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An Experimental Analysis of Natural Heat Transfer between Rectangular Solid and Perforated Fins Having Different Perforation Characteristics

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Abstract: This paper presents a comparative study for amount of natural convection heat transfer of solid and perforated faced fins. Effect of number of perforation and its size on natural convection characteristic is also investigated. Experiment is being done for solid fins and perforated fins having different number of perforations on its surface. Effect of size of the perforation and fins spacing on the surface where it need to be mounted is also examined. Solid works software is used for the modelling of the fins and steady state thermal model of ANSYS software is used for the numerical analysis and optimization of the fin's porosity. Analysis is done for 1,2, 3, 4, 5 row inline and zig-zag perforations for different pores diameter which are 4mm, 6mm, 8mm, 10mm and 13mm respectively. Fins spacing on the mounted surface is also an influencing parameter to control the natural heat transfer. Fins spacing is taken 6mm, 8mm, 10mm, 12mm respectively. After the detailed analysis it was concluded that perforated fin should be used over the solid fins to improve the heat transfer rate and for the temperature decrement of the fins surface. Analytical results have presented in this paper in which it is shown that perforated fins having 5 row zig-zag pattern holes with 10mm hole diameter and 10 mm fins spacing can give the optimized result.

Keywords: Natural Heat Transfer, Perforated Fins, ANSYS, Solid Works

1. Introduction

Fins or extended surfaces are well known for enhancing the heat transfer rate from the surfaces. Different types of fins can be used for significant improvement of heat transfer from the surfaces i.e., rectangular, parabolic, triangular, trapezoidal etc. Fins can be attached on the outer or inner surface of the body. Mostly used fins are rectangular in shape as these fins are low in cost and light in weight. Various studies had done about the effect of shape of the fin on rectangular shaped cooling channel and made a comparative study between NACA pin fins and circular pin fins and found NACA fins seek more effective and potential to create the cooling effects [1)]. Comparative study of fins were also made with microchannel heat sink for the calculation of effect of wall resistance on the total thermal resistance of heat sink and it was found that fins model was more effective and Biot number for the same is less than 0.1 [2,3)]. Detached fins were also used on turbine channel and studies were done about its effect for turbulent flow when rotor of the turbine is rotating at high speed [4)]. Coating over the surface of the material can also reinforce the thermal behaviour of the material which also influence the amount of heat transfer from the surface. Mica mineral was used for the coating of the steel structure [5)]. Some studies were presented for forced convection heat transfer using the extended surfaces for low values of Reynold's number [6,7)]. Analytical simulation had done for natural convection of finned surfaces and calculated the Nusselt number for the same [8)]. Heat transfer behaviour of perforated fins was studied. Conduction-Convection mode of heat transfer was taken and Navier-Stroke equations was used for the analysis purpose and it was concluded that perforated fins have higher rate of heat transfer than the solid fins [9,10)]. An experimental study on perforated vertical fins for force convection heat transfer was made in which fins are mounted on the surface of heat exchanger which is used as heat sink and analysis was done on the basis of size and geometry of the perforation and it was concluded that circular perforation have highest amount of heat transfer followed by rectangular and triangular perforation [11,12)]. Some analysis was done on perforation technique also and it was concluded that increasing the number of perforation and size of perforation increases the heat transfer amount and perforated fins also offer outstanding hydraulic performance as compared to solid fins [13,14)]. Some examination were done for different perforation pattern in case of natural convection heat transfer in which fins are connected at different angles from 0° to 90° having diameter variation from 4 to 12 mm and it was concluded that maximum amount of heat transfer could be achieved when fins are at the orientation of 45°[15]. Fins were used for cooling of heat sinks by nanofluids. Different types of nano fluids such as TiO_2, Al_2O_3, Cu etc with dispersion in water was used as a nano fluids [16]. Navier-Stroke energy equation was used for mathematical calculation and it was found that lowest value of Nusselt number is found for nanofluid TiO_2 , average value is found for Al_2O_3 nano fluid and maximum amount of Nusselt number could be achieved for Cu nano-fluid [17,18]. Effect of perforation on thermal and fluid dynamic behaviour of heat exchanger was studied. FEM technique was used fir the comparison purpose between solid and perforated fins and it was concluded that fin efficiency and effectiveness can be improved after making perforations over the fins surface [19,20]. Optimum design and size of perforated fins was calculated. CFD and Levenberg methods were used for the mathematical analysis. 6 different design were created for the same and it was found that 6-7% of decrement can be developed in perforated fins than solid pin fins [21]. Perforated pin fins with inline and staggered arrangement were used as heat sink and it was found that staggered arrangement would be more effective for heat transfer enhancement [22]. Circular perforated fins with varying holes diameters was used for forced convection heat transfer and all modelling was done by using solid works [23]. Some experiments were done for turbulent convection heat transfer from perforated fins. For the same number was taken 0.7. Fourier's law was used to evaluate the heat transfer inside the fins surface and it was calculated that longitudinal perforation had shown good results in terms of heat transfer rate [24]. In the current experiment:

