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NUMERICAL INVESTIGATIONS ON RECTANGULAR PLATE FIN WITH PERFORATIONS USING ANSYS

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ABSTRACT

Fins are widely used for enhancement of heat transfer in many engineering applications. The objective of the present work is to investigate the effect of number of perforations, its size and geometry of perforation on the heat transfer through a fin. For the purpose, a rectangular plate fin is analysed in Ansys under steady state thermal condition. The circular, triangular, square, and elliptical shapes of perforations are considered for the heat transfer analysis of the fin. The temperature distributions along the length of the fin for all the cases of perforations are studied and the results are compared with the non-perforated fins. It is observed that the elliptical perforations in the fin gives higher rate of heat transfer as compared to other types of geometry. The number of perforations and geometry of perforation affect the heat transfer through a fin significantly. The temperature gradient along the length of the fin increases with the increase in size and number of perforations. The percentage increase in the temperature drop along the length of fin is 47 % for elliptical perforations while, it is 36 % for triangular perforations. The circular perforations in a plate fin gives minimum heat transfer.

Keywords*: Free convection, Heat transfer, Rectangular plate fin, Numerical simulation, Perforations.*

I. INTRODUCTION

In the present era, demand for efficient devices is increasing rapidly. At the same time, there is a increased demand for more and more compact size devices. However, with the miniaturization, temperature increases rapidly and there is no scope for heat removal. Hence, it may lead to malfunctioning of that component and also reduces the life of that particular component as well as damage the related components. Therefore, to have effective heat transfer from the device, fins are widely preferred option. Fins are the extended surfaces which increase the heat transfer from the surface of component. With the use of fins, there is a need additional material for fins apart from the component material. Thus, cost of manufacturing component with fin will increase.

Research till now has shown that that the perforations increase the heat transfer rate. If perforated fins are used in place of non perforated fins, not only the heat transfer rate increases but also the weight of fin reduces that is the material required and its cost also decreases. Thus, by application of perforated fins, heat transfer rate increases significantly and heat transferring devices work more effectively.

II. LITERATURE REVIEW

Shenghui Liu et al. [1] have theoretically and numerically shown that the fin effectiveness of the printed circuit heat exchanger (PCHE) is enhanced by selecting fin with high thermal conductivity, decreasing the ratio of the fin thickness to the radius of the channels, or having small convective coefficient; and the fin efficiency is improved with high fin thermal conductivity, thick fin and low convective coefficient of the working fluid. Guodong Qiu et al. [2] have found that when there are no solar radiation, the fin efficiency is independent of the excess temperature while in presence of solar radiation , the excessive temperature significantly affect the fin efficiency. When the solar energy is used for assisting the fin heat transfer, the various factors should be considered simultaneously in accordance with the actual situations for effective working of fin. Tehmina Ambreen, Man-Hoe Kim [3] got the numerical result that the nanofluid cooled circular fins showed highest thermal performance whereas water cooled square fins showed smallest values. In the nanofluid cooled heat sink with square, circular and hexagon fins, Nusselt number is increased by 26%, 44% and 62% respectively as compared to water cooled square fins. The impact of fin shape on the Nusselt number has greater influence at higher Reynold number. Aadel A. R. Alkumait et al. [4] have numerically demonstrated that the flat finned tube display more increment in heat transfer than circular finned tube and the triangular perforation shape provide higher enhancement in heat transfer rate shown by Nusselt number. Ibrahim T. K. et al. [5] experimentally presented that perforations in the fin result in the higher temperature gradient along the fin length as compared to the non-perforated fins. It is observed that the heat transfer coefficient of the heat sink depends on the perforation shape and geometry. They found that triangular perforation gives higher heat transfer coefficient as compared to the circular and rectangular perforations. Obula Reddy Kummitha, B.V.R. Reddy [6] compared the grey cast iron and Magnesium alloys, best composite materials, with aluminium alloy andit was presented that aluminium is best suited for fin materialin case of tapered fins for culindrical blocks of IC engine. Abdolali Khalili Sadaghiani, Ali Koşar [7] have numerically investigated that among the different pin fin shapes, diamond shaped fins lead to higher Nusselt number as compared oblong, rectangular,elliptical fin shape. At high Knudsen number and the flow corresponding to the second-order boundary condition, the pin fin shape hardly affect the average Nusselt number. A. Kalyan Charan et al. [8] have numerically concluded that the Nusselt number is higher for perforated fin as compared with non- perforated fin. The previous researchers have shown that heat transfer through perforated fins is more than that of the non-perforated fins.

