Experimental Study of Heat Transfer of Rectangular Fin Arrays with 02 Number Perforations and 03 Velocities

Ratik Manusmare[1] Dr. M Basavaraj[2]
[1]M. Tech. Student [2]Professor
[1,2]Department of Mechanical Engineering
[1,2]B.I.T. Ballarpur, Dist. Chandrapur, Maharashtra, India

Abstract— The present paper reports an experimental study to investigate the heat transfer enhancement over rectangular fin arrays with and without circular perforation of 5mm and 7mm diameter by forced convection. The temperature drop for fin with perforation is more compared to fin without perforation for same heat input of 12.50W and for 03 different velocities. The cross sectional area of the rectangular duct was 210 mm x 230 mm. The data used in performance analysis were obtained experimentally for fin arrays of material aluminum, by varying size of perforation as well as by varying Reynolds number from 7.7×104 to 21×104. It is observed that the Reynolds number and size of perforation have a larger impact on heat transfer coefficient and Nusselt number for both fin with perforation and fin without perforation.

Key words: Fins, Temperature Distribution, Perforation, Forced Convection, Velocity

I. Introduction

The surface area exposed to the surroundings is frequently increased by the attachment of protrusions to the surfaces, and the arrangement provides a means by which heat transfer rate can be substantially improved. The protrusions are called fins or spines, and these extensions may be of different configuration. Ibrahim et al. [1], investigated the effect of perforation area on temperature distribution of rectangular fin under natural convection, their experimental and theoretical results indicated that along the perforated fin length the temperature drop was higher than that for non-perforated fin, the rate of temperature drop along the perforated fin decreased with decreased of the perforation dimension. Also, they found for the perforated fin that contained a larger perforation diameter, the heat transfer coefficient ratio was higher than that contained smaller perforation diameter.

A. V. Zoman et al. [2], conducted a study on heat transfer enhancement using fins with perforation, their results show that Nusslet number increased with increasing number of perforations on rectangular fin array and heat transfer enhancement depend on number of perforations, size and shape of perforation, thickness of perforated fin and thermal conductivity of material. S. Kale et al. [3], conducted an experimental study on electronic equipments cooling through rectangular fin array by using natural convection. They studied the high heat flux cooling of electronic equipments and devices with various methods, they found that fin was one of the most inexpensive and common ways to dissipate unwanted heat hence its study is very important for improved design and also improving the heat dissipation rate performance of the plate by using different fin geometry and fin array also by other parameter such as fin height, fin spacing.

Nomenclature

- A_{front}: area restricting the air flow
- Q_T : heat supplied
- A: cross-sectional area of duct
- Q_{loss}: heat loss from setup
- A_s: total heat transfer area of fin array
- Q_{con}: total heat convicted from fin array
- A_h: Surface area of heater
- h: Convective heat transfer coefficient
- A_b: fin base area
- R_{th} thermal resistance of fin
- A_c: cross-sectional area of fin
- P: perimeter of fin
- V_{avg}: Effective air flow velocity
- De: hydraulic diameter of duct
- q: volumetric flow rate of air in duct
- Re: Reynolds number
- T_s: Average surface temperature of fin array
- Nu: Nusselt number
- T_o: temperature of bulk air flow
- K: thermal conductivity of fin
- T_b: base temperature
- T_h: surface temperature of heater
- L: Characteristics length of fin
- h_t: Convective HT coefficient of heater
- V_d: velocity of air in duct

Greek Symbols

- η_{fin}: fin efficiency
- ε_{fin}: fin effectiveness
- v: kinematic viscosity of air

II. Material and methods

A. 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).

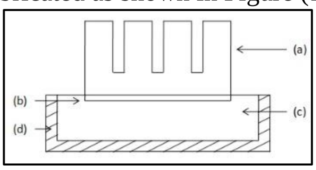

Fig. 1: Solid fin with heater and heat sink

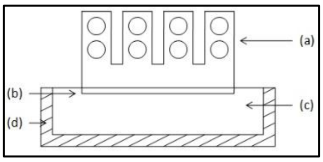

Fig. 2: Perforated fin with heater and heat sink

(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 aluminum 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.

