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Enhancement of Natural Convection Heat Transfer from Perforated Fin

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Abstract:

A comprehensive theoretical and experimental study was carried out on the thermal performance of a pin fin heat sink. An experimental model was shows that have the capability of predicting influence of effective surface area of pin fin on thermal heat transfer coefficient. Pin fin array are used in many applications to enhance heat transfer and also shows enhancement of heat transfer coefficient for different material of fin. Several different type of experiment test were run out with corresponding variation including the material of pin fin and different perforation on pin fin .Perforation with circular cross section are along the height of pin fin and there number varies from 1 to 3. The result indicates that the material having higher thermal conductivity with higher number of perforation gives more heat transfer coefficient. The effect of perforation on heat transfer was investigated.

Keyword: Natural Convection, Fin materials, Round pin fins, Heat sink

1. Introduction

Pin fins have a variety of applications in industry due to their excellent heat transfer performance e.g. in cooling of electronic component, in cooling of gas turbine blade, Heat exchangers etc. The fins industry has been seeking ways to reduce the size and cost of fins. This demand is often justified by the high cost of the high thermal conductivity metal and also they wants to reduce the weight of fins especially in airplanes and motorcycles applications. Both in-line and staggered fin arrangements significantly enhanced the heat transfer in comparison to the surface without fins. Nu number increased with increasing Re number both on the basis of the total surface area and the projected area for in-line and staggered arrange-ments. For the staggered array, the dependence of the variation of Nu number with fin spacing was smaller than the in-line arrangement on the basis of total surface area. For both in-line and staggered arrangements based on the projected area, the performance efficiency $\eta$was greater than 1 for all fin spacing's and Reynolds numbers [1]. The temperature drop along the perforated fin length is consistently larger than that on an equivalent non-perforated fin. The magnitude of enhancement is proportional to the fin thickness and its thermal conductivity. The gain in the heat dissipation rate for the perforated fin is a strong function of both the perforation diameter and lateral spacing. The perforation of fins enhances the heat dissipation rates and at the same time decreases the expenditure for fin materials [2]. In pressure loss the heat transfer enhancement of drop-shaped pin fins is weaker than that of circular pin fins. [3]. Overpopulated pin fins decreased the enhancement of heat transfer. The enhancement of heat transfer from the discrete heat source using pin-fin arrays was found more significant for horizontal enclosures [4]. $\overline{Nu}$ for sideward arrangement was slightly higher than those for upward arrangement at high Ra. $\overline{Nu}$ of sideward arrangement was higher than those of upward arrangement. Solid pin fin heat sink yielded the highest $\overline{Nu}$ of both upward and sideward facing orientations. The temperature difference between the base plate and surrounding air value decreases with increasing Di/Do [5]. Average friction coefficient, pressure drop and average Nusselt number decrease with increasing perforation [6]. The heat transfer performance of triangle perforated fin is superior to the serrated fin under the Reynolds number [7]. Performance of sideward arrangement exhibits a greater dependence on fin structure [8]. Perforation enhance the heat transfer coefficient and reduce the module temperature effectively. The dimensionless temperature of heat sources decreases gradually with the holes open area ratio [9].

There are two ways to increase heat transfer rates, to increase convection heat transfer coefficient and to increase the surface area.

2. Experimental Analysis

2.1 Principle of Working

The pin fin of different material are mounted on the base surface of aluminum plate which is common throughout the experiment. The base of the surface is heated with the help of coil throughout the whole surface of base plate .The heat supplied by the heating coil conducted through the perforated fin and unfinned area. The whole experiment is done in the enclosed room. Due to the free convection there is the exchange of heat between the air and heated pin fins .The pin fins on the plate acts as a heat exchanger.

Eight thermocouples measure the temperature of fin and one thermocouple measure the ambient temperature. Twelve thermocouple were mounted on the base plate to measure the average temperature of base plate. By keeping the current fixed, different set of reading obtained.

First by installing solid fin of different material experiment is carried out, the same procedure is adopted by changing the pin fin but having one, two and three perforation respectively**.**

2.2 Constructional Feature

The material selected for the project work is pure aluminum, mild steel, pure copper as it is easily available in

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cylindrical form. The pin fins are placed on the base plate, below the base plate heater coil is mounted, below that press board is kept and below that iron plate kept to support the coil and below that glass wool insulation material is placed having K=0.04 w/mK.The perforated fin are placed vertical or horizontal base plate . As the main objective of project is to compare the enhancement in heat transfer coefficient by keeping mild steel as the base material.

2.3 Design Parameters

Perforated Fin

Aluminum, Copper and mild steel have been selected for experimentation due to easy availability. For the experimentation one set of solid fin and three sets of perforated fins were taken for different perforations and compared their performance.