In the present paper, the numerical simulations are carried out on the rectangular plate fin with perforations. The various shapes of perforations such as circular, elliptical, square and triangular are considered in the present work. The effect of number of perforations and size of perforations on the heat transfer of fin is investigated using Ansys software.

III. NUMERICAL SIMULATION OF FIN

Model of single rectangular plate fin is prepared using ANSYS 19.1. In the first part of the numerical simulation, steady state heat transfer analysis of solid rectangular plate fin is carried out while, in the later part, various cases of perforated plate fin are simulated. Table 1 gives the specifications of perforated and non-perforated fin. The fin geometry is imported in the modelling section of ANSYS and meshing is done. Table 2 shows the meshing parameters. Analysis of fin is done by initializing the boundary conditions: ambient temperature as 25 °C, base temperature of fin as 100 °C, convective film coefficient as 20 W/m^2 K. The fin is assumed to be insulated at its tip.
Heat transfer analysis is conducted for various sizes and shapes of perorations. Theses parameters are stated below.

- Number of perforations: 2, 3, 4, 5 perforations.
- Perforation size: 2mm, 3mm, 4mm diameter and equivalent sizes for other shapes of perforations.
- Fin base temperature: 100 ^{0}C, 200 ^{0}C, 300 ^{0}C, 400 ^{0}C, 500 ^{0}C.
- Perforation shape: Circular, square, triangular, elliptical perforation with constant perforation area of 12.56 mm^2 for each perforation shape.

Table 1. Specification of Fin

Fin Parameter	Specification
Material	Aluminium
Length, mm	50
Width, mm	10
Thickness, mm	2
Isotropic Thermal Conductivity, W/m K	237.5
Density, kg/m^3	2689
Specific heat at constant pressure, J/ kg K	951

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Table 2. Mesh Statistics

Mesh parameter	Number
Nodes	6936
Elements	1164

IV. RESULTS AND DISCUSSION

In the present paper, temperature distributions and heat transfer for fins with different perforations such as circular, elliptical, square and triangular are studied numerically. The results are compared with the heat transfer from fin without perforations. The effect of size and number of perforations on the temperature distributions of the fin is analysed.

4.1 Validation of Simulation:-

For the validation of the simulation, analytical solutions for rectangular plate fin without perforations are obtained assuming one-dimensional steady state heat transfer. The adiabatic boundary condition is assumed at the tip of the fin. The simulated temperature profile for solid rectangular plate fin is compared with the analytical results of temperature distribution. Fig. 1 shows the comparison of analytically obtained temperature distribution along the length of non-perorated fin with the simulated results. It is clear from Fig.1, the analytical and simulation results are found to be nearly same.

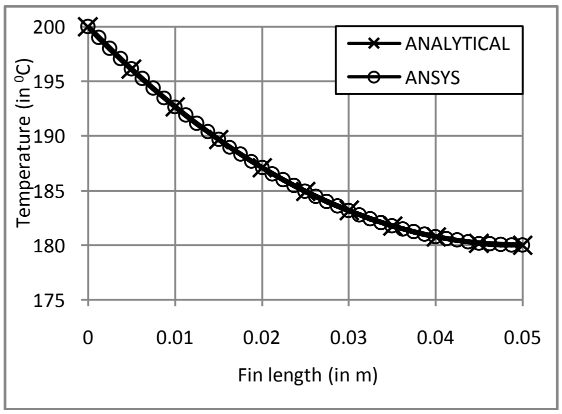

Fig. 1. Comparison between Ansys and analytical results

4.2 Effect of Shape of Perforations

The effect of various shapes of perforations such as circular, elliptical, square and triangular on the heat transfer performance of the fin is studied. The number of perforations and area of perforation for all the types of perforation shapes is kept constant. Fig. 2 shows the temperature distributions for the fin with circular perforations.

