Experimental investigation on rectangular fins with holes in natural convection

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Abstract - In the present experimental study the effect of circular holes on rectangular fins under natural convection heat transfer has been presented. The effect of increase in perforation diameter and angle of inclination on the natural convection heat transfer from rectangular fin array are taken into consideration. The natural convection heat transfer under steady state condition from the solid fin array and the perforated fin arrays with 4 mm fin spacing , fin perforation diameter (4, 6 and 8mm) and fin inclination angle (0, 30, 45, 60 and 90˚) were analyzed and compared. The enhancement in the heat transfer coefficient was achieved with the increase in the fin perforation diameter. With the variation in fin inclination angle from 0° to 90° also the heat transfer was enhanced.

***Keywords:* rectangular fins, natural convection, heat transfer, solid fin array, fin inclination**

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1. Introduction

The fins are extended surfaces which increase the heat transfer rate by increasing the area of heat transfer. Fins are used in automobile engines, heat exchangers, refrigerators, transformers, electronic devices etc. In many industrial applications the free convection cooling by air is most widely utilized because they are inexpensive, more reliable, light in weight and easy to manufacture. Although the forced convection has higher heat transfer coefficient as compared to the natural convection but the manufacturing and operating cost will increase significantly and the weight and noise will also increase. Therefore, natural convection is better for most of the applications. Natural convection heat transfer rate can be increased by increasing the fin area but at the cost of increased weight, bigger size and higher cost of fins. Performance of the fins in terms of heat transfer rate with reduction in size, cost and weight of fins can be achieved by making certain changes in the geometry. By the use of perforated fins the heat transfer coefficient can be enhanced with reduction in weight and cost of fins. In the past few years many studies were performed in order to determine the optimum fin configuration which provides heat transfer enhancement through the rectangular fins by providing the perforations of different shapes and sizes under natural convection.

Awasarmol et al. [1] investigated experimentally the heat transfer enhancement of perforated fin array with different perforation diameter and at different inclination angles under natural convection. They concluded that perforated fins give enhanced heat transfer and saving in material as compared to solid fins. Md. Farhad Ismail et al. [2] numerically investigated turbulent heat convection from solid and longitudinally perforated rectangular fins. They concluded that circular and square perforated fins have almost the same amount of heat removal rate but circular perforated fins have significantly less pressure drop than that of square perforated fins. Shaeri et al [3] studied numerically the effects of size and number of perforations on laminar heat transfer characteristics of an array of perforated fins with the maximum perforations and concluded that in a laminar flow and at a constant porosity, a fin with fewer perforations is more efficient to enhance the heat transfer rate compared with a fin with more perforations. Damook et al. [4] carried out experiments to determine the effect of perforation on heat transfer and pressure drop characteristic. They concluded that, the Nusselt number increases with increase in number of pin perforations whereas both the pressure drop across the heat sink and fan power needed to pump the air through them reduces. Huang et al. [5] investigated numerically the overall convection heat transfer enhancement for long horizontal rectangular fin array with perforations through the fin base and found that perforations improved heat transfer performance significantly and the overall heat transfer coefficients could be more than twice as large as that without perforations for long fin arrays. Kundu et al. [6] investigated analytically the performance and optimum design of porous fin. They concluded that as compared to a solid fin there was a considerable increase in heat transfer through porous fins for any profile. Shaeri et al. [7] investigated numerically the heat transfer of a heated array of rectangular perforated and solid fins attached on a flat surface and concluded that perforated fins give better performances and effectiveness by increasing number of perforations. Kundu et al. [8] studied analytically annular step porous fins and found that with the consideration of the porous material and moving condition of fins, heat transfer can be increased for a constraint mass of a fin. Lin et al. [9] investigated numerically the average heat transfer and fluid flow characteristics of the staggered circular tube bank fin heat exchanger with curved delta winglet vortex generators(CDWVGs) and found that interrupted annular groove fin shows excellent performance at higher Reynolds number and the annular groove's radial and circumferential locations have a very low effect on the average heat transfer and fluid flow characteristics. Fujii et al. [10] investigated numerically and experimentally the natural convection heat transfer from an array of vertical parallel plates with discrete and protruding heat source. They proposed a correlation expression for the local Nusselt number and a method for estimating the maximum inner temperature of the heat source. Güvenç et al. [11] experimentally investigated the natural convection heat transfer in rectangular fin array. They concluded that for every fin height, for a given base-to-ambient temperature difference, there exists an optimum value for the fin spacing for which the heat transfer rate from the fin array is maximized. Dogan et al. [12] studied experimentally heat transfer from longitudinal fins inside a horizontal channel and concluded that for mixed convection heat transfer the optimum fin spacing which yields the maximum heat transfer is S = 8 – 9 mm and optimum fin spacing depends on the value of Rayleigh number. Sara et al. [13] investigated heat-transfer enhancement and pressure drop over a flat surface in a channel flow due to perforated rectangular cross-sectional blocks attached on its surface. It was found that the solid blocks could lead to energy loses up to 20% in spite of higher heat-transfer. The energy lost was recovered by perforations opened in the blocks which lead to energy gains up to 40%. Taji et al. [14] investigated experimentally heat transfer from horizontal rectangular fin array in natural and assisting mode of mixed convection. They have considered mainly two types of flow patterns (i) single chimney flow pattern ($L/H \leqslant 5$) and spacing about 8–10 mm, (ii) sliding chimney flow pattern $L/H > 5$ and small spacing less than 6 mm. They concluded that the average heat transfer coefficient was increased up to 69.46% at the cost of very small energy input (0.3 – 0.65W) surface. Singh et al [15] studied experimentally the enhancement of heat transfer by embossed heat sink having repeated impressions on the fin surface subjected to natural convection. They concluded that maximum heat transfer enhancement is with impression angle of 45° and impression pitch of 12mm. Giri et al. [16] investigated numerically the natural convection heat and mass transfer from vertical fin array surrounded by moist air. They concluded that beyond a certain streamwise distance, further fin length does not improve the heat transfer performance. In the present work the thermal performance of rectangular fin array is investigated under free convection heat transfer with perforation diameter and fin inclination as variable parameters.

