J Integr Sci Technol, 2016, 4(1), 5-9 Article

Journal of Integrated
SCIENCE & TECHNOLOGY

An Experimental Study of Heat Transfer Enhancement in the Perforated Rectangular Fin

Lalta Prasad,* Sonika Tewari, Ashwani Kumar

Department of Mechanical Engineering, G. B. Pant Engineering College, Ghurdauri, Pauri Garhwal, Uttarakhand 246194, India.

Received on: 25-Sept-2015 Accepted on: 11-Dec-2015 Published on: 19-Jan-2016

ABSTRACT

The main objective of this study is to understand the effect of number of perforations on convective heat transfer experimentally investigated. Perforations in the fins are one way that used to improve its effectiveness. In this study, the steady state heat transfer from the solid fin and perforated fin arrays are measured. The temperature drop along the perforated fin length is consistently higher than that for the equivalent non – perforated fin. The inlet temperature of the cylinder core was in the rage of 353^{o}C-953^{o}C for voltage range 100 V to 220 V. The heat transfer depends on the porosity of the fin. Heat dissipation rate is increased in the range of 20% to 70% with increase in the number of perforations (24 to 60) up to certain level. If further increase in perforation numbers this leads to reduction of the heat dissipation from the fin.

Keywords: Heat transfer enhancement, Perforation numbers, Natural convection, heat transfer coefficient, Fin array

INTRODUCTION

A growing number of engineering disciplines are concerned with the energy transitions requiring the rapid heat dissipation from a surface to surroundings. The most attractive parameter is to increase the surface area exposed to the surroundings by the attachment of protrusions to the surface in order to increase the heat transfer rate from the surfaces. The protrusions are called extended surfaces or fins or spines. The fins serve the purpose of increasing the heat flow area. Some of the use of fins found in many engineering problems like internal combustion engines, heat exchangers, refrigeration, cryogenic process, nuclear fuel elements and electrical apparatus e.g. transformers and motors.[1] Sahin and Demir[2] carried out experimental study on heat transfer and friction factor for heat exchanger fitted with square cross sectional perforated fins. They reported that the use of perforated fins of square cross section increases the heat transfer rate which depends on the on the clearance ratio and inter-fin spacing ratio. The experimental analysis of on heat transfer enhancement and the corresponding pressure drop over a flat surface equipped with cylindrical cross-sectional perforated pin fins in a rectangular channel.

Dhumne and Farkade[3] reported the experimental analysis of on heat transfer enhancement and pressure drop over a flat surface equipped with cylindrical cross-sectional perforated pin fins in a rectangular channel. The use of the cylindrical perforated pin fins leads to heat transfer enhancement as compared to the solid cylindrical fins. Tanya[4] reported the study on heat transfer and pressure drop for a rectangular channel equipped with arrays of diamond-shaped elements. Both in-line and staggered fin arrays were considered, for values of the longitudinal and transverse spacing. Thermal performance comparisons with data for a rectangular channel without fins showed that the presence of the diamond-shaped elements enhanced heat transfer for equal mass flow rate and pumping power. Awasarmol and Pise[5] carried out experimental study to quantify and compare the natural convection heat transfer enhancement of perforated fin array with different perforation diameter and at different angles of inclination. They found that the heat transfer coefficient was increased with perforated fins of 12 mm perforation diameter at the angle of orientation 45°, which shows about 32% enhanced heat transfer coefficient as opposed to the solid fin array. Shaeri and Jen[6] reported the effects of size and number of perforations on laminar heat transfer characteristics of an array of perforated fins at the highest porosity. They found that in a laminar flow and at a constant porosity (Porosity was defined as volume of perforations divided by volume of a solid fin), a fin with fewer perforations is more efficient to enhance the heat

Address:
Dr. Lalta Prasad
Associate Professor, MED, G.B.Pant Engineering College,
Pauri Garhwal (Uttarakhand) 246194, India
Tel:+918979223769
Email: laltagbpec@gmail.com

Cite as: *J. Integr. Sci. Technol., 2016, 4(1), 5-9.*

JIST ISSN 2321-4635

http://pubs.iscience.in/jist

transfer rate compared with a fin with more perforations. Karabacak and Yakar[7] investigated the effect of holes placed on perforated finned heat exchangers on convective heat transfer. A perforated finned heater was compared with an imperforate finned heater to observe the differences in heat transfer and pressure drop. They found that the Nusselt numbers for the perforated finned positions were higher than the Nusselt numbers for the imperforate state.