- Rectangular shaped fins with circular perforation is taken.
- Analysis is done for inline as well as for zig-zag pattern over the surface of the fins.
- Influence of perforation diameter and fins spacing over the mounted surface is also analyzed.
- Analysis is done on 15, 20, 25, 30, 35 W heater input.
- Solid works is used for the system modelling and ANSYS software is used to determine the effect of the parameters on natural convection.

Novelty of the experiment is that the analytical work has been done by considering all possible input parameters in case of solid/perforated fins installation over the surface.

2. Experimentation and Results:

Fins are used as an extended surface to enhance the heat transfer from the base. In the current experiment rectangular shaped fin with zig zag perforation pattern is taken for the analysis. It was observed in various literature that perforation in the fins material reduced the weight of the component and also enhance heat transfer rate at the same time [25-32]. A comparison is made between solid fin and perforated fins. Some parameters were considered for analysis which are number of perforations, dimension of perforation and fin spacing. Fourier's law of heat conduction is used to evaluate the conductive heat transfer from the fin surface:

$$Qconduction = -kA\left(\frac{dt}{dx}\right) \quad (1)$$

Total amount of heat transfer from the fins to the atmosphere can be evaluate by using the following equation:

$$Q_{fin} = \sqrt{hpkA_{cs}}(t_o - t_a)\tanh(mL) \quad (2)$$

Where, h= heat transfer coefficient, W/m2°C
p= perimeter of the fin
k= thermal conductivity of the fin material, W/m°C
A_{cs} = cross-sectional area of the fin
Schematic representation of experiment detail is shown in figure 1.

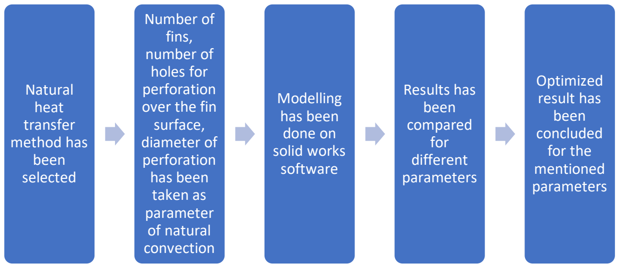

Figure 1: Schematic experimental representation

For the analysis, length of the fin is taken as 200 mm, thickness of the fin is 8 mm, height of the fin is (80+30) mm, base plate dimension is 200×104 mm^2 and diameter of the heating rod is 20mm. On solid aluminium fin perforation of different diameter from 4mm to 12 mm) is drilled to form the perforated fin. Various configuration of perforations are made on the fins which are:
1 row perforation with 15 inline perforations
2 row perforation with 15 inline perforations in first and 14 inline perforations in second row
3 row perforation with zig-zag inline perforations
4 row perforation with zig-zag inline perforations
5 row perforation with zig-zag inline perforations
Modelling of the fins are done by using solid works and analysis of the same by considering one by one parameters is done by ANSYS software. Now mathematical analysis and comparison of the temperature distribution behaviour is explained under: Range of input parameters such as number of perforation rows, diameter of the perforations and fins spacing are given in table 1.

Table 1: Parameters of the thermal analysis

Parameters	Value
Number of perforated rows	1,2(Inline perforation),3,4,5(Zig-Zag perforation)
Diameter of pores	4mm, 6mm, 8mm, 10mm, 12mm
Fins spacing	6mm, 8mm, 10mm, 12mm

2.1 Analysis of temperature distribution based on number of perforations:

First analysis is done which is based on number of zig-zag perforations. Initially holes of same diameters are drilled on the solid fins in 1 row, 2 row, 3 row, 4 row and 5 row and heating of the fins varied from of 15 W to 35W. Figure 2 & 3 represents the ANSYS model of the temperature distribution in the different fins.