2. Nomenclature

The following Nomenclature has been selected for the proposed experimental setup.

Ae	total exposed area of solid fin array block, m^2
h	convective heat transfer coefficient, W/m^2K
L	fin length, m
H	fin height, m
t	thickness of fin, m
N	Number of fins
Q	heat transfer rate, W
ΔT	temperature difference = T_s-T_a
Ts	fin surface temperature
Ta	Ambient temperature
FAB	fin array block
S	fin spacing
Ѳ	fin inclination angle

3. Solid and Perforated Fins

Material Used: Aluminum alloy (6061) was casted and these castings were machined and cut to the desired size and shape of the fins. Then holes of different diameters were drilled to make perforated fin array block ready.

Fin array blocks: Two similar fin arrays when fitted back to back is termed as fin array block (FAB). In this experimental investigation ten numbers of FABs has been used.

Hole Pattern: On the basis of investigation of Awasarmol et al. [1] the best perforation arrangement was found to be 2RZ i.e. two row zigzag arrangement. So, for this experimental investigation 2RZ was selected as perforation arrangement for all the perforated FABs. **Perforation diameter**: 4mm, 6mm and 8mm perforation diameters were selected for this experimental investigation.

Fin spacing: Fin spacing has a significant effect on the heat transfer rate. In this study the fin spacing of 4mm was selected.