The number of perforations are 5 with 4 mm diameter. Fig. 3, 4 and 5 show the temperature distributions obtained in Ansys for elliptical, square and triangular shapes of perforations respectively.

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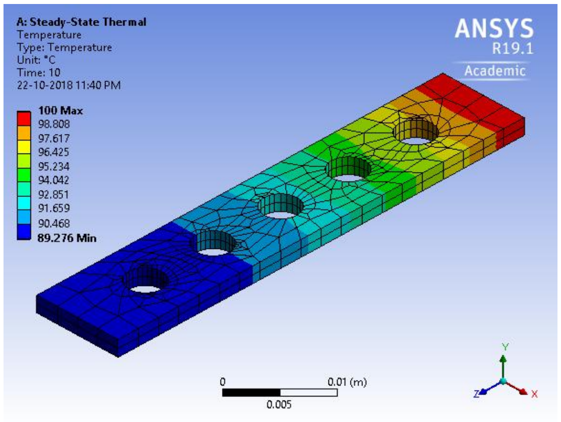

Fig. 2. Temperature distribution for fin with circular perforations (4 mm diameter)

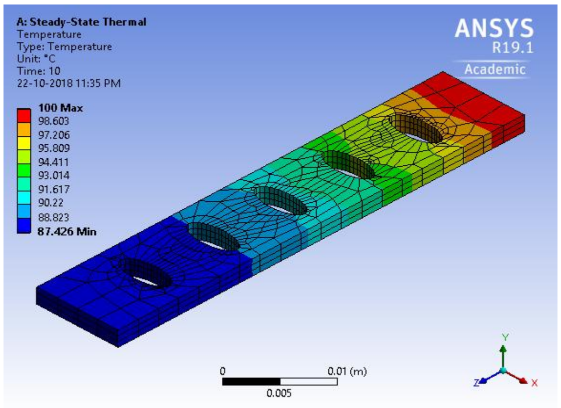

Fig. 3. Temperature distribution for fin with elliptical perforations (size equivalent to 4mm diameter)

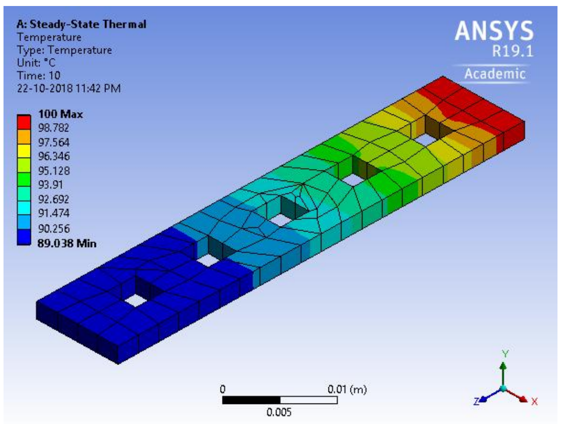

Fig. 4. Temperature distribution for fin with square perforations (size equivalent to 4mm diameter)

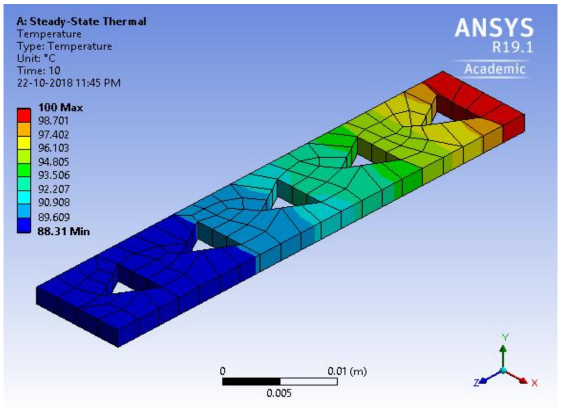

Fig. 5. Temperature distribution for fin with triangular perforations (size equivalent to 4mm diameter)

The size of perforations is kept equivalent to 4 mm diameter of circular perforation. It is clear from Fig. 2, 3, 4 and 5 that the temperature gradient along the length of the fin for elliptical perforations is greater than that for all other shapes of perforations.