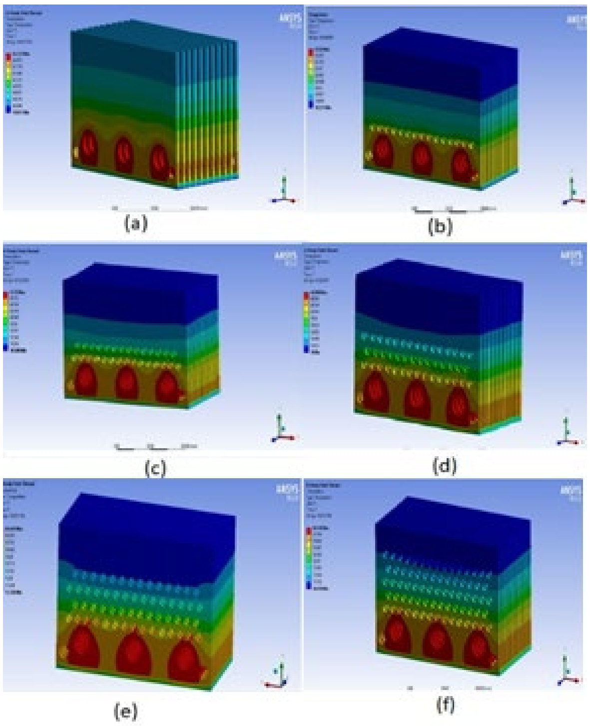

Figure 2: (a) Temperature distribution in solid fins for 35W heater input, (b) Temperature distribution in 1 row perforated fins for 35W heater input, (c) Temperature distribution in 2 row perforated fins for 35W heater input, (d) Temperature distribution in 3 row perforated fins for 35W heater input, (e) Temperature distribution in 4 row perforated fins for 35W heater input, (f) Temperature distribution in 5 row perforated fins for 35W heater input

Mathematical values of temperature distribution in different fins are shown in table 1 and it is concluded that significant reduction in temperature can be obtained in the fin with 5 rows zig-zag perforation with different heat input and graph between temperature and heater input is represented in Table 2.

Table 2: Temperature distribution in solid and perforated fins

HEATER I/P	SOLID	1RP	2RP	3RP	4RP	5RP
15 W	33.13°C	33.02°C	32.72°C	32.24°C	31.90°C	31.32°C
20 W	42.02°C	41.92°C	41.21°C	40.83°C	40.21°C	39.03°C
25 W	55.31°C	54.12°C	53.84°C	52.94°C	51.99°C	51.25°C
30 W	58.72°C	58.12°C	57.72°C	56.93°C	56.12°C	55.43°C
35 W	62.33°C	61.92°C	61.32°C	60.98°C	60.44°C	60.14°C

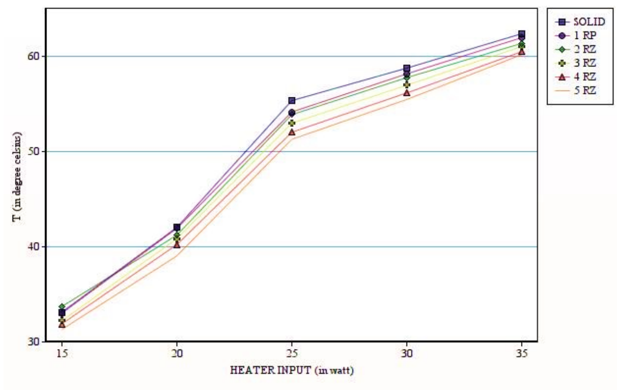

Figure 3: Temperature change in the fins with various heat input.

2.2 Analysis of temperature distribution based on diameter of perforation

Second analysis is being done based on different diameter of perforation. Various perforations are created on fins surface having diameters 4mm, 6mm, 8mm, 10mm and 12mm respectively. Now analysis for the temperature distribution and heat transfer is done by ANSYS for different diameters. ANSYS modelling and comparison of solid fin with 5 row perforated fins for heater input of 35 W and is represented in figure 4.