Fin Dimensions

Height of fin	= 50 mm
Diameter of Fin	= 12mm
Distance between two fins	= 42mm (Horizontal), 60mm (Vertical)
Dia. Of hole	= 3.5 mm
No. of perforation	=1, 2, 3
Base plate	= 150 x 150 square mm

2.4 Experimental Setup

Figure. No. 2.4a: Experimental Setup

Place the pin fin in position. Make the connection with dimmerstate. Put on power supply. Adjust the heater input i.e. voltage. Wait till steady state is reached and note down the temperature (T1) to (T9). Similar readings can be taken for various pin fin material with different perforation. By keeping the fixed heater input different set of reading are to be taken. Similarly take the observations for different material, different perforation by replacing pin fin one by one.

3. Data Reduction

The Steady state rate of heat transferred from the heat sink by natural convection, $Q^{\cdot}_{c}$ can be determined. This rate of heat transfer by convection can be described as:-

$Q^{\cdot}_{c} = \left(h_{bp} A_{bp} + h_f A_f \eta_f\right)\left(T_{bp} - T_a\right)$ ....(1)

Where

$h_{bp} \rightarrow$ convective heat transfer coefficient of base plate, (w/m^{2}K)

$A_{bp} \rightarrow$ Surface area of base plate, m^2

$h_f \rightarrow$ Convective heat transfer coefficient of fin, w/m^{2}K

$A_f \rightarrow$ Surface area of fin, m^2

$\eta_f \rightarrow$ fin efficiency

$T_{bp} \rightarrow$ Temperature of base plate, ^{0}C

$T_a \rightarrow$ Temperature of air, ^{0}C

Introducing the overall fin efficiencies, η_0 into the above equation and considering that, $h_{bp} = h_f = \bar{h}$ then.

$Q^{\cdot}_{c} = \bar{h} A_t \eta_0 \left(T_{bp} - T_a\right)$ ....(2)

Where

$\bar{h} \rightarrow$ average heat transfer coefficient, w/m^{2}K

$A_t \rightarrow$ Total surface area, m^2

$\eta_0 \rightarrow$ Overall efficiency

$\eta_0 = 1 - \frac{A_f}{A_t}\left(1 - \eta_f\right)$ ....(3)

$\eta_f = \frac{T_{fm} - T_a}{T_{bp} - T_a}\left(1 - \eta_f\right)$ ....(4)

Where

$T_{fm} \rightarrow$ mean fin temperature, ^{0}C

$A_t = A_{bp} + A_f$ ....(5)

$A_{bp} = WL - A_{fp}$ ....(6)

Where L & W are the length and width of base plate respectively

$A_{fp} \rightarrow$ Projected area of pin fin

$A_{fp} = N_f \frac{\pi}{4} D^2$

Where

$D \rightarrow$ diameter of pin fin

$A_f = N_f\left[\frac{\pi}{4}D^2 + \left(\pi D H_f - (n)\frac{\pi}{4}d_h^2\right) + (n)\pi d_h \times D\right]$ ....(7)

Where

$H_f \rightarrow$ is the pin fin height

$d_h \rightarrow$ perforation diameter

$N_f \rightarrow$ total nu. Of pin fin heat sink

$n \rightarrow$ number of perforation

The average convective heat transfer coefficient based on the total heat transfer surface area can be determined from equation (5) as :-

$\bar{h} = Q^{\cdot}_{c} / A_t \eta_0 \left(T_{bp} - T_a\right)$....................................(8)

4. Results and Discussion

In the experimentation different materials, different perforation is used to compare the enhancement of heat transfer coefficient. The effect of different material of pin fin on natural convection heat transfer is studied for different perforation (one, two, and three). Calculation are carried out for mild steel pin fin. The enhancement in heat transfer coefficient due to use of perforated fin.

From the experimentation results shows that in case of perforated fin with copper material enhancement of heat transfer coefficient is more as compare to other two material.

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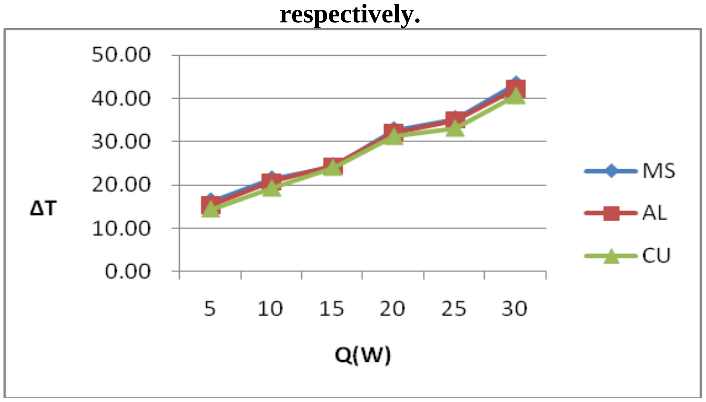
In this experimentation four set of fins were taken, one solid fin set and three set of perforated fin at different voltage 5W, 10W, 15W, 20W, 25W, 30W. Six observations taken at different voltage for respective material and perforation.