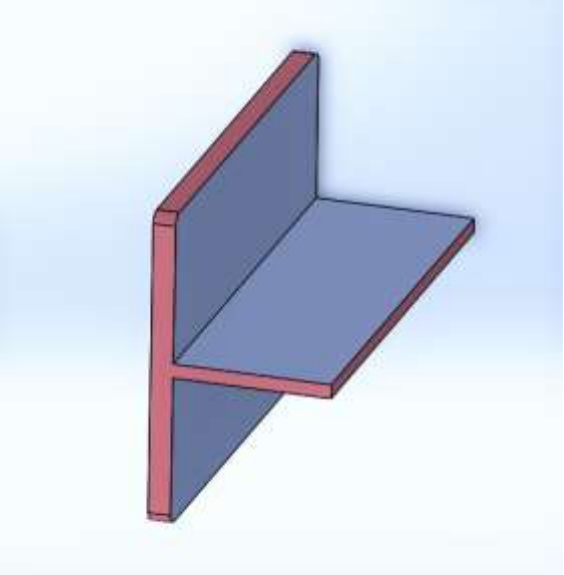

Fig 1. Solid fin

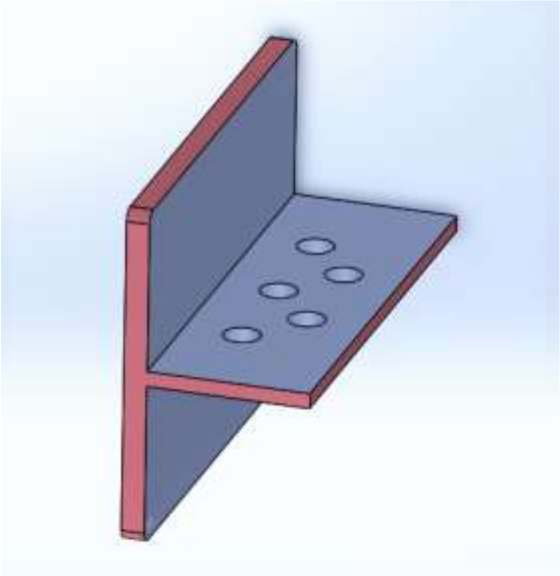

Fig 2. Perforated fin (With 2RZ perforation arrangement**)**

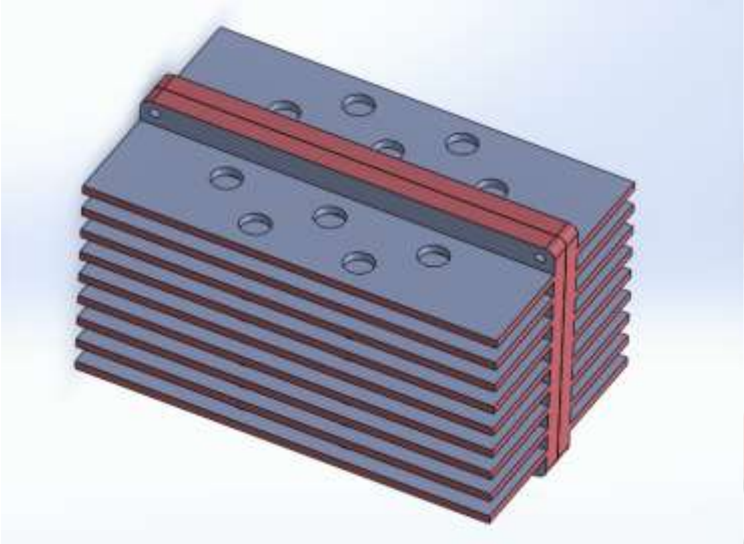

Fig 3. Fin Array Block (FAB)

4. Experimental setup and instrumentation

The experimental set up consists of a digital watt meter and a variable transformer with the input of 220 V and 50–60 Hz and output of 0–240 V, 4 A to supply regulated power to the heater. A 450 Watt heater was fixed back to back between the base plates of two identical fin arrays. Four thermocouples were used to record the base and tip temperatures of the fins and one to record the ambient temperature. A temperature indicator and a stand to hold and rotate the fin array blocks were used. For this experimental study one solid fin array block and 3 numbers of perforated fin array blocks of aluminum were used.

Fig. 4 Fin array blocks

Fig. 5

Experimental Setup

5. Procedure

After fixing solid FAB in the stand at 0° inclination the heating was started and after steady state condition was reached the temperatures were recorded for 15 W power input, then inclination angle was increased to 30° and again fins temperatures were recorded at the same 15 W power input. Similarly for 45, 60 and 90° inclinations various temperatures were recorded. Then input power was raised to 25 W and after steady state condition was reached the fin and ambient temperatures were recorded. Then the input power was raised to 35 W and 45 W and the above procedure was repeated after the steady state condition was reached. The perforated FAB (d=4mm) was fixed on the stand next and the above procedure was repeated. Next perforated FAB (d=6mm) and FAB (d=8mm) were fixed and the temperatures were recorded. All these four FABs were having fin spacing of 4mm and made a set for the study of effect of perforation diameter on the heat transfer rate.