Type of Fin	Fin without perforation	Fin with two perforations of 5 mm Ø	Fin with two perforations of 7 mm Ø
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 (mm)	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

Table 1: Geometry of various types fin array studied.

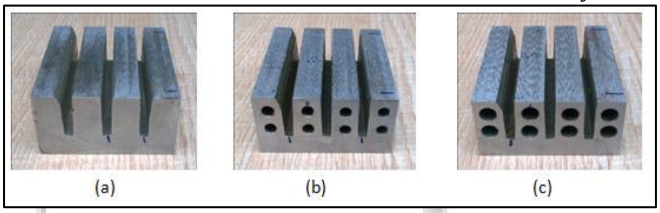

Fig. 3: Schematic view of the fin arrays (a) Fin without perforation, (b) Fin with two perforations of 5mm, (c) Fin with two perforations of 7mm.

B. *Measuring Equipments*

The experiment is conducted for air velocities of 6.2 m/sec, 10.3 m/sec, and 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.

C. *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 03-different velocities for both fin without perforation and fin with perforation.

Fig. 4: Experimental setup

III. RESULT AND DISCUSSION

The experimental investigation carried out for fin without perforation and with perforation of 5 mm and 7 mm diameter for forced convection with constant heat input of 12.50W is maintained throughout. The effect 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, $A\text{-}A_{front}$

$$V_{avg} = \frac{q}{A - A front} \text{ (m/sec)} \quad (1)$$

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

The duct Reynolds number (Re) is defined as,

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

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

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

$$Q_{loss} = h_t \times A_h \times (T_h - T_o) \text{ (watt)} \quad (5)$$

Now, the convective heat transfer coefficient (h) and thermal resistance (R_{th}) are calculated as,

$$h = \frac{Qconv}{As\,(Ts - T_o)} \text{ (w/m}^2\text{k)} \quad (6)$$

$$R_{th} = \frac{1}{h \times As} \text{ (k/w)} \quad (7)$$

In order to represent heat transfer coefficient in a dimensional way, Nusselt number (Nu) defined as,

$$Nu = \frac{h \times L}{K} \quad (8)$$

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.

$$\eta_{fin} = \frac{(Ts-T_0)\times\frac{\tanh(ml)+(\frac{h}{mk})}{1+(\frac{h}{mk})\times\tanh(ml)}\times\sqrt{hPKAc}}{(Tb-T_0)\times\frac{\tanh(ml)+(\frac{h}{mk})}{1+(\frac{h}{mk})\times\tanh(ml)}\times\sqrt{hPKAc}} \quad (9)$$

Where,

$$m = \sqrt{\frac{h\times p}{K\times Ac}} \quad (10)$$

Fin effectiveness ε_{fin}

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

$$\varepsilon_{fin} = \frac{h\times As\times(Ts-T_0)}{h\times Ab\times(Tb-T_0)} \quad (11)$$

A. Effect of Reynolds number on heat transfer coefficient and Nusselt number

The effects of Reynolds number on the heat transfer coefficient and Nusselt number as shown in Figs. 5 and 6. It is found that the Reynolds number increases, the heat transfer coefficient and Nusselt number increases for both fin with perforation and without perforation but for fin with perforation has higher value of heat transfer coefficient and Nusselt number than fin without perforation at a particular Reynolds number. Also, as diameter of perforation increases heat transfer coefficient and Nusselt number increases.