EXPERIMENTAL SETUP AND METHODOLOGY

Experimental conditions

In the present work, the seven aluminum straight fins (105 mm long, 180 mm wide and 2 mm thick) were chosen. There is one non-perforated fin and six perforated fins (perforated diameter 10 mm). The numbers of perforations per fin were 24, 32, 36, 44, 55 and 60 their diameter was 10 mm. These fins were fitted radially on an aluminum cylinder of 60 mm diameter and 210 mm long. One hole was drilled in the cylinder and one heating element was inserted in the cylinder as shown experimental setup in Figure 1.0. This aluminum cylinder is working as heat sink. The heat is generated within the heat sink by means of one heating element power of 670 W.

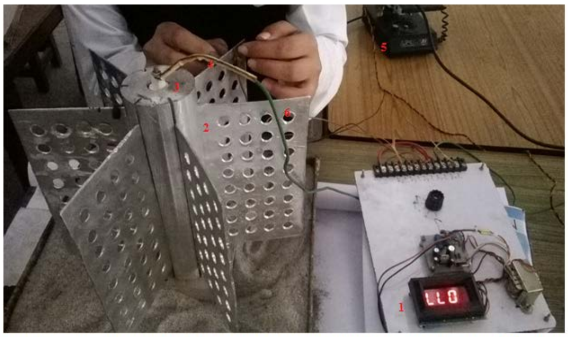
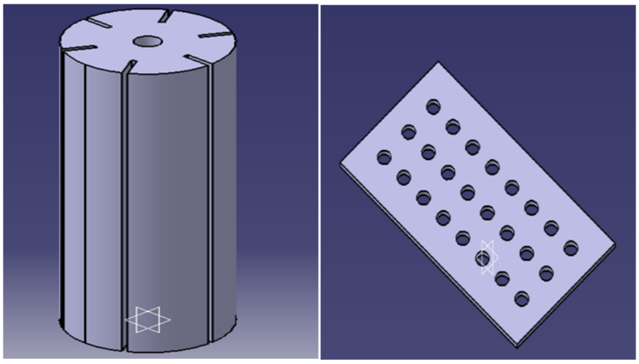


Figure Legends; 1. Temperature indicator; 2. Fin; 3. Cylinder; 4. Heating element wire; 5. Voltage regulator; 6. Perforated hole

Figure 1. Photographic image of Experimental set up

A variable transformer of type 2P1 with input 240 V and 50 Hz and output 0-240 V, 20 A and 7.5 kVA were used to regulate the voltage supplied to the heating elements. A data acquisition system was used to record the data. K-type thermocouples were used to measure the temperature at the surface of the test fin at equal spacing of 20 mm located along the length of fin. The voltage was varied in the range of 100 V, 140 V, 180 V and 220 V. The experimental set up was allowed to run until steady state condition was achieved then after the necessary measurements were recorded.

Figure 2(a) shows the design of aluminum cylinder in the Catia software. The length and diameter of the cylinder was 210 mm and 60 mm respectively. A hole of size 18 mm was bored in the cylinder and six numbers of slots (2.5×8 mm) were cut on the outer surface of the cylinder. The cylinder was assumed to behave as heat sink during experimental study. Figure 2(b) shows the design of aluminum plate(Fin) in the Catia software. The length and height of the plate was 105 mm and 180 mm respectively. A hole of size 10 mm was drilledin in the plate. The number of holes (perforation) in the plate were varying from 24 to 60 to understand the effect of perforations on heat transfer rate from the fin.