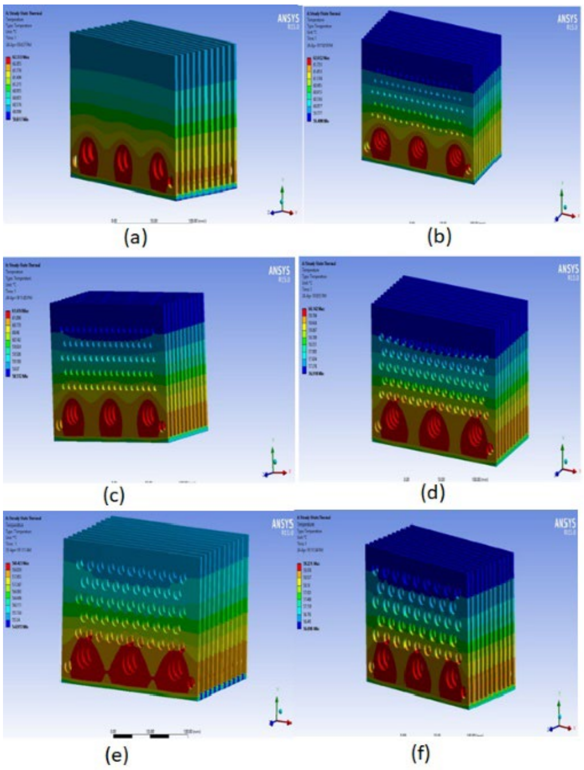

Figure 4: (a) Temperature distribution in solid fins for 35W heater input, (b) Temperature distribution in 4 mm diameter perforated fins for 35W heater input, (c) Temperature distribution in 6 mm diameter perforated fins for 35W heater input, (d) Temperature distribution in 8 mm diameter perforated fins for 35W heater input, (e) Temperature distribution in 10 mm diameter perforated fins for 35W heater input, (f) Temperature distribution in 12 mm diameter perforated fins for 35W heater input

Mathematical value of temperature distribution in fins having perforations of different diameter is represented in table 2 and figure 5 represent the graph between temperature change with perforation diameter and with the help of the same it can be concluded that significant reduction in temperature can be obtained in the fin with 10 mm diameter holes then further increment in the holes diameter starts decreasing the heat transfer coefficient because conductive heat transfer decreases with increase of hole diameter.

Table 3: Temperature distribution for various perforation diameters

HEATER I/P	SOLID	4mm	6mm	8mm	10mm	12mm
15 W	33.13°C	32.20°C	32.02°C	31.32°C	28.79°C	29.80°C
20 W	42.02°C	41.31°C	41.11°C	39.03°C	36.23°C	37.15°C
25 W	55.31°C	54.02°C	52.23°C	51.25°C	49.31°C	50.86°C
30 W	58.72°C	57.12°C	56.76°C	55.43°C	52.71°C	53.33°C
35 W	62.33°C	62.01°C	61.41°C	60.14°C	58.42°C	59.22°C

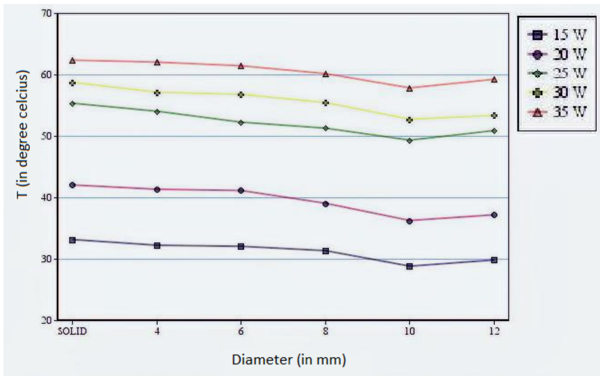

Figure 5: Temperature variation at varying perforation diameter for different heat input

2.3 Temperature distribution based on fins spacing

Third analysis is being done based on fins spacing to obtain maximum amount of heat dissipation rate. It is clear in above mention analysis that optimized value of temperature distribution can be obtained when perforated fin with 5 row perforations having 10 mm hole diameter is considered. To achieve the significant temperature reduction from fin surface, analysis is focussed on spacing between the two consecutive fins starting from 6mm to 12 mm with the steps of 2 mm and it was concluded that space between two fins should be 10 mm. At this fin spacing maximum amount of heat transfer coefficient could be achieved. Further increment in fins spacing reduces the heat transfer due to the merging of boundary layers which restrict the heat transfer. ANSYS modelling of the fins with above mentioned parameters is discussed in Figure 6.

