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Performance Evaluation of Rectangular Fins with Holes in Free Convection

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Abstract: In the present work, an experimental study has been conducted on rectangular fin array with holes under free convection heat transfer. The effect of perforation diameter and angle of inclination on heat transfer from rectangular fin array have been analysed. The performance of solid fin array and the perforated fin arrays with fin spacing 6mm, fin perforation diameter of 4, 6 and 8mm, and fin inclination angle 0, 30, 45, 60 and 90º, are investigated and compared in steady state heat transfer. It was found that with the increase in the fin perforation diameter, the increase in the heat transfer rate was achieved with the advantage of weight reduction of fin array block. With the increase in fin inclination angle from 0 to 90º, an increase in heat transfer rate was also observed.

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

I. INTRODUCTION

Free convection cooling by air is extensively used in industries as it is cheap, light weight, easy to manufacture and reliable. The fins are extended surfaces which increase the heat transfer rate by increasing the area of heat transfer. Fins are widely used in heat exchangers, refrigerators, automobile engines, transformers and electronic devices etc. As the heat transfer coefficient for natural convection is low as compared to forced convection, it is required to increase the heat transfer rate. Increasing the fin area enhances the heat transfer rate 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 making certain changes in the geometry. Though the heat transfer rate can be increased by forced convection, the manufacturing and operating cost will increase remarkably with more weight and noise. Hence, free convection is better for many applications. Among the various types of fins, rectangular fins are used most extensively for heat transfer enhancement because they are simple in design, cheap and easy to manufacture. With the use of perforated fins the heat transfer coefficient can be enhanced with reduction in weight and cost.

In the literature, it has been found that many studies have been performed in order to determine the optimum fin configuration which provides higher heat transfer through the rectangular fins by changing the geometry under free convection.

Huang et al. [1] studied numerically the overall convection heat transfer enhancement for long horizontal rectangular fin array with perforations through the fin base. they found that the perforations improved the performance remarkably and the overall heat transfer coefficients improved by two folds. Shaeri et al. [2] investigated numerically the performance of a heated array of rectangular perforated and solid fins and found that perforated fins give better performances and effectiveness with the increase in number of perforations. Awasarmol et al. [3] experimentally investigated the heat transfer enhancement of perforated fin array with different perforation diameter and at different inclination angles in free convection. They found that perforated fins provide more heat transfer and saving in material as compared to solid fins. It was observed that increase in the heat transfer coefficient for 12 mm perforation diameter at the angle of orientation 45°, was about 32% as compared to solid fin array, with about 30% saving in material by mass. Damook et al. [4] experimentally determined the effect of perforation on heat transfer and pressure drop characteristics. They found that the Nusselt number increases with increase in number of pin perforations while the pressure drop across the heat sink and fan power needed to pump the air through them decreases. Shaeri et al [5] numerically investigated 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. Ismail et al. [6] numerically investigated turbulent heat convection from solid and longitudinally perforated rectangular fins. They inferred that circular and square perforated fins have almost the same amount of heat removal rate but circular perforated fins have remarkably less pressure drop than that of square perforated fins. Kundu et al. [7] studied analytically the performance and optimum design of porous fin. As compared to a solid fin there was a significant increase in heat transfer through porous fins. Kundu et al. [8] worked on annular step porous fins and concluded that with the use of the porous material and moving condition of fins, heat transfer can be enhanced for a given mass of a fin. Lin et al. [9] studied the staggered circular tube bank fin heat exchanger with curved delta winglet vortex generators for heat transfer and fluid flow characteristics and concluded that interrupted annular groove fin shows excellent performance at higher Reynolds number and the annular groove's radial and circumferential locations have a very little effect on the average heat transfer and fluid flow characteristics. Ahmadi et al. [10] studied numerically and experimentally the steady-state external natural convection heat transfer from vertically-mounted rectangular interrupted fins. They found that adding interruptions to vertically-mounted rectangular fins can enhance the heat transfer considerably. Azarkish et al. [11] investigated the optimum geometry and the number of fins for maximum rate of heat transfer from the array. The effects of the base temperature, the fin length and the height of array on the optimum geometry and on the number of fins were investigated by comparing the results obtained for several test cases. Rao et al. [12] studied numerically the natural convection heat transfer from a horizontal fin array by considering adjacent internal fins as two-fin enclosures. One side of the fin array was exposed to limited enclosure and other side to infinite fluid medium. Numerical results were obtained to study the effectiveness for different values of fin heights, emissivities, number of fins in a fixed base, fin base temperature and fin spacing. They obtained regression equations for calculating the average Nusselt number, heat transfer rate and effectiveness for a fin array. Akyol et al. [13] investigated experimentally the heat transfer and friction loss characteristics in a horizontal rectangular channel with hollow rectangular fins over one of its heated surface; they determined correlation equations for Nusselt number, friction factor and thermal performances for straight channel with fin and without fins. Xiaoling et al. [14] experimentally investigated the thermal performance of two types of heat sinks and concluded that plate pin fin heat lower thermal resistance and more pressure drop than plate fin heat sinks.