(a) Aluminum Cylinder

(b) Perforated Fin

Figure 2. 3D image of (a) aluminum cylinder (b) perforated

RESULTS AND DISCUSSIONS

Mathematical Analysis of Perforated Fin

Generally, the heat transfer coefficient and effective heat transfer area could be increased by using perforated fins and the increase in heat transfer coefficient and surface area depends on the geometry of the perforations.[8]

In the present study, the number of perforations in x-direction and y-directions are Nx and Ny respectively. The dimension of the fin is known in x- direction and y-directions L and W respectively. The perforation cross sectional area (Ac) is assumed and then the dimension of any perforation is calculated. The surface area of the uniform longitudinal rectangular perforated fin can be expressed as follow:

$$\begin{aligned} A_{fp} &= A_f + N_C(A_{pc} - 2A_c) \\ &= A_f + N_x \times N_y (A_{pc} - 2A_c) \qquad \text{...}Eq.(1) \end{aligned}$$

In order to compare the heat transfer surface area of the perforated fin (Afp) to that of the conventional one (Af), the fin surface area ratio (SAR) is introduced and is given by Eq. (2).

$$\begin{aligned} SAR &= A_{fp} / A_f \\ &= 1 + \frac{[N_x \times N_y (A_{pc} - 2A_c)]}{A_f} \qquad \text{...}Eq.(2) \end{aligned}$$

The material volume of the perforated fin is compared with the volume of non perforated fin by volume reduction ratio (VRR) which is expressed as Eq. (3):

$$\begin{aligned} VRR &= V_{fp} / V_f \\ &= \frac{(L \times W \times t - N_x \times N_y \times A_c \times t)}{(L \times W \times t)} \\ &= 1 - \frac{(N_x \times N_y \times A_c)}{(L \times W)} \qquad \text{...}Eq.(3) \end{aligned}$$

Similarly, the perforated fin has less weight than that of equivalent non- perforated one. This aspect is expressed by the fin weight reduction ratio (WRR) defined as Eq. (4):

$$WRR = \frac{W_{fp}}{W_f} = \frac{(W_f - N_x \times N_y \times A_c \times t \times \rho)}{W_f} = 1 - \frac{(N_x \times N_y \times A_c \times t \times \rho)}{(L \times W)} \qquad ...Eq.(4)$$

According to the perforation shape and dimension that is cut out from the fin body, the fin with the circular perforation pattern is studied. The number of perforation in longitudinal direction Nx, in the transverse direction Ny and the perforation diameter is d. The direction perforation spacing Sx and Sy:

$$L = N_x \times d + (N_x + 1)S_y \qquad ...(Eq.(5)$$

$$S_x = (L - N_x d)/(N_x + 1) \qquad ...(Eq.(6)$$

$$S_y = (W - N_y d)/(N_y + 1) \qquad ...(Eq.(7)$$

The heat transfer surface area of the fin can be expressed as Eq. (8):

$$A_{fp} = A_f - 2N_c A_c + N_c A_p = A_f - 2N_c(A_p - 2A_c) = A_f + \pi N_c d(t - d/2) \times N \qquad ...Eq.(8)$$

The SAR and VRR can be expressed as Eq. (9) and Eq. (10) respectively:

$$SAR = 1 + \frac{[\pi \times b \times N_x \times N_y \times (t - \frac{d}{2})]}{(2W \times L + W \times t)} \qquad ...Eq.(9)$$

$$VRR = 1 - \frac{[N_x \times N_y \times (\pi/4) \times d^2]}{(L \times W)} \qquad ...Eq.(10)$$

Analysis of Heat Transfer Coefficient

An experimental correlation to estimate the convection heat transfer coefficient of the array of vertical oriented parallel flat plate given by Kraus and Bar-Cohen[9] as shown in Eq.(11).