6. Data reduction

The experiments were performed and steady state observations were recorded. Table 1 summarizes the parameters included in the experimentation. In this steady state condition, total heat supplied to the heat system is equal to the total heat flow out of the system. The following equations were used to find the heat transfer coefficient.

$$Q = hA_e\Delta T$$

Where h = convection heat transfer coefficient

Ae = Total exposed area of solid FAB (m^2)

ΔT = temperature difference = Ts-Ta

Where Ts = Fin surface temperature

Ta = Ambient temperature

Table 1

Parameters for experimentation

Length of fin array L (m)	.075			
Height of fin H (m)	.027			
Thickness of fin t (m)	.002			
Heater Input power Q (W)	15	25	35	45
Fin spacing S (m)	.004			
Number of fins N	10			

Total exposed area of solid FAB (Ae) = Exposed area of middle fins + exposed area of two end fins + exposed area of base channels = $[(L \times H \times 2) + (H \times t \times 2) + (L \times t)] \times (N-1) + [L \times H + H \times t + L \times t] \times 2 + [L \times S \times (N-1)]$

So, we get $Ae = .046038\ m^2$
From above relation $h = Q / Ae\, \Delta T$

7. Results and discussion

The effect of increase in perforation diameter for perforated FABs is compared with each other and with solid FAB. The effect of change in fin spacing (S), heater input and fin inclination angle on the performance of rectangular fin is discussed below.

7.1 Effect of perforation diameter

1. The effect of fin perforation diameter on heat transfer coefficient is presented in Fig. 6. As seen from this figure, the solid fin has minimum heat transfer coefficient and the increase in perforation diameter causes an increase in the heat transfer coefficient. The reason for this increase may be due to the change in the interactions. As compared to solid fins the perforated fins have higher contact surface with the air. Thus the perforated fins have higher heat transfer rate than the solid fins. The heat transfer coefficient increases rapidly as the air flow approaches near the hole entrance due to increase in the air flow velocity resulting in a reduced boundary layer thickness.
2. It is also seen from Fig 10, Fig 11, Fig 12 that there is a significant rise of heat transfer coefficient values between fins with perforations of 6 mm compared to that with perforations of 4 mm. Similarly for FAB with 8mm perforations the heat transfer coefficient is further increased. It is clear from the graph that the thermal resistance of the solid fin is higher than the perforated fins. The value of thermal resistance decreases with larger perforations. The temperature drops across the perforations as these holes restricts the flow of heat. The temperature drop along the perforated fin is more than that for the equivalent non-perforated fin.
3. When compared to solid fin the weight of perforated fin is significantly reduced and this is an important goal of fin optimization. So perforated fin array is economical.

7.2 Effect of fin inclination

Fig. 7 and Fig. 8 shows that fin excess temperature ΔT decreases with the increase in fin inclination angle. In the Fig. 8 the variation of fin excess temperature ΔT for solid fin array block with variation in fin inclination angle is presented. As seen from the figure, the ΔT decreases with the increase in fin inclination angle from 0° to 90°. As is seen from Fig. 9 and Fig. 10 the heat transfer coefficient increases with the increase in fin inclination angle. It means that cooling of the FAB goes on improving when the orientation is changed from 0° (horizontal) to 30°, 45°, 60° and 90° (vertical). This increase in heat transfer rate and hence improved cooling is due to the fact that when the power input is supplied to the heater, temperature of air near the fin surface increases. Due to increase in temperature the air density decreases and air starts moving in the upward direction due to buoyancy effect. In comparison with horizontal fins (0°), the vertical fins (90°) provide less resistance to the flow of air. And hence ΔT decreases. In case of all the perforated fins, when air passes along the fin, whirl or turbulence is created near the perforation. Extent of turbulence increases with increase in perforation diameter. Fig 8 shows ΔT variation with variation of fin inclination for perforated fin FAB with 4mm perforation diameter. As seen from this fig. the ΔT further decreases with the increase in fin inclination angle, which shows that for perforated fin the heat transfer rate is further increased with the rise in fin inclination angle.