4.3 Effect of Number of Perforations

The effect of number of perforations on the heat transfer from fin for all the shapes of perforations is investigated keeping area of perforation constant. Fig. 6 shows the effect of circular perforations on temperature distribution along the length of fin.

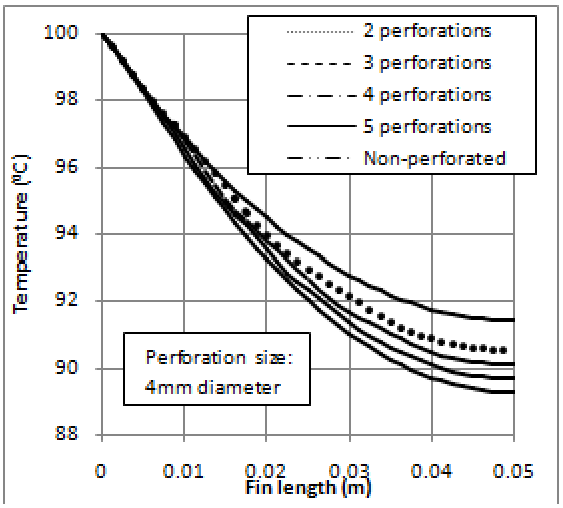

Fig. 6. Effect of circular perforations on temperature distribution

The maximum number of perforations for the specified fin are limited to 5. Therefore, in the present study, the number of perforations are varied from 2 to 5 . The diameter of perforation is 4 mm. The temperature distributions with perforations are also compared with that of the fin without perforations. It is clear from Fig. 6 that the temperature gradient along length of the fin increases with the increase in number of perforations. It is also noted that the heat transfer rate is more for the perforated fin as compared to the fin without perforations. Fig. 7, 8, and 9 shows temperature distributions for elliptical, square and triangular perforations, respectively.

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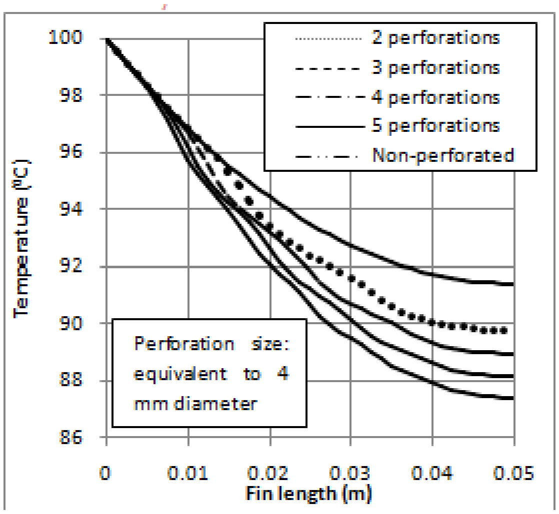

