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Thermal Analysis of Fin Arrays with and without Perforations for Different Velocities

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Abstract

In this paper experimental study on rectangular fin array and its thermal analysis with different perforations using forced convection heat transfer for non-perforated fin and perforated fin was investigated for 4-rectangular fins for 05 different velocities of 6.2 m/sec, 8.7 m/sec, 10.3 m/sec, 12.6 m/sec & 15.4 m/sec. The pattern of perforated rectangular fin contains 2-circular hole of diameter 5mm & 7mm. Results show that the heat transfer coefficient of perforated fin is more in comparison with fin without perforation, it increased with increased in perforation diameter. Also, it is found that heat dissipation enhancement, higher efficiency and effectiveness for fin with perforation, with increasing the diameter of perforation in addition to the considerable reduction in weight in comparison with fin without perforation.

Keywords: Fin Efficiency, Forced convection, Temperature distribution, Perforation, Effectiveness.

1. Introduction:

Mehedi Ehteshum et al. [1], the heat transfer enhancement is an important topic of thermal engineering. Every day there are new inventions and development in mechanical and electrical device. As the size and mass of these system components are shrinking, their power consumption rate is constantly increasing. In this study, the improvement of heat transfer coefficient and other thermal attribute of rectangular fin array with circular perforations for different velocities under transient flow condition were studied. The thermal analysis of rectangular fin arrays with perforation size and number by comparing the perforated fins with its solid counterpart was the best means to evaluate improvement or non-improvement in heat transfer brought about by introducing the perforations.

R. Muthukumarn et al. [2], conducted an experimental study on performance of pin fin heat sink under forced convection. They experimentally studied the convective heat transfer and pressure drop in a heat exchanger with different pin-fin arrays. Their results show a significant jump in heat transfer is registered pin-fin for all the values of Reynolds number. Ganesh kumar et al. [3], presented and investigated the conjugate mixed convection heat transfer through perforated fins. Their results showed that at a given location along the perforated fins the local temperature difference was more for hollow-cylindrical perforated pin fin than that of solid perforated pin fin. This was so because more surface area of hollow-cylindrical perforated pin fin was exposed to air which increases the convective heat transfer rate both from inside as well as outside surface of the pin fin, height, fin spacing.

2. Material and Methods:

2.1 Experimental Setup:

In this experiment, a rectangular solid fin array with 4 fins and fin with perforation of 5 mm and 7 mm diameter are designed and fabricated as shown in Figure (1) and (2).

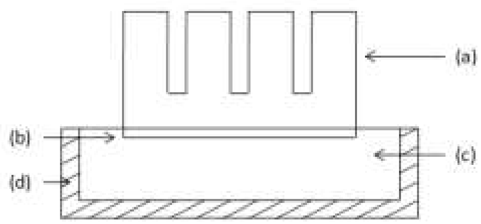

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Figure 1: solid fin with heater and heat sink

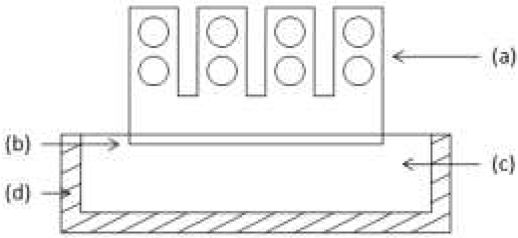

Figure 2: perforated fin with heater and heat sink

(a) Fin array, (b) heater plate, (c) insulation of plaster of Paris, (d) wooden box

Figure (1) and (2) shows the full details of fin arrangement with and without perforation of aluminium material having the thermal conductivity (K=228 w/m^2 k). The fin dimensions are shown in the table (1).

The rectangular duct was made with acrylic material of dimensions of 230mm×210mm×900mm. The F. D. fan is used driven by D.C. motor for different air velocities.

Table 1: Geometry of various types fin array

Type of Fin	Solid Fin	Fin with two hole of 5 mm	Fin with two hole of 7 mm
No. of fin	4	4	4
No. of perforations	0	8	8
Diameter of perforation D (mm)	-	5	7
Length of rectangular array L (mm)	65	65	65
Width of rectangular array W (mm)	61	61	61
Height of rectangular array H (mm)	31	31	31
Channel width W_c	5	5	5
Fin width W_f (mm)	11.5	11.5	11.5
Fin height H_f (mm)	21	21	21
Total surface area A_s (mm^2)	19337	27187	30151
Base area A_b (mm^2)	3965	3965	3965
Mass (gm)	290	260	230

Figure 3: Schematic view of the fin arrays (a) Fin without perforation, (b) Fin with two perforations of 5mm, (c) Fin with two perforations of 7mm.

2.2 *Measuring Equipments:*

The experiment is conducted for air velocities of 6.2 m/sec, 8.7 m/sec, 10.3 m/sec, 12.6 m/sec & 15.4 m/sec. The heat supplied to the heater and velocities are varied with a help of regulator. The heat input is measured by analog wattmeter. All temperatures are measured using type-K thermocouples diameter of 1mm.