For solid aluminum material enhancement in heat transfer coefficient is 0.89%. For solid copper material enhancement in heat transfer coefficient is 1.25%. For mild steel material with single perforation, the enhancement in heat transfer coefficient is 0.30%. For aluminum material with single perforation, enhancement in heat transfer coefficient is 1.11%. %. For copper material with single perforation, enhancement in heat transfer coefficient is 1.48%. For mild steel material with double perforation, the enhancement in heat transfer coefficient is 0.62%. For aluminum material with double perforation, enhancement in heat transfer coefficient is 1.38%. %. For copper material with double perforation, enhancement in heat transfer coefficient is 1.74%. For mild steel material with triple perforation, the enhancement in heat transfer coefficient is 0.88%. For aluminum material with triple perforation, enhancement in heat transfer coefficient is 1.66%. For copper material with triple perforation, enhancement in heat transfer coefficient is 2.11%.

From the experimentation it is clear that, as the perforation increases, the enhancement of heat transfer coefficient increases. Also the thermal conductivity of material increases the heat transfer coefficient get increases.

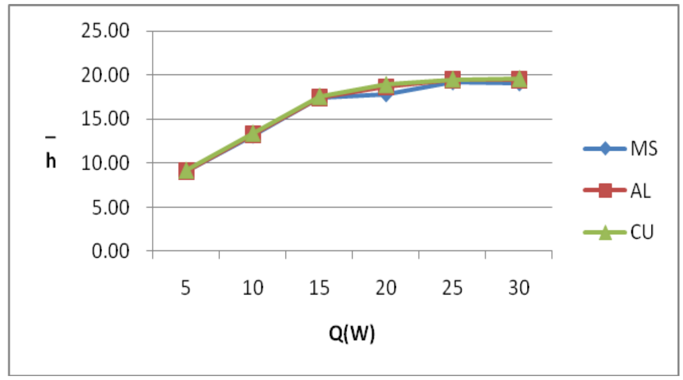
Discussion on Graphs

Graph No. 4.1: Variation of heat transfer coefficient with Heat input for mild steel, aluminum, copper material respectively.

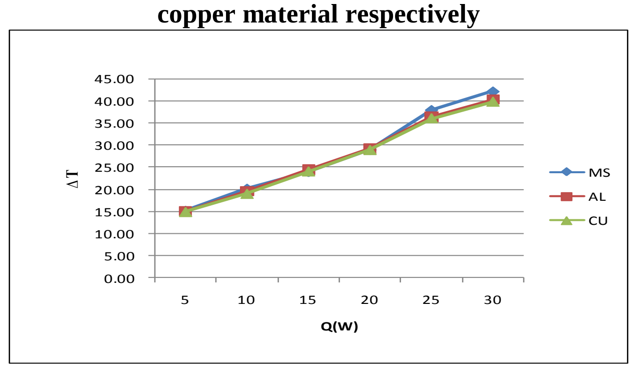


Graph No. 4.2: Variation of temperature difference with heat input for mild steel, aluminum, copper material respectively.

From the Graph No. 4.1 shows the enhancement of heat transfer coefficient with heat input for M.S.,Al,Cu material and shows that Average heat transfer coefficient is maximum in copper material that is 16.06 W/m^2K and Graph No. 4.2 shows the difference in temperature is maximum in mild steel material with respect to heat input.

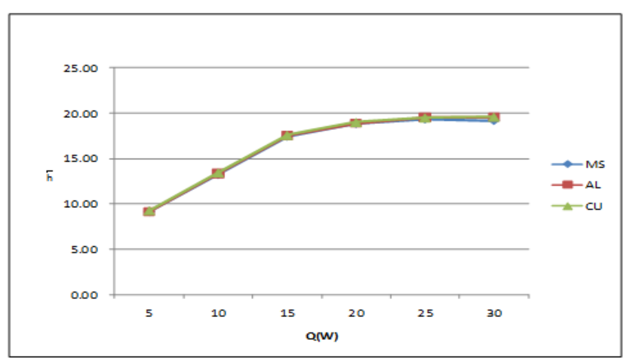


Graph No. 4.3: Variation of heat transfer coefficient with Heat input for single perforated mild steel, aluminum, copper material respectively

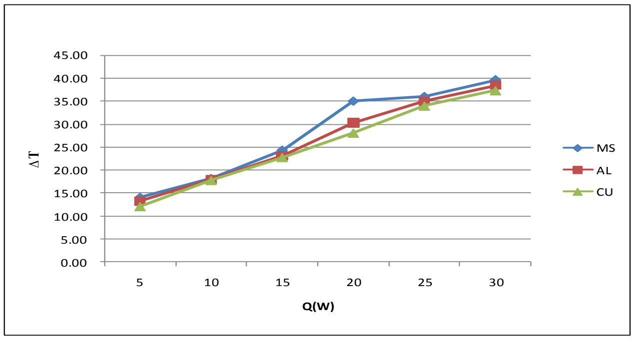


Graph No. 4.4: Variation of temperature difference with heat input for single perforated mild steel, aluminum, copper material resp.