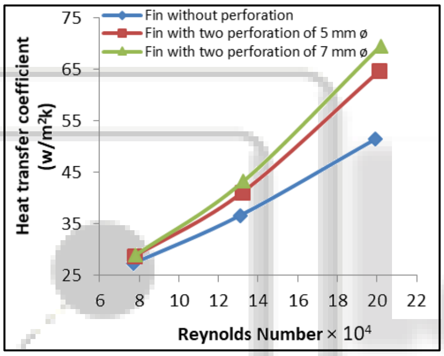

Fig. 5: Effect of Reynolds number on convective

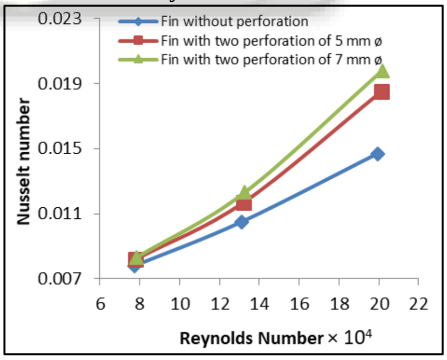

Fig. 6: Effect of Reynolds number on Nusselt number y heat transfer coefficient

B. 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. 7 and 8. 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.

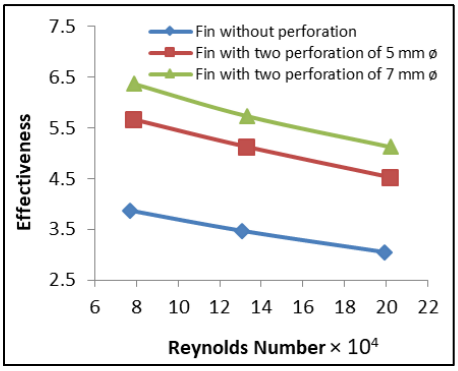

Fig. 7: Effect of Reynolds Number on fin effectiveness

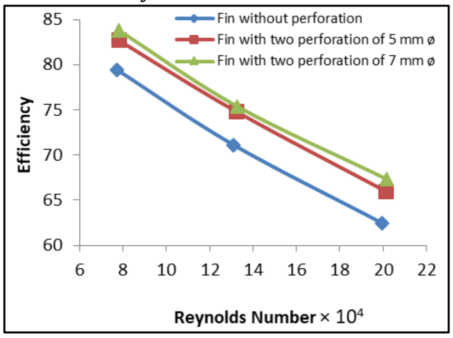

Fig. 8: Effect of Reynolds Number on fin efficiency

C. Effect of Reynolds number on thermal resistance

Fig. 9 shows the effect of Reynolds number on the thermal resistance, it is observed that for perforated fin the thermal resistance is less compared to fin without perforation, if Reynolds number increases thermal resistance decreases for both perforated and non-perforated fin, it is also found that as the size of perforation increases the thermal resistance decreases.

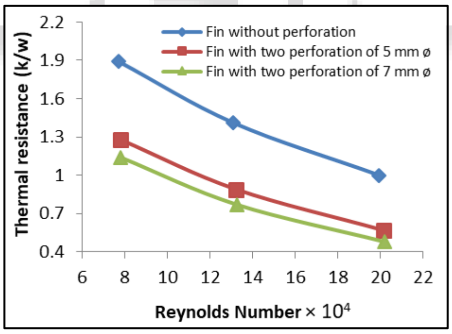

Fig. 9: Effect of Reynolds number on thermal resistance

D. Effect of velocity on temperature and heat transfer coefficient

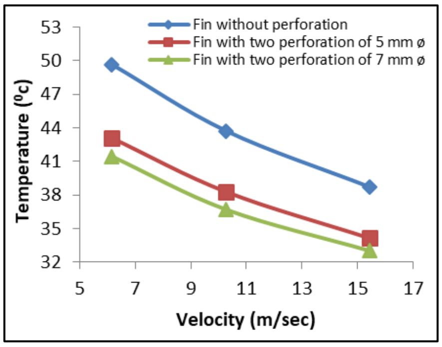

Fig. 10: Effect of velocity on temperature of fin

Fig. 10 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.

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. 11. 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.