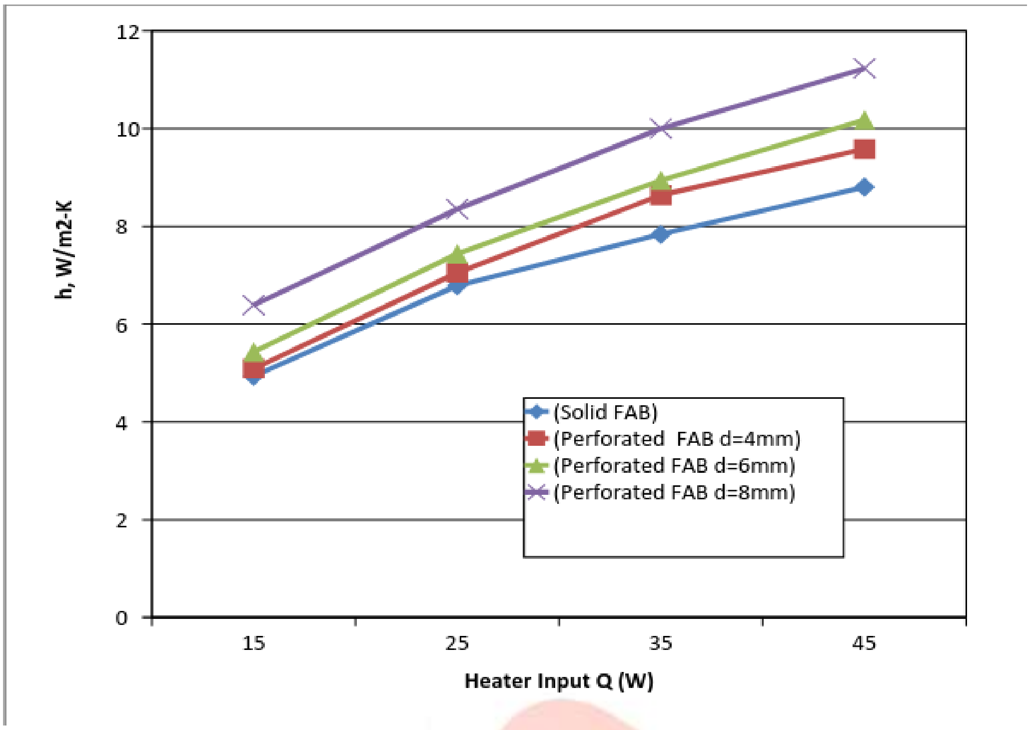

Fig.6 Effect of perforation diameter on heat transfer coefficient

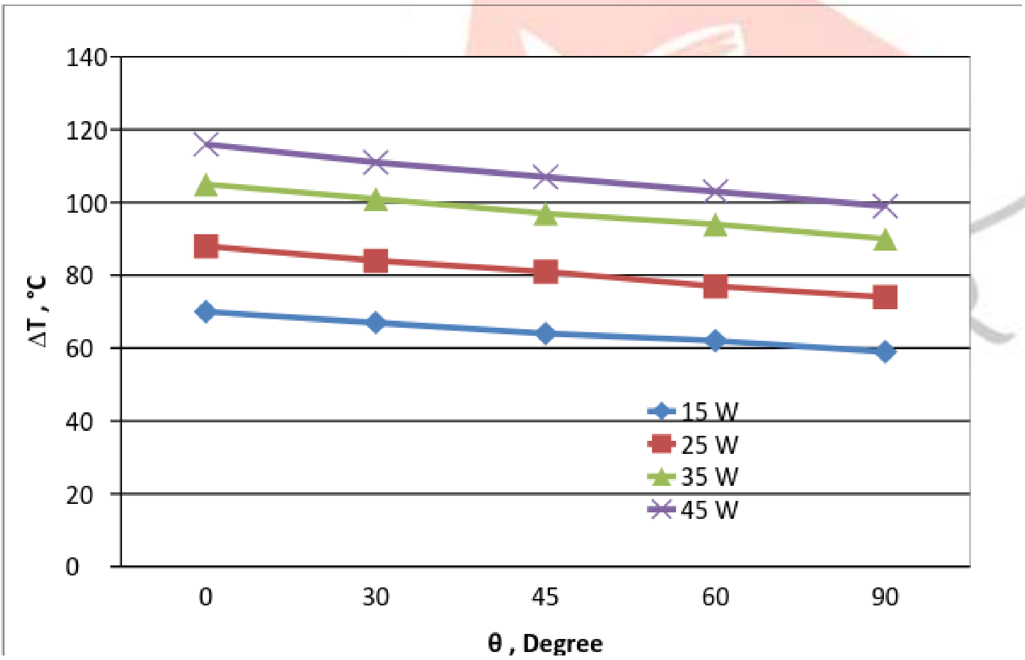

Fig. 7 Effect of fin inclination angle (θ) on fin excess Temperature ΔT for different heater input power for solid FAB with 4 mm fin spacing