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.

II. 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
Θ	fin inclination angle

III. EXPERIMENTAL SETUP

For manufacturing the fins, Aluminum alloy (6061) was casted and then machined to the desired size and shape of the fins. Holes of different diameters were drilled to make perforated fin array block (FAB). Two similar fin arrays when fitted back to back is termed as fin array block . In the present study, ten numbers of FABs have been used. As per Awasarmol et al. [1] the best perforation arrangement was found with 2RZ i.e. two row zigzag arrangement. So, 2RZ was selected as perforation arrangement for all the perforated FABs. Perforations with 4mm, 6mm and 8mm diameters were selected. In this study the fin spacing of 6mm was selected.

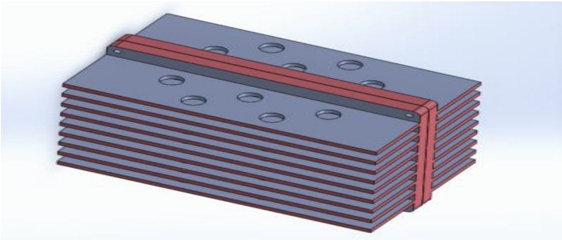

Fig 1. Fin Array Block (FAB)

A. Instrumentation

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 was used to supply regulated power to the heater. A 450 W heater was fixed between the base plates of two identical fin arrays. Four thermocouple wires were used to record the base and tip temperatures of the fins and one to record the ambient temperature. A temperature indicator was used for the display of temperatures. A stand was designed and fabricated to hold and rotate the fin array blocks were used. In the present study, three fin array blocks with 4mm, 6mm and 8mm perforation diameter and 6mm fin spacing were used.