2.3 *Experimental Procedure:*

The experimental setup (Figure-04) is started by setting all connections for **30-45** minutes till it obtains steady state condition. Once steady state is obtained, readings are taken for one heat input of **12.50W** and for **05**-different velocities for both fin without perforation and fin with perforation.

Figure 4: Experimental setup

3. Result and Discussion:

The experimental investigation carried out for fin without perforation and with 02 perforation of 5 mm and 7 mm diameter for forced convection with constant heat input of 12.50W is maintained throughout. The effects of various parameters are studied and discussed here.

The following relations are used to determine and study the thermal analysis of fin without perforation and with perforation.

In order to better reflect the actual effective velocity at the measurement section in the duct, the average velocity is calculated using the effective fluid flow area, $A\text{-}A_{front}$

$$V_{avg} = \frac{q}{A-Afront}\ (m/sec) \qquad 1)$$

$$q = A\times V_d \quad (m^3/sec) \qquad 2)$$

The duct Reynolds number (Re) is defined as,

$$Re = \frac{Vavg \times De}{v} \qquad 3)$$

D_e= 0.21m

v = kinematic viscosity of air at mean film temperature

Heat input (Q_t) to the heater is directly obtained from analog wattmeter. The convection loss (Q_{loss}) from the surface of heater, which is not contributing to actual heat transfer from the fin and heat radiated from fin array (Q_{rad}) are also calculated. Here, Q_{rad} is negligible compared to convective heat transfer from fin (Q_{conv}). Therefore, it is neglected. The Q_{conv} can be derived from following relation

$$Q_{conv} = Q_t - (Q_{loss})\ (watt) \qquad 4)$$

$$Q_{loss} = h_t \times A_h \times (T_h - T_0) \qquad 5)$$

Now, the convective heat transfer coefficient (h) is calculated as,

$$h = \frac{Qconv}{As\ (Ts-T_0)}\ \ (w/m^2k) \qquad 6)$$

Fin efficiency η_{fin}

It is defined as the ratio of actual heat transfer rate from the fin to the heat transfer rate from the fin when the entire fin was at base temperature, i.e.

$$\eta_{fin} = \frac{(Ts-T_0)\times\frac{\tanh(ml)+(\frac{h}{mk})}{1+(\frac{h}{mk})\times\tanh(ml)}\times\sqrt{hPKAc}}{(Tb-T_0)\times\frac{\tanh(ml)+(\frac{h}{mk})}{1+(\frac{h}{mk})\times\tanh(ml)}\times\sqrt{hPKAc}} \qquad 7)$$

$$\text{Where, } m = \sqrt{\frac{h\times p}{K\times Ac}} \qquad 8)$$

Fin effectiveness ε_{fin}

It is the ratio of heat lost from fin to heat lost without fin as,

$$\varepsilon_{fin} = \frac{h\times As\times(Ts-T_0)}{h\times Ab\times(Tb-T_0)} \qquad 9)$$

3.1 Effect of Reynolds number on heat transfer coefficient

The effects of Reynolds number on the heat transfer coefficient as shown in Fig. 5. It is found that the Reynolds number increases, the heat transfer coefficient increases for both fin with perforation and without perforation but for fin with perforation has higher value of heat transfer coefficient than fin without perforation at a particular Reynolds number. Also, as diameter of perforation increases heat transfer increases.

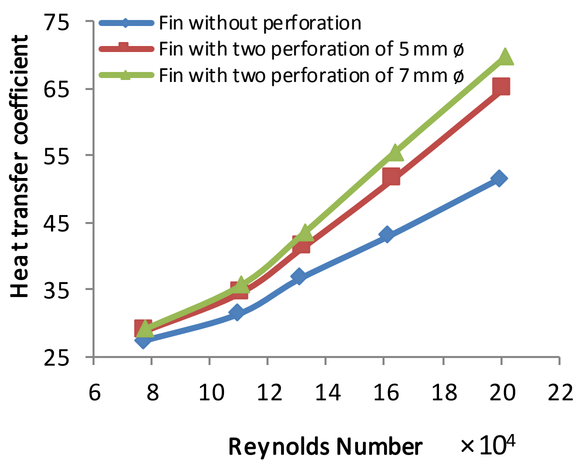

Fig. 5: Effect of Reynolds number on convective heat transfer coefficient

3.2 Effect of Reynolds number on effectiveness and efficiency

The comparative relations of effectiveness and efficiency of fin without perforation and fin with perforations as shown Figs. 6 and 7. Results show that the efficiency and effectiveness of both perforated and non-perforated fin decreases with increase in Reynolds number. The fin with perforation of 7 mm has higher value of efficiency and effectiveness in comparison with the fin with perforation of 5 mm. Therefore for higher diameter fins with perforation is better for heat transfer.