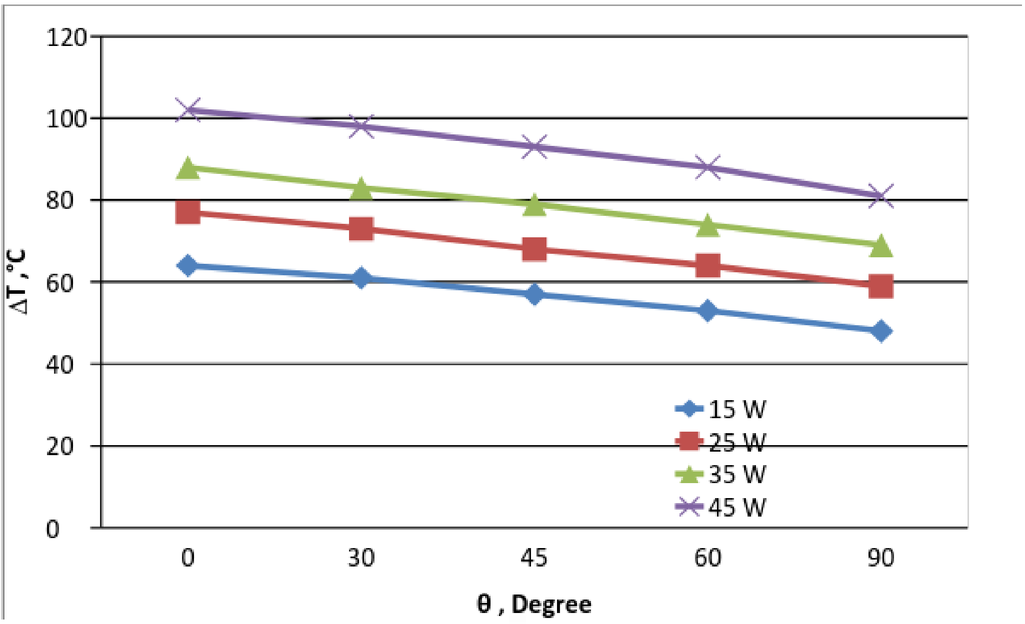

Fig. 8 Effect of fin inclination (θ) on fin excess temperature (ΔT) at different heater input power for FAB with 4mm perforation diameter