$$Nu = \frac{h \times B}{K} = \frac{Ra(1 - e^{-\frac{35}{Ra}})^{0.75}}{24} \qquad ...Eq.(11)$$

Where: B is the average space between adjacent fins.

$$Ra = \frac{\rho^2 \times g \times \beta \times C_p \times B^4 \times \Delta T}{\mu \times k \times L} \qquad ...Eq.(12)$$

Many researchers[8,10] have reported the heat transfer coefficient for perforated surfaces as a function of open area ratio (OAR). The open area ratio is defined as a ratio of the actual open area to the maximum possible perforation open area as given in Eq. (13).

$$OAR = \frac{OA}{OA_{\max}} = \frac{A_c \times N_c}{A_c \times N_{c,Max}} = \frac{A_c \times N_x \times N_y}{A_c \times N_{x,Max} \times N_{y,Max}} \qquad .Eq.(13)$$

Where $N_{x,max}$ and $N_{y,max}$ are the maximum possible number of the perforations along the fin. These numbers related with the perforation spacing equal zero. The perforated surface heat transfer coefficient ratio (Rh) was reported by Kakac et al.[11] as given in Eq.(14).

$$R_h = 1 + \frac{0.75 \times OA}{OA_{\max}}$$

The film heat transfer coefficient of the perforated surface (h_{ps}) is expressed as:

$$h_{ps} = R_h \times h = [1 + \frac{0.75 \times OA}{OA_{\max}}] \times h \qquad ...Eq.(14)$$

The distance between two fins was calculated by using the Eq. (15):

$$S = \frac{(\pi \times D - t \times 6)}{6} \qquad ...Eq.(15)$$

Where; D is the diameter of the cylinder and t is the thickness of the fins.

The area of the rectangular fins ($A_1 = L \times t$) and the area of the perforation ($A_2 = n \times \pi/4 \times d_2$) were calculated and the cross sectional area of the fin ($A_{cs} = A_1 - A_2$) was calculated to find the heat transfer coefficient as given in Eq. (16)

$$h = \frac{(1.31 \times k)}{S} \qquad ...Eq.(16)$$

Where; k is the thermal conductivity of the material and S is the distance between two fins.

The value of various parameters were constant like $A_c = 78.54$, $N_{x,max} = 4$, $N_{y,max} = 12$ and $OA_{max} = 1369,92$.

Table 1. Various parameters calculated by using above equations

Perf. (no.)	Ac	Nx	Ny	OA	SAR	R_h	WRR
0	78.54	0	0	0.00	1.000	1.000	1.000
24	78.54	4	6	1884.96	0.944	1.375	0.906
32	78.54	4	8	2513.28	0.925	1.500	0.874
36	78.54	4	10	3141.60	0.906	1.625	0.843
44	78.54	4	12	3769.92	0.113	1.750	0.812
55	78.54	4	14	4398.24	0.131	1.875	0.780
60	78.54	4	16	5026.56	0.150	2.000	0.749

The various parameters were calculated by using above equations (1-14) and the values are shown in the Table 1.

Heat Flow Analysis in Ansys

The temperature distribution and heat flux variation analysis was carried out by using ANSYS-14.0 in this study. The temperature distribution and heat flux along the length of fin at constant voltage (220V) is shown in the Fig. 3 and 4 respectively. Under steady state condition, the temperature variation along the length of fin was in the range of 22-703^{o}C as shown in the Figure 3. Whereas the heat fluxes variation in the fin along the length is shown in the Fig. 4.