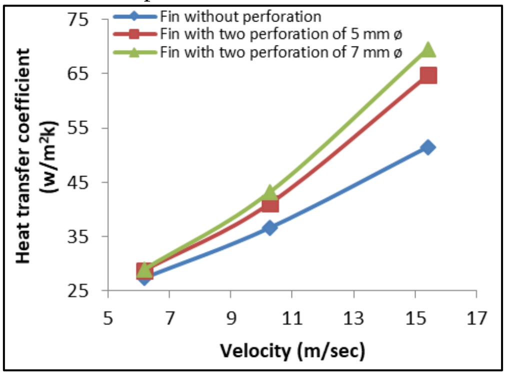

Fig. 11: Effect of velocity on heat transfer coefficient

IV. CONCLUSION

A study was carried out to investigate the thermal analysis of rectangular fin array without perforation and with perforations for velocities of 6.2 m/sec, 10.3 m/sec and 15.4 m/sec. It is found that for perforated fin that contained a larger perforation diameter, the surface heat transfer coefficient and Nusselt number was higher than that contained small perforation diameter. The heat transfer coefficient and Nusselt number increases with increasing the Reynolds number whereas thermal resistance, efficiency and effectiveness decreases with increasing Reynolds number.

REFERENCE

[1] T. K. Ibrahim, F. Basrawi, M. N. Mohammed and H. Ibrahim, "Effect of perforation area on temperature distribution of the rectangular fins under natural convection", ARPN journal of engineering & applied science, vol.11, pp. 6371-6375, 2016.
[2] A.V. Zoman and D. D. Palande, "Heat transfer enhancement using fins with perforation: a review", International journal of engineering science & research technology, International journal of engineering science & research technology, vol. 5, issue-7, pp. 786-7889, 2016.
[3] S. Kale and V. Bhatkar, "Electronic equipments cooling through rectangular fin array by using natural Convection: a review", Technical research organization India, vol. 02, issue 02, 2015.
[4] K. H. Dhanawade, V. K. Sunnapwar and H. S. Dhanawade, "Thermal analysis of square and circular perforated fin arrays by forced convection", International journal of current engineering & technology, vol. 2, pp. 109-114, 2014.
[5] H. N. Deshpande and S. G. Taji, "Experimental study of heat transfer from horizontal rectangular fins with perforations under natural convection", International journal of engineering research & technology, vol. 3, issue-2, pp. 2026-2031, 2014.
[6] G. G. Kumar, K. Sridhar and B. A. Kumar, "Experimental studies on conjugate mixed convection heat transfer through perforated fins", International Journal of Science, Engineering and Technology Research, vol.4, issue-6, pp. 1803-1807, 2015.
[7] M. F. Ismail, M. O. Reza, M. A. Zobaer and M. Ali, "Numerical investigation of turbulent heat convection from solid and longitudinally perforated rectangular fins", "Procedia Engineering", vol. 56, pp. 497-504, 2013.
[8] Domkundawar & Domkundawar, "Heat and Mass Transfer Data Book", Third Edition, Delhi, pp. 1.1-3.16, 2011.
[9] D. S. Kumar, "Heat and Mass Transfer", Eighth Edition, Delhi, pp. 222-223, 2013.
[10] C. P. Kothandaraman and S. Subramanyan, "Heat and Mass Transfer Data Book", Seventh Edition, Delhi, pp.10- 34, 2010.
[11] R. Hagote and S. Dahake, "Enhancement of Natural convection heat transfer coefficient by using V-fin array", International journal of engineering research and general science, vol. 03, issue-2, pp. 151-158, 2015.
[12] U. M. Vinaya Kumara, K. N. Krishnamurthy and Akash Deep, "Experimental Analysis of Rectangular Fin Arrays with Continuous Fin and Interrupted Fins Using Natural and Forced Convection", International journal of innovative research in science, engineering and technology, vol. 5, issue-8, pp. 15117-15125, 2016.