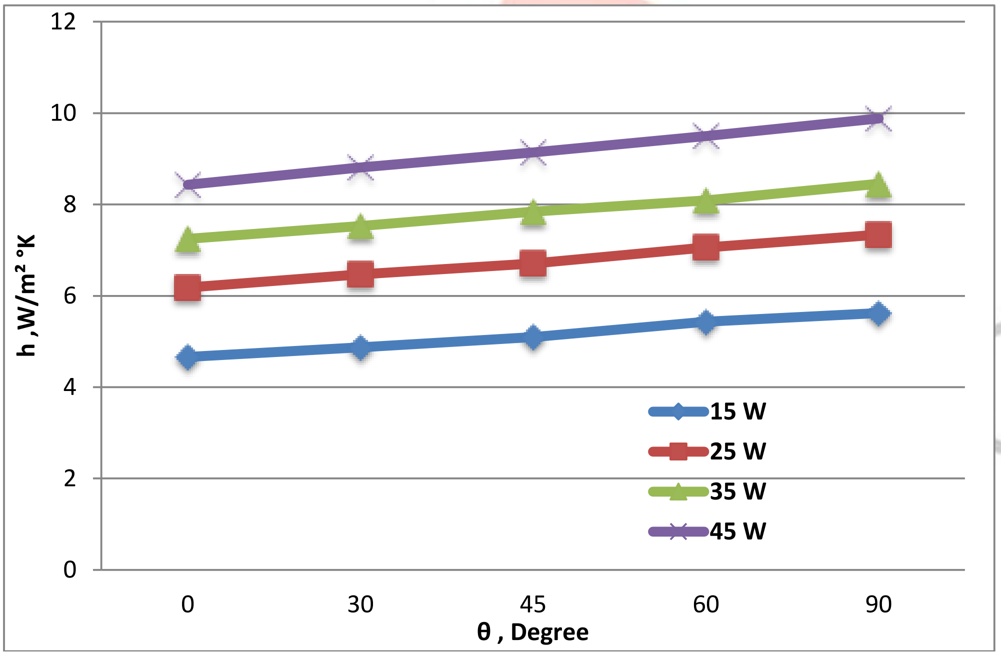

Fig. 9 Effect of fin inclination θ on heat transfer coefficient h at different heater input for solid FAB with 4mm fin spacing

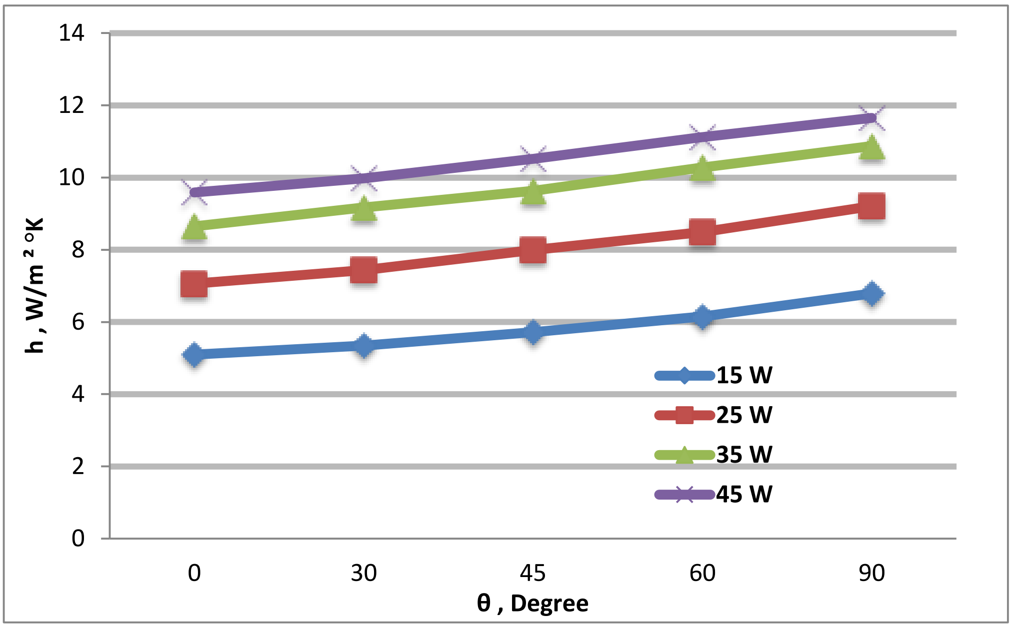

Fig. 10 Effect of fin inclination θ on heat transfer coefficient at different heater input for FAB with 4 mm perforation diameter and 4 mm fin spacing.