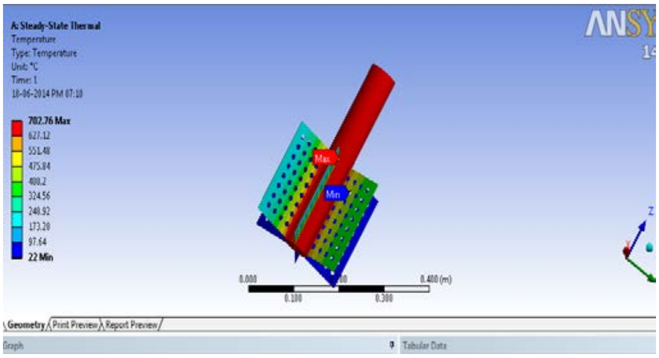


Figure 3. Temperature Distribution along the length of fins at constant voltage (220V)

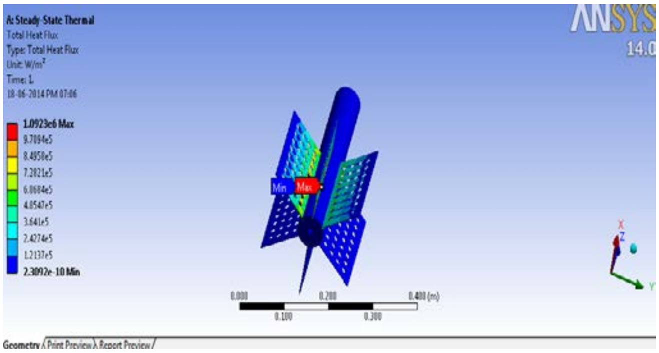


Figure 4. Heat transfer along the length of fins at constant voltage (220V)

Heat Dissipation at the tip of the perforated fin is calculated by using equation 17 as given below:

$$Q_{fin} = kA_{cs}m(t_0 - t_a) \times \frac{(\tanh(ml) + \frac{h}{km})}{\{1 + \frac{h}{km}\tanh(ml)\}} \qquad ...Eq.(17)$$

The variation of heat flow in the perforated fins is shown in Fig. 5.0. The various values of different parameter are either calculated or taken from the literature like perimeter of fin (p) = 364 mm, mass of fin (m) = 0.239 kg, heat transfer coefficient (h) = 10.02 W/m^2 K and thermal conductivity of Aluminum (k) = 225 W/m K. Figure 5.0 shows the effect of perforation numbers on the heat dissipation for varying voltage from 100-220 volt. It was found that the heat dissipation was increases with the perforation numbers at varying applied voltages (100-220 V). It has been seen that maximum heat dissipation (47 W) was take place for perforation 60, for applied voltage of 220 volt; this is due to higher temperature at the centre of the cylinder core as compared to the other voltages.

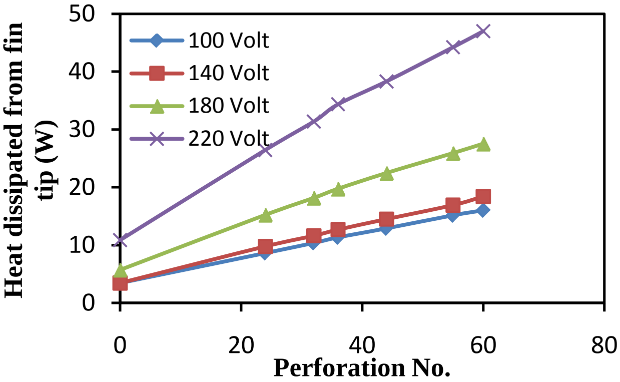


Figure 5. Effect of Perforation No. on Heat Transfer Front the Fin Tip at varying Voltage.

Figure 6 shows that the effect of length of the fin on the temperature at varying number of perforations. It has been seen from the figure 6 that the temperature decreases with the increase in the length of the fin for varying perforation numbers. For a particular length of the fin, temperature decreases with increase in the number of perforation. The possible reason for drop in the temperature is lower temperature gradient along the length of the fin.