From the Graph No. 4.3 shows the enhancement of heat transfer coefficient with heat input for M.S.,Al,Cu material having one perforation, also shows that copper materials have increase in average heat transfer coefficient is 16.10 W/m^2K and Graph No. 4.4 shows the difference in temperature is less in aluminum material as compare to mild steel.

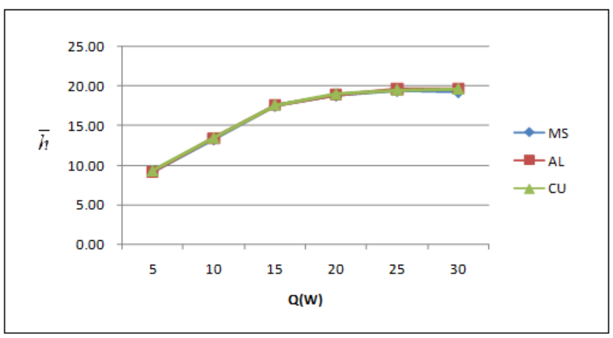


Graph No. 4.5: Variation of heat transfer coefficient with Heat input for double perforated mild steel, aluminum, copper material respectively.

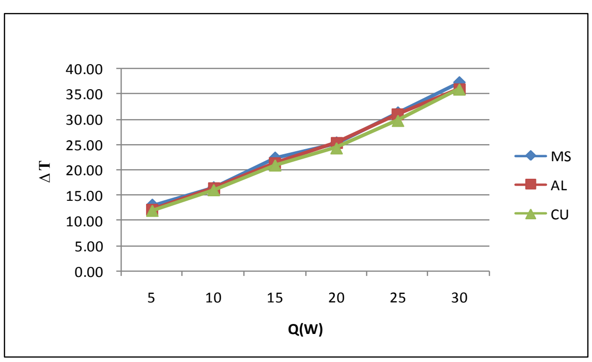


Graph No. 4.6: Variation of temperature difference with heat input for double perforated- mild steel, aluminum, copper material respectively.

From the Graph No. 4.5 shows the enhancement of heat transfer coefficient with heat input for M.S.,Al,Cu material having two perforation is less in mild steel material that is 15.96 W/m^2K and Graph No. 4.6 shows the difference in temperature is maximum in mild steel material with respect to heat input for double perforation.

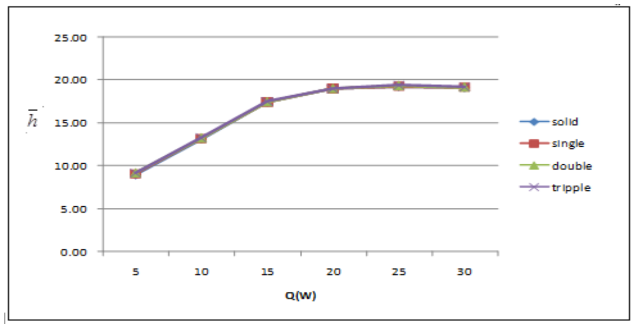


Graph No. 4.7: Variation of heat transfer coefficient with Heat input for triple perforated mild steel, aluminum, copper material respectively.

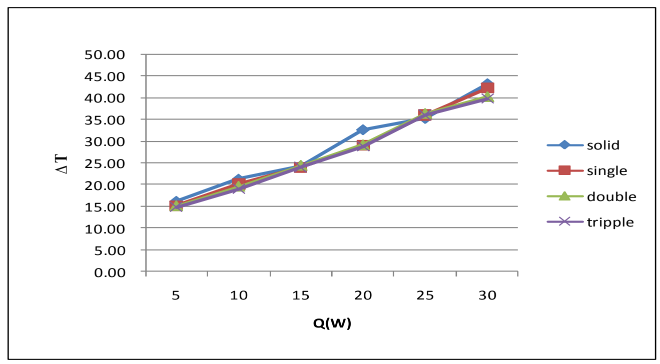


Graph No. 4.8: Variation of temperature difference with heat input for triple perforated mild steel, aluminum, copper material

From the Graph No. 4.7 shows the enhancement of heat transfer coefficient with heat input for M.S.,Al,Cu material with three perforation is higher in copper material that