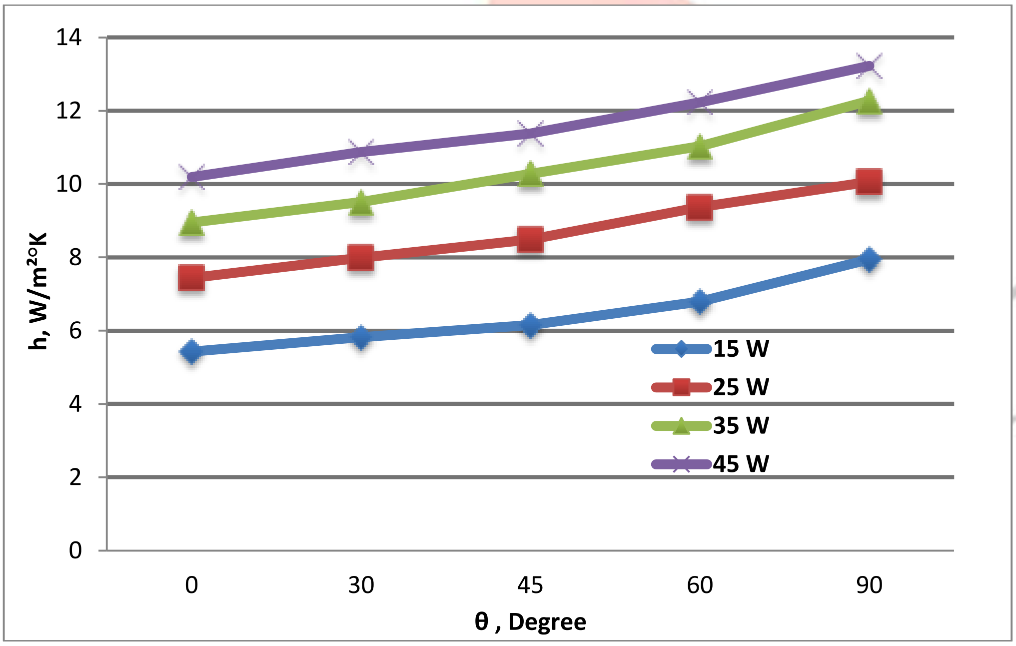

Fig. 11 Effect of fin inclination θ on heat transfer coefficient at different heater input for FAB with 6 mm perforation diameter and 4 mm fin spacing.

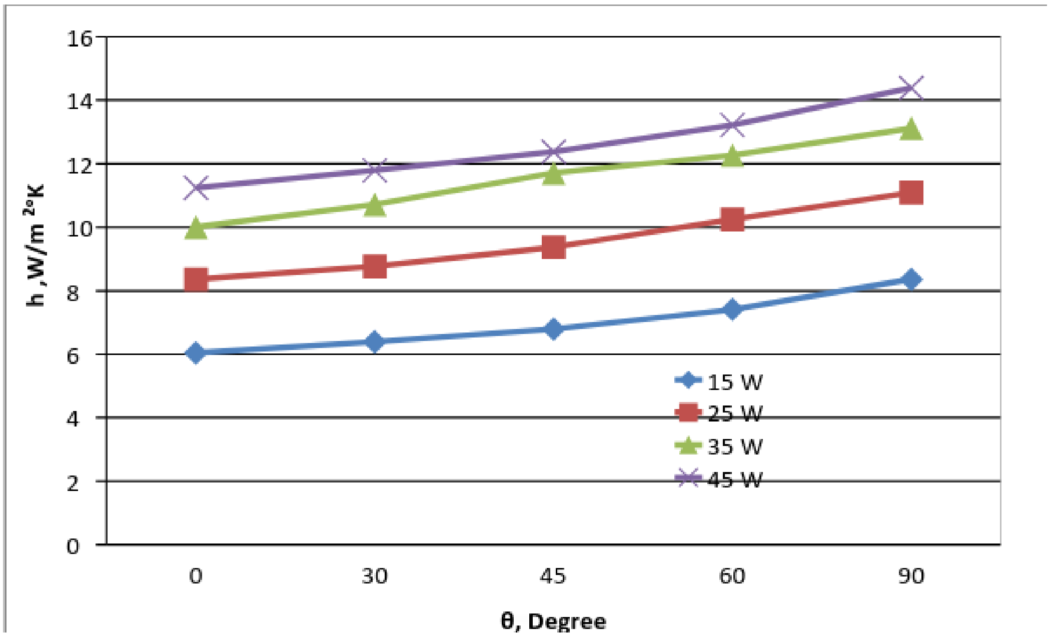

Fig. 12 Effect of fin inclination θ on heat transfer coefficient at different heater input for FAB with 8 mm perforation diameter and 4 mm fin spacing.

8. Conclusions

The effects of perforations diameter, angle of inclination of fins and fin spacing on natural convection heat transfer from rectangular fin array were studied experimentally. A test bed was built and 10 numbers of heat sinks of different fin spacing and different perforation diameters were cast, machined and tested.

Outcome of the Experimental investigation are as follows:

1. The test results showed an increase in heat transfer from perforated fins as compared to solid fins.
2. There is an increase in the natural convection heat transfer coefficient with the increase in the diameter of the perforated fins.
3. The convection heat transfer coefficient increases when the fin inclination is varied from 0° to 90°.
4. The perforated fins not only enhance the heat transfer rates but decrease the fin materials size, weight and cost as well.

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