Fig. 7. Effect of elliptical perforations on temperature distribution

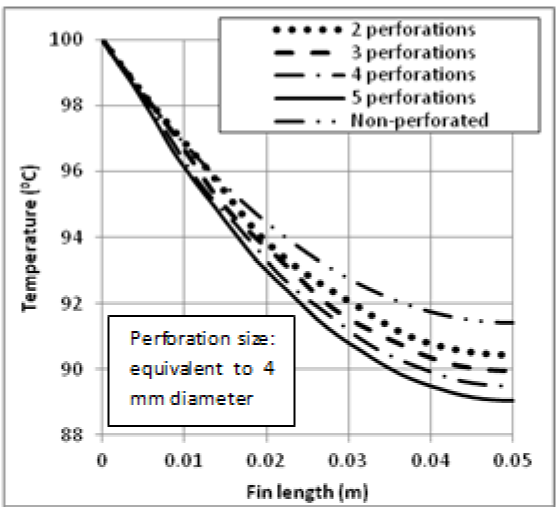

Fig. 8. Effect of square perforations on temperature distribution

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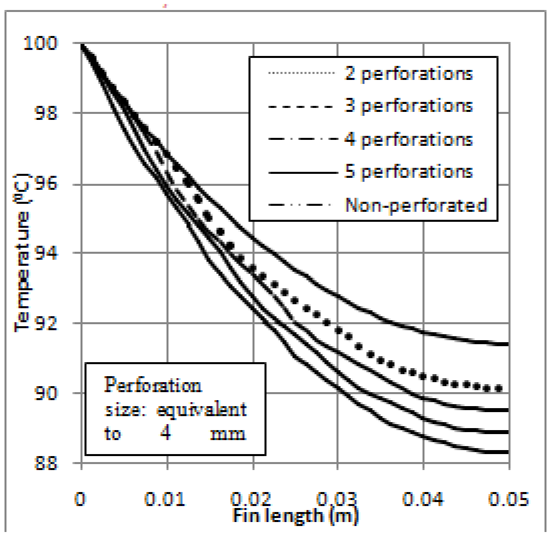

Fig. 9. Effect of triangular perforations on temperature distribution

It is observed that the temperature gradient increases with the increase in number of perforations for all the shapes: circular, elliptical, square and triangular. The maximum temperature drop is obtained with 5 number of perforations. However, temperature drop along the length of fin in the case of elliptical perforations is greater than that of other shapes. Fig. 10 shows effect of number of perforations on the tip temperature for all the shapes of perforations.

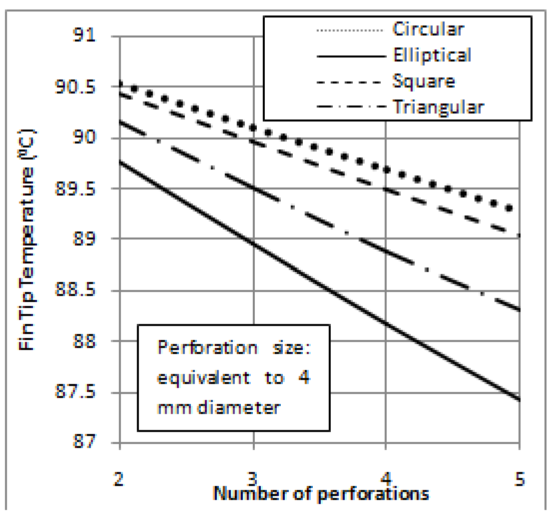

Fig.10. Temperature at the fin tip for various cases

4.4 Effect of Size of Perforations

Fig. 11 shows the effect of size of perforations on the heat transfer rate for the elliptical shape of perforations.