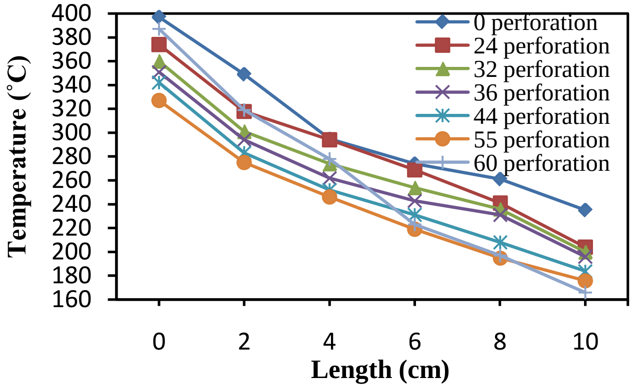


Figure 6. Effect of length on temperature distribution for varying perforations at constant voltage (220V)

CONCLUSIONS

The heat transfer analysis on perforated fin was carried out in the present study. The following conclusions were drawn as given below:

- The temperature drop along the perforated fin length is consistently higher than that for the equivalent non – perforated fin.
- The gain in heat dissipation rate for the perforated fin is a strong function of the perforation dimension.
- It was observed that heat dissipation rate was increased in the range of 20% to 70% with increase in the number of perforations (24 to 60) up to certain level. If further increase in perforation numbers this leads to reduction of the heat dissipation from the fin.
- There are several reasons for decrease in heat dissipation from the fin like metal to metal contact, heat flow by conduction and convection as well as radiation surface.
- The heat dissipation depends on the various parameter like thickness of fin, conductivity of material, lateral

spacing, shape of the perforation and temperature of the surrounding.

ACKNOWLEDGEMENT

Authors are thankful to students (Ankita Nautiyal, Ashwariya Aswal, Haseen and Prema) and staff of the Mechanical Engineering Department, G. B. Pant Engineering College, Ghurdauri, Pauri Garhwal, for providing necessary help during the course of the experimental work.

REFERENCES

1 R. Yadav. Heat and mass transfer, 5th edition, Central Publication house, Allahabad, India (**2004**).

2 B. Sahin, A. Demir. Performance analysis of a heat exchanger having perforated square fins. *Appl. Therm. Eng*. **2008**, 28, 621–632.

3 A.B.Dhumne, H.S. Farkade. Heat Transfer Analysis of Cylindrical Perforated Fins in Staggered Arrangement, *Int. J. Innovative Technol. Exploring Engin.* **2013**, 2(5), 225-230.

4 G. Tanda. Heat transfer and pressure drop in a rectangular channel with diamond-shaped elements. *Int. J. Heat Mass Tran.* **2001**, 44(18), 3529–3541.

5 U.A. Awasarmol, A.T. Pise. An experimental investigation of natural convection heat transfer enhancement from perforated rectangular fins array at different inclinations. *Exp.Therm. Fluid Sci.***2015**, 68, 145–154.

6 M.R. Shaeri, T.C. Jen. The effects of perforation sizes on laminar heat transfer characteristics of an array of perforated fins. *Energ. Convers. Manage.* **2012**, 64, 328–334

7 R. Karabacak, G. Yakar. Forced convection heat transfer and pressure drop for a horizontal cylinder with vertically attached imperforate and perforated circular fins. *Energ. Convers. Manage*. **2011**, 52(8-9), 2785–2793.

8 A.H. AlEssa, M.Q. Al-Odat. Enhancement of natural convection heat transfer from a fin by triangular perforations of bases parallel and toward its base, *Arab. J. Sci. Eng.* **2009**, 34(2B).

9 A.D. Kraus, A. Bar-Cohen. Design and Analysis of Heat Sinks, John Wiley and Sons, New York, NY, **1995**.

10 R.R. Jassem. Effect the form of perforation on the heat transfer in the perforated fins. SAVAP International, Part-I: Natural and Applied Sciences, **2003**, 4(3), 198-207.

11 S. Kakac, A. Bergles, A. Mayinger. Heat exchanger thermal–hydraulic fundamentals. ISBN-10: 3540152431, Publisher: Springer; 1st edition (**1981**)