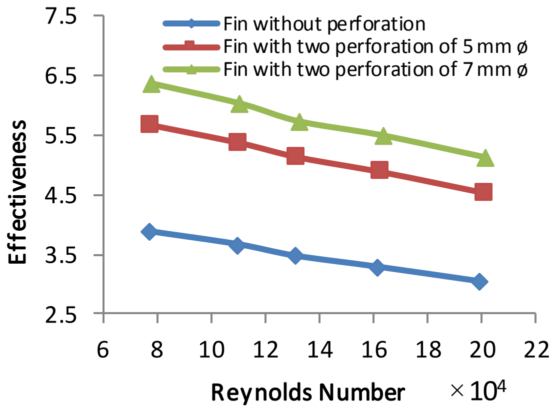

Fig. 6: Effect of Reynolds Number on fin effectiveness

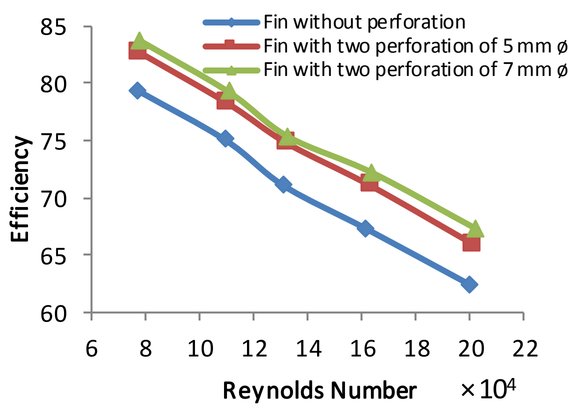

Fig. 7: Effect of Reynolds Number on fin efficiency

3.3 Effect of velocity on temperature and heat transfer coefficient

Fig. 8 shows the effect of velocity on average temperature of fin for both perforated and non-perforated fin. Results shows that velocity increases the temperature decreases, the temperature drop is more in case of perforated fin than fin without perforations.

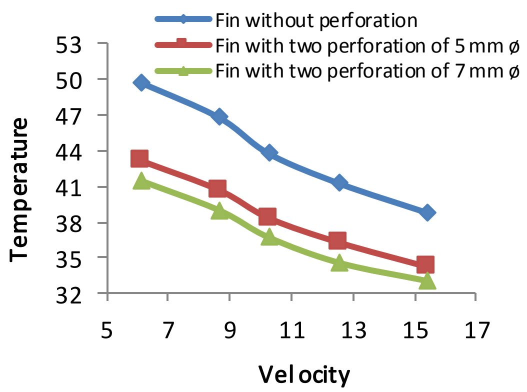

Fig. 8: Effect of Velocity on temperature of fin

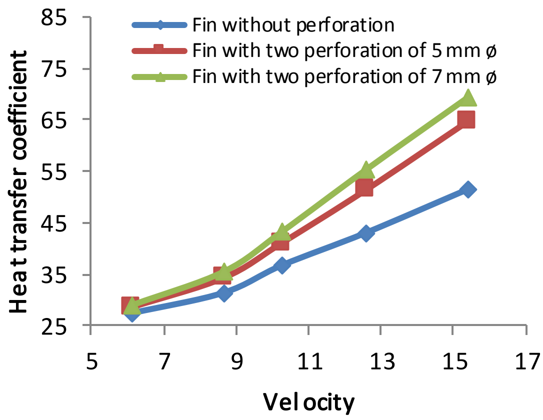

Fig. 9: Effect of Velocity on heat transfer coefficient

The comparative results of velocities of air on heat transfer coefficient for fin without perforation and fin with perforations of 5mm and 7mm shown in Fig. 9. Results shows that velocity increases the heat transfer coefficient increases for both perforated and non-perforated fin, but fin with perforation has higher value of heat transfer coefficient than the fin without perforation.

4. Conclusion:

Experimental investigations have been carried out in order to investigate the thermal analysis of rectangular fin array without perforation and with 02 perforations of 5 mm and 7 mm diameters for 05 different velocities. It is found that heat transfer coefficient increases with increasing the Reynolds number whereas efficiency and effectiveness decreases with increasing Reynolds number. Therefore, for perforated fins of 5mm and 7 mm diameter, efficiency and effectiveness is more than non-perforated fin.

Nomenclature

A_{front}	area restricting the air flow
A	cross-sectional area of duct
A_s	total heat transfer area of fin array
A_h	surface area of heater
A_b	fin base area
A_c	cross-sectional area of fin
Q_T	heat supplied
Q_{loss}	heat loss from setup
Q_{con}	total heat convected from fin array
h	convective heat transfer coefficient

h_t	convective HT coefficient of heater
R_t	thermal resistance of fin
P	perimeter of fin
De	hydraulic diameter of duct
q	volumetric flow rate of air in duct
Re	Reynolds number
Nu	Nusselt number
V_{avg}	effective air flow velocity
V_d	velocity of air in duct
K	thermal conductivity of fin
L	characteristics length of fin
T_s	average surface temperature of fin array
T_o	temperature of bulk air flow
T_b	base temperature
T_h	surface temperature of heater
	Greek symbols
η_{fin}	fin efficiency
ε_{fin}	fin effectiveness
ν	kinematic viscosity of air

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