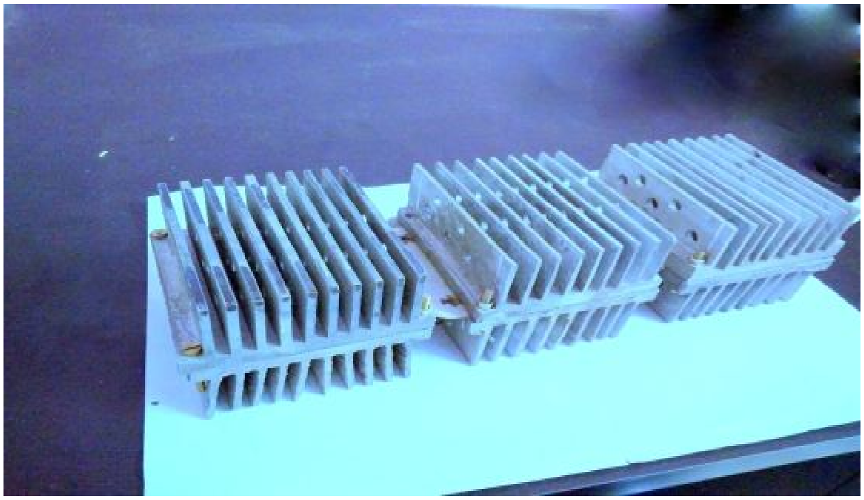

Fig. 2 Fin array blocks

B. Experimental procedure

The FAB (d=4mm) was fixed in the stand at 0° inclination and heating was started and when steady state condition was reached the temperatures were recorded for 15 W power input. After that inclination angle was increased to 30° and again temperatures were recorded at the same 15 W power input. In the same manner, various temperatures were recorded for the inclinations of 45, 60 and 90°. The above procedure was repeated for 25, 35 and 45 W. The similar experiments were repeated for perforated FAB (d=6mm) and perforated FAB (d=8mm).

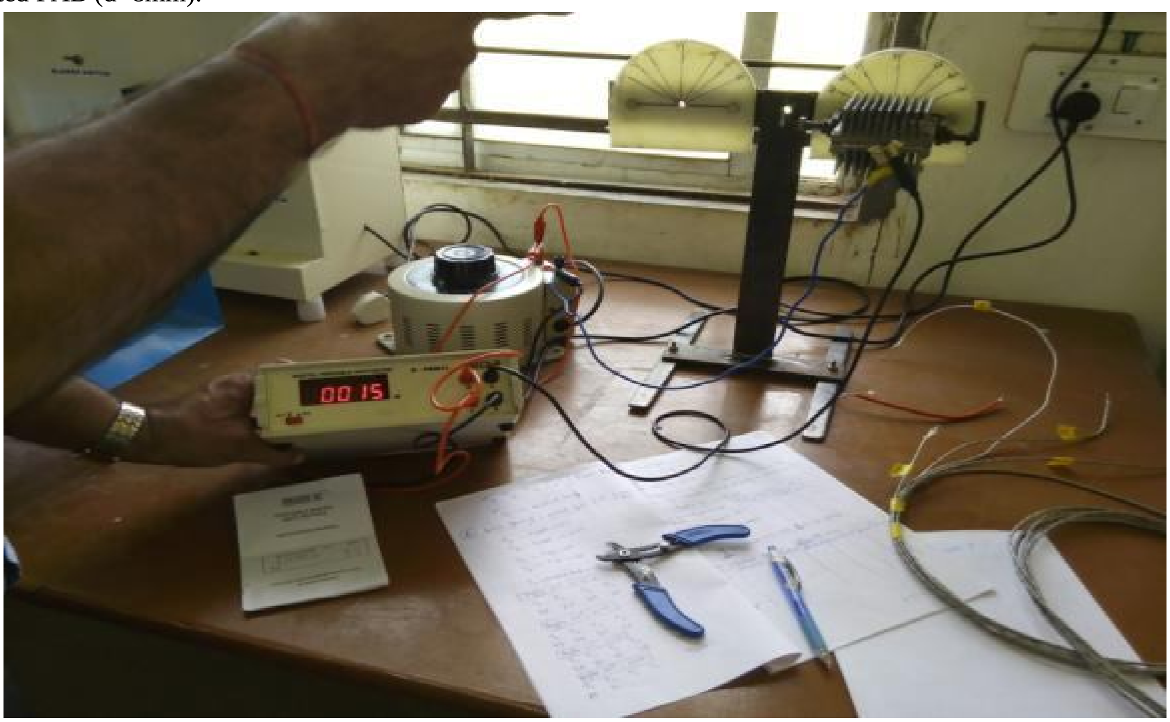

Fig. 3 Experimental Setup

IV. DATA REDUCTION

Table 1 shows the values of parameters used in the experimentation. In the steady state, total heat supplied to system is equal to the total heat flow out of the system. The following relations are used to find the heat transfer coefficient.