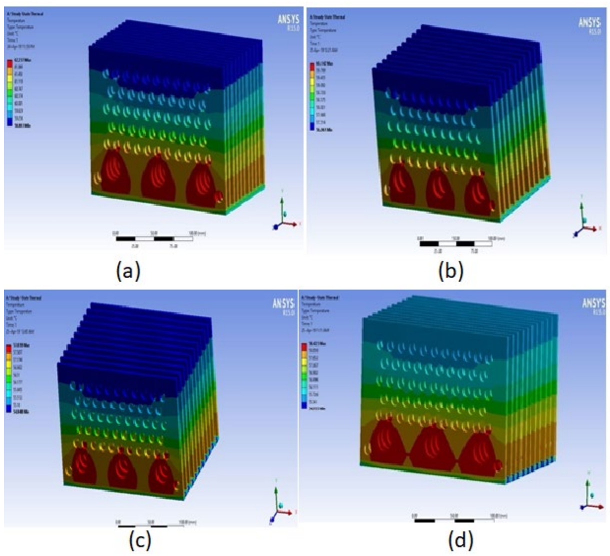

Figure 6: (a) Temperature distribution in the fins having 6mm fins spacing with 35W heater input, (b) Temperature distribution in the fins having 8mm fins spacing with 35W heater input (c) Temperature distribution in the fins having 10mm fins spacing with 35W heater input, (d) Temperature distribution in the fins having 12mm fins spacing with 35W heater input

Table 3 depicts the mathematical value of temperature distribution, and it is showing that minimum temperature can be achieved with 10mm fins spacing. Figure 7 represents a relationship between temperature and fins spacing at different heat input and it can be analysed that maximum heat transfer can be attained at fin spacing of 10 mm.

Table 4: Temperature distribution with different fins spacing

HEATER I/P	6mm	8mm	10mm	12mm
15 W	33.02°C	31.32°C	30.94°C	31.27°C
20 W	41.92°C	39.02°C	38.72°C	39.71°C
25 W	53.23°C	51.23°C	50.84°C	51.64°C
30 W	57.42°C	55.43°C	54.12°C	55.28°C
35 W	62.23°C	60.14°C	57.83°C	58.42°C

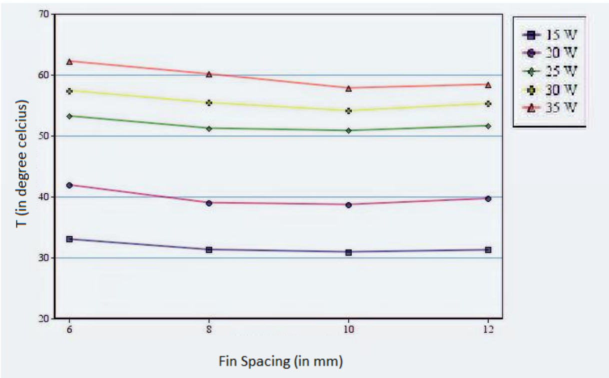

Figure 7: Temperature variation at different fins spacing for different heat input

3. Conclusion

Recent study is focussed on the natural heat transfer behaviour of the solid and perforated fins. Analysis is being done by steady state thermal model in ANSYS which is based on number of perforations, size of perforation and spacing between the fins and various conclusions are being made:

In the current paper 35 W heat input is taken for analysis purpose and it was concluded that when comparison is made for number of perforations then it was found that temperature reduces significantly from solid fin to perforated fins. 1 row, 2 row, 3 row, 4 row and 5 row perforations are made on the fins and minimum temperature obtained on 5 row perforated fin for natural convection. So, 5 rows perforated fins can be used to enhance the amount of heat transfer.

Second comparison is made based on dimension of the perforation. Perforations of different diameters i.e. 4mm, 6mm, 8mm, 10mm and 12mm are created on the surface of the fin and after the analysis of heat transfer it can be concluded that minimum temperature is obtained for 10 mm perforation diameter. So, 10 mm diameter perforated fins can be used to increase the amount of heat transfer.

Third comparison is done based on attached fins spacing. Fins are attached on the surface with different fins spacing which are 6mm, 8mm, 10mm and 12mm. After the analysis through ANSYS it is concluded that significant reduction can be seen for 10 mm fin spacing.

So current experiment describes that, perforated fins are more useful than solid fins to improve the heat transfer. Various combinations can be made to reduce the temperature distribution. This paper conclude that 5 rows perforated fins with 10 mm perforation diameter and 10 mm fins spacing can be used for significant improvement in natural convection heat transfer.

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