujari, Polaya Chintada, Anil Kumar Inkulu and G. Ganana Deepa, "Experimental investigation of heat sink circular pin fin and conical spines subject to natural convection". Recent Advances in Material Sciences, pp. 3-16, 2019.
5. Rupali V. Dhanadhya, Abhay S. Nilawar & Yogesh L. Yenarkar, "Theoretical study and finite element analysis of convection heat transfer augmentation from horizontal rectangular fin with circular perforation". International Journal of Mechanical and Production, Vol. 3(2), pp. 187–192, 2013.
6. Ashish B. Samarth, Kapil S. Sawankar, "Thermal performance of perforated pin-fin arrays in staggered arrangement", International journal of science and engineering research, Vol. 5(7), pp. 777–783, 2014.
7. G.P. Lohar, S.G. Taji, "Experimental investigation for optimised fin spacing in horizontal re ctangular fin array for maximum the heat transfer under natural convection and force convection". International journal of Engineering Research & Technology (IJERT), Vol. (3), pp. 1451-1453, 2014.
8. Abdullah H.M. AIEssa and Nabeel S. Gharaibeh, "Effect of triangular perforation orientation on the heat transfer augmentation from a fin subjected to natural convection". Advances in applied science research, Vol. 5(3), pp. 179-188, 2014.
9. Mitesh H. Patil, Santosh V. Patil, E.R. Deore, Gaurav A. Chaudhari, "Design & analysis of perforated rectangular fin array with varying percentage of perforation", International Advanced Research Journal in Science, Engineering and Technology, Vol, 3(9), pp. 26–31, 2016.
10. Akhilesh Kumar Singh, Rajiv Varshney,"Experimental investigation on rectangular fins with holes in natural convection", International journal of engineering development and research, Vol, 5(4), pp. 157–166, 2017.
11. Subodh Kumar Sharma, Ajay Kumar, Pratibha Kumari, "Experimental investigation of temperature in fins". International Journal of Applied Engineering Research, Vol. 13(6), pp. 354–357, 2018.
12. R. K. Rajput, "Heat and mass transfer" 6^{th} Edition, Published by S.Chand; New Delhi; 2015; p.206.

ABBREVIATION

Symbol	Meaning
Ori.	Oriented
T_x	Temperature at distance x from base
$T\infty$	Ambient Temperature.
T_b	Base Temperature.
h	Convective heat transfer coefficient.
A_c	Crass sectional Area.
Num.	Numerical
Exp.	Experimental

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