$Q = hAe\Delta T$

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 and 45
Fin spacing S (m)	.006
Number of fins N	9

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 = .04256 m^2

From above relation $h=Q/Ae\,\Delta T$

V. RESULTS AND DISCUSSION

The effect of perforation diameter for perforated FABs is evaluated and compared. The effect of change in perforation diameter, fin inclination angle with heater input power on the performance of rectangular fin is discussed below.

A. Effect of perforation diameter Fig. 4 shows the effect of fin perforation diameter on heat transfer coefficient. It has been found that the solid fin has minimum heat transfer coefficient and the increase in perforation diameter increases the heat transfer coefficient. The perforated fins have higher contact surface with the air as compared to solid fins. Therefore, 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 near the hole.There is a significant increase in heat transfer coefficient values as the perforation diameter increases from 4mm to 6 mm. Similarly, for 8 mm perforation diameter the heat transfer coefficient is further increased (Fig. 6, 8 and 10). It is evident from the figures that the thermal resistance of the solid fin is higher than the perforated fins. The thermal resistance decreases with the increase in perforations. It is found that 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 fins without perforations.Figure 5 shows the effect of fin inclination on fin excess temperature at different heater input power for FAB with 4mm perforation diameter. Whereas figures 7 and 9 show the effect of fin inclination (θ) on fin excess temperature (ΔT) at different heater input power for FAB with 6 mm and 8 mm perforation diameters, respectively. It was observed that the fin excess temperature decreases with theincreasein the perforation diameter as the temperature drops across the perforations and larger the perforation diameter higher is the temperature drop.The mass of perforated fin is significantly reduced as compared to solid fin. Thus, perforated fins are economical as well as light weight.

B. Effect of fin inclination

It has been found that fin excess temperature ΔT decreases with the increase in fin inclination angle (Fig. 5, 7 and 9). Fig. 5 shows the variation of fin excess temperature ΔT for perforated fin array block (d=4mm) with variation in fin inclination angle. Fin excess temperature decreases with the increase in fin inclination angle from 0° to 90°. Fig. 7 and Fig. 9 show that the heat transfer coefficient increases with the increase in fin inclination angle. It can be concluded that cooling of the FAB improves when the orientation is changed from 0° to 90°. The reason for this is that when the power input is supplied to the heater, temperature of air

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near the fin surface increases. Due to increase in temperature the density of air decreases and air starts moving upwards. The vertical fins (90°) provide less resistance to the flow of air as compared to the horizontal fins (0°) and, thus, ΔT decreases. In the perforated fins, when air passes along the fin, whirl or turbulence is created near the perforation. Degree of turbulence increases with increase in perforation diameter. Fig 7 shows variation of ΔT with variation of fin inclination for perforated FAB with 6mm perforation diameter. As shown in figure 7, ΔT further decreases with the increase in fin inclination angle, and for perforated fin the heat transfer rate is further increased with the increase in fin inclination angle.

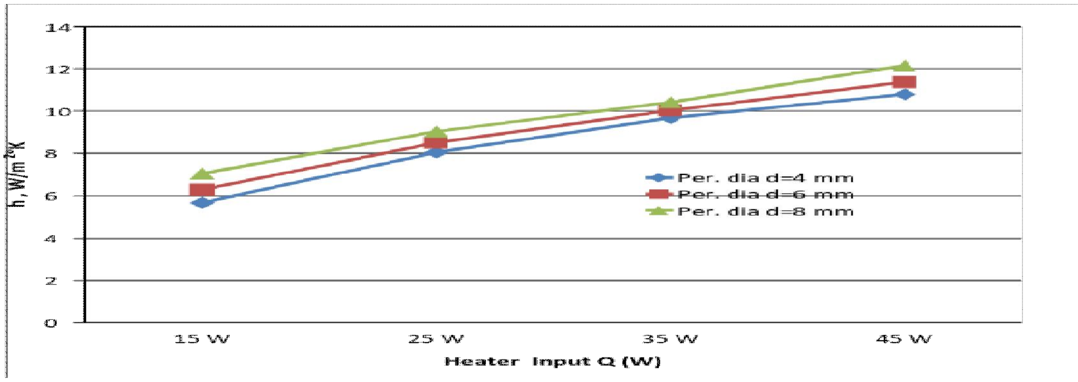

Fig. 4 Effect of perforation diameter on heat transfer coefficient h(S=6mm)

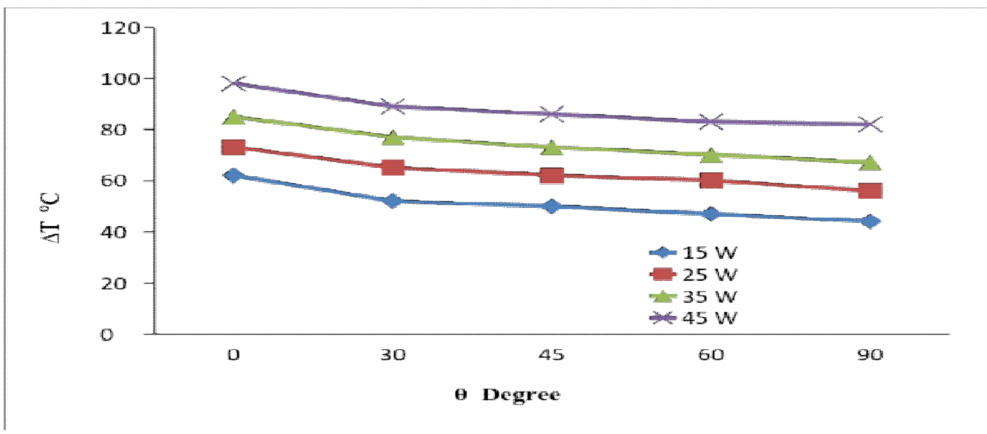

Fig. 5 Effect of fin inclination (θ) on fin excess temperature (ΔT) at different heater input power for FAB with 4mm perforation diameter

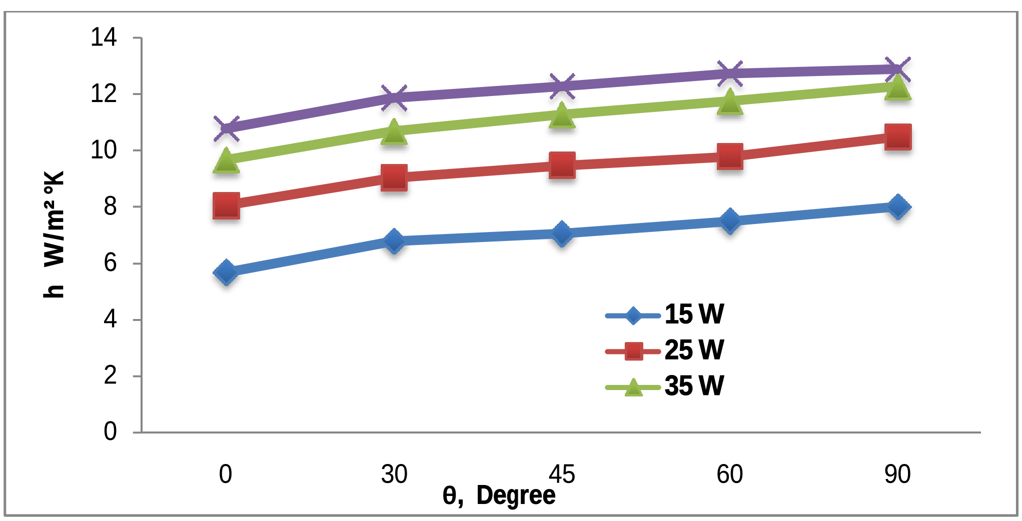

Fig. 6 Effect of fin inclination (θ) on heat transfer coefficient h at different heater input power for FAB with 4mm perforation diameter

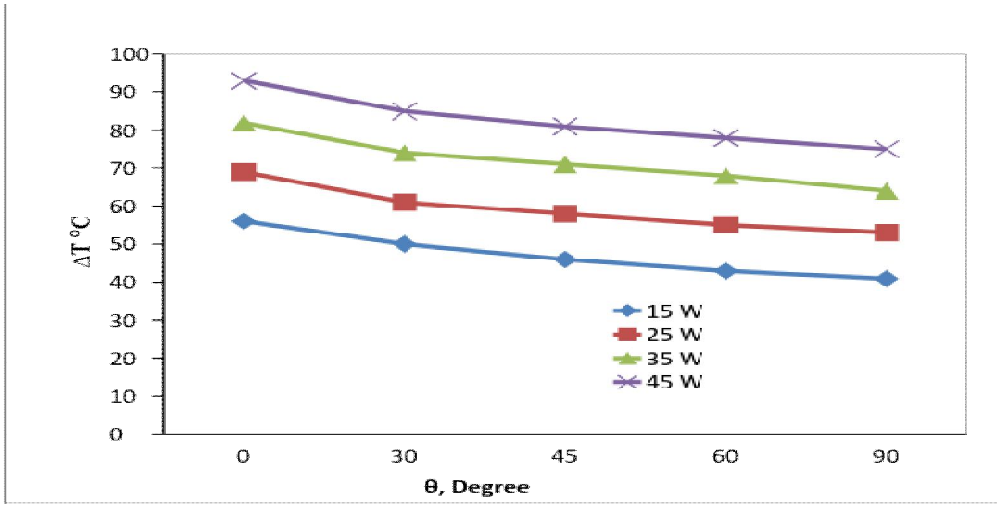

Fig. 7 Effect of fin inclination (θ) on fin excess temperature (ΔT) at different heater input power for FAB with 6 mm perforation diameter

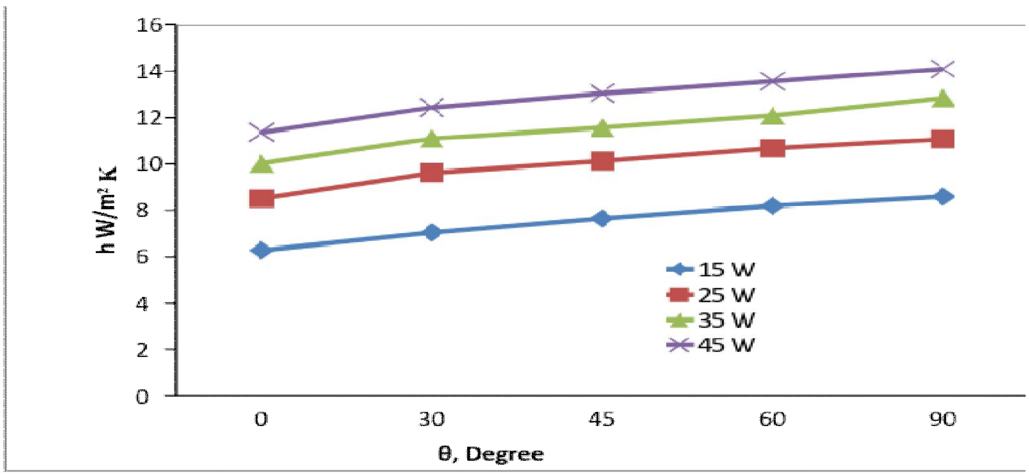

Fig. 8 Effect of fin inclination (θ) on heat transfer coefficient h at different heater input power for FAB with 6 mm perforation diameter

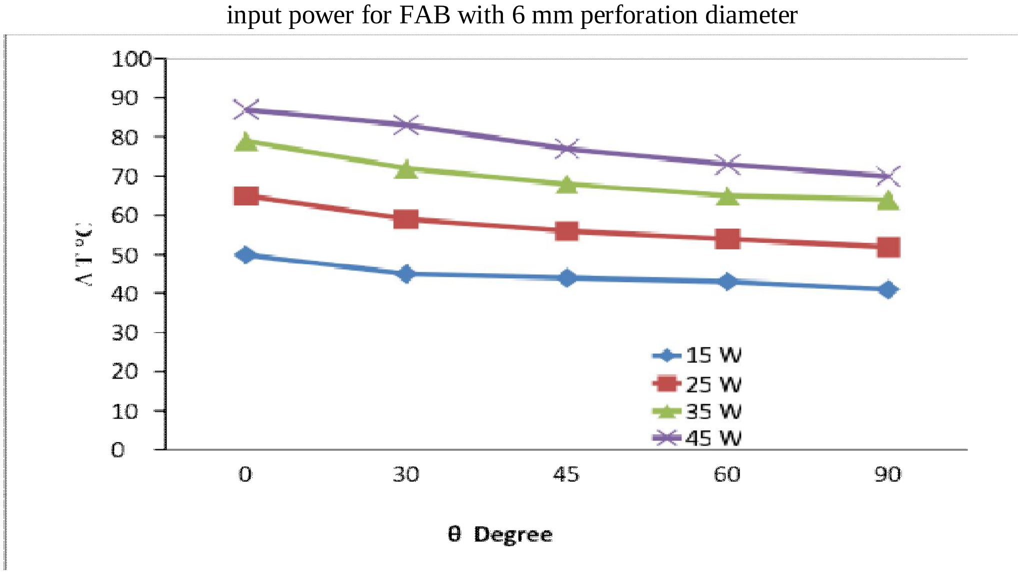

Fig. 9 Effect of fin inclination (θ) on fin excess temperature (ΔT) at different heater input power for FAB with 8 mm perforation diameter

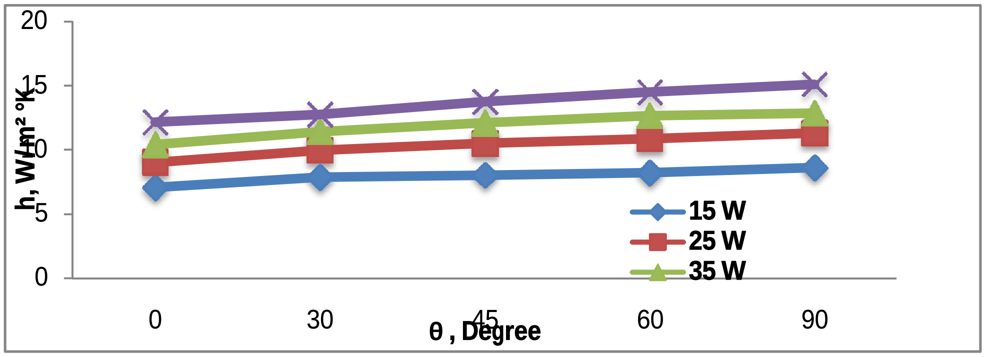

Fig. 10 Effect of fin inclination (θ) on heat transfer coefficient h at different heater input power for FAB with 8 mm perforation diameter

VI. CONCLUSIONS

In the present work, an experimental study has been carried out on rectangular fin array with holes under free convection heat transfer. The effect of perforation diameter and angle of inclination on heat transfer from rectangular fin array have been analysed. The performance of solid fin array and the perforated fin arrays with fin spacing 6mm, fin perforation diameter of 4, 6 and 8mm, and fin inclination angle 0, 30, 45, 60 and 90º, are investigated and compared in steady state condition. It was found that with the increase in the fin perforation diameter, the increase in the heat transfer rate was achieved with the advantage of weight reduction of fin array block. With the increase in fin inclination angle from 0 to 90º, an increase in heat transfer rate was also observed. A testbed was fabricated and 3 numbers of FABs of 6mm fin spacing and different perforation diameters were cast, machined and tested. Following conclusions are drawn from the study.

A. An increase in heat transfer from perforated fins was observed as compared to solid fins.
B. Heat transfer coefficient was found to be increased with the increase in the diameter of the perforated fins
C. convection heat transfer coefficient increases with the increase in fin inclination from 0 to 90°
D. The perforated fins enhanced the heat transfer rates as well as decreased the fin materials, weight and cost.

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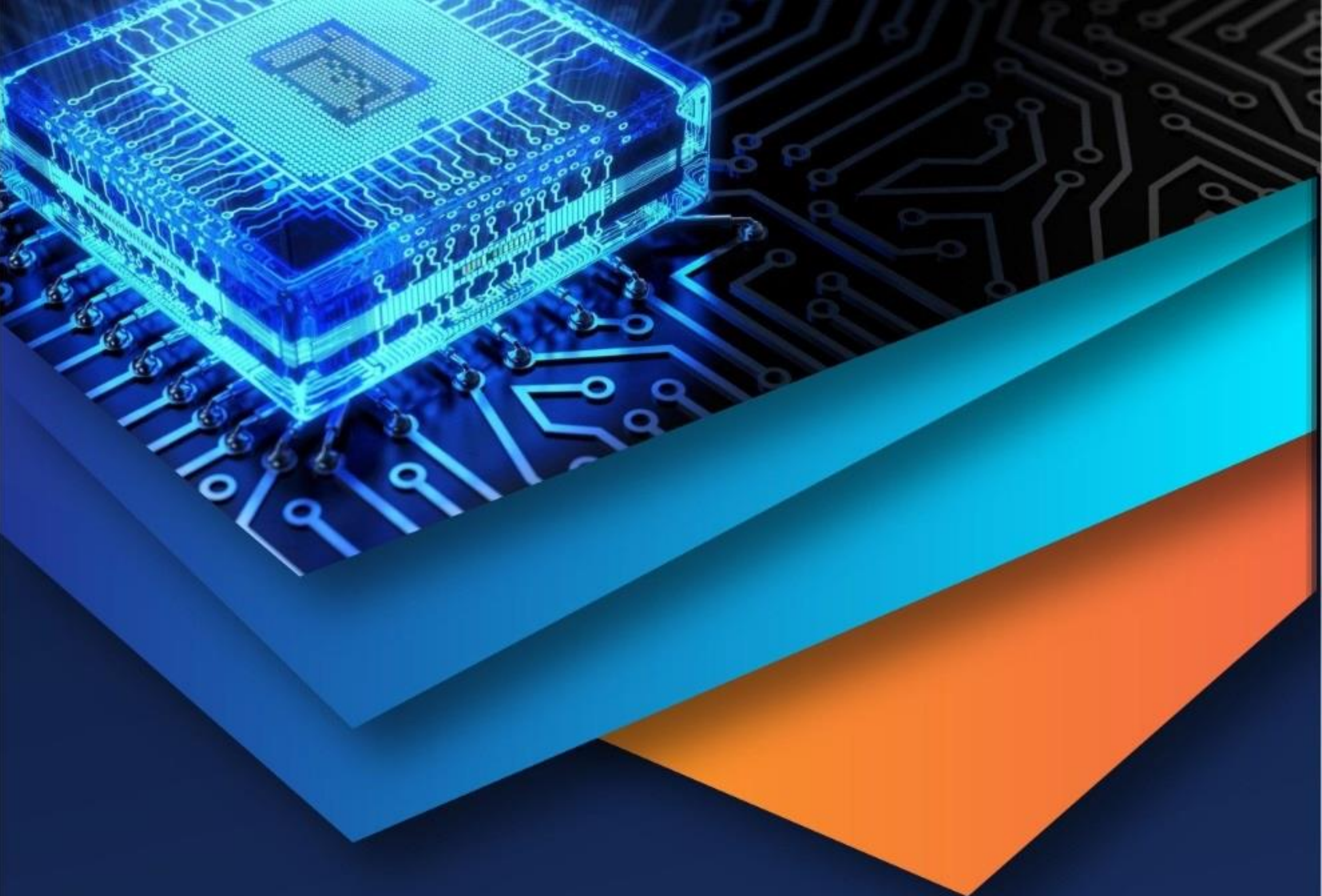

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