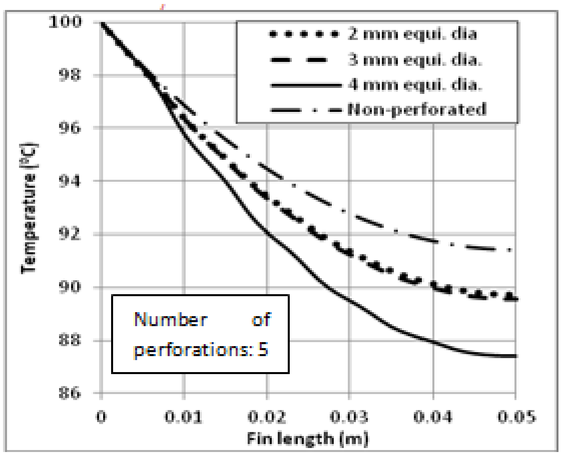

Fig. 11. Effect of size of elliptical perforations

The size of perforations is varied from shear area equivalent to 2 mm to 4 mm diameter, keeping number of perforations equal to 5. It is noted from Fig. 11 that the there is increase in temperature gradient along the length of fin with respect to increase in size of perforations. Highest temperature gradient or lowest tip temperature is obtained for size equivalent to 4 mm diameter perforation due to higher rate of heat transfer as compared to all other sizes of perforations and solid fin. Fig. 12 gives the variations in temperature along the length of fin with elliptical perforations (5 numbers) with respect to base temperature of fin.

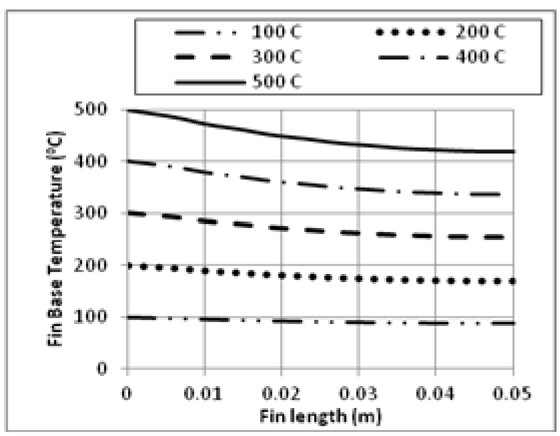

Fig.12. Effect of base temperature on temperature distribution of elliptical perforated fin (Number of perforations: 5, Equivalent size: 4mm diameter).

The size of perforations is kept equal to shear area (12.56 mm^2) equivalent to 4 mm diameter. The temperature drop along the length of the fin increses with the increase in base temperature. In the above discussions, it is revealed that 5 number of perforations and shear area equivalent to 4 mm diameter gives maximum heat transfer rate for the perforated fins.

Fig. 13 compares temperature distributions for all the shapes of perforations. For elliptical shape, temperature drop is greater than that for all other types of perforated fins and a fin without perforations.

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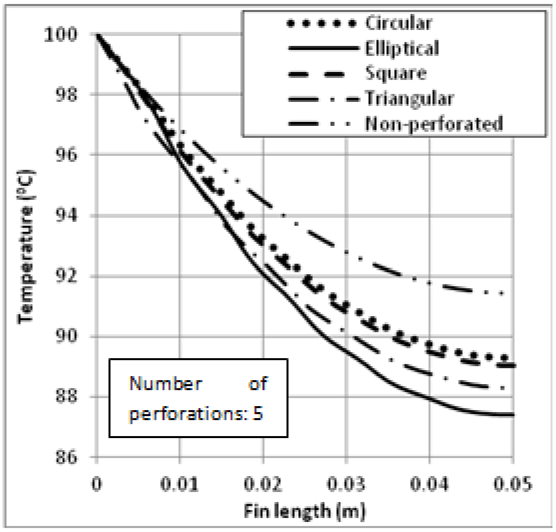

Fig. 13. Effect of different perforation shapes of equivalent area as 12.56 mm^2 on temperature distribution

Table 3 summarizes the percentage increase in temperature difference as compared to non-perforated fin along the length with 5 number of perforations and 4 mm equivalent diameter for all the shapes of perforations.

Table 3. Effect of perforation shape on temperature distribution.

Perforation Shape	Increase in temperature difference, %
Circular	25
Elliptical	47
Square	28
Triangular	36

V. CONCLUSIONS

In this present work, the effect of shapes, size and number of perforations on the heat transfer from the rectangular plate fin is numerically investigated. The heat transfer performance is evaluated in terms of temperature distribution along the length of fin. It is concluded that the temperature gradient and hence, heat transfer rate increases with the increase in number of perforations and its size for all the shapes of perforations. Elliptical perforations gives higher temperature gradient along the fin length as compared to other shapes. The heat transfer rate for the circular perforations is minimum as compared to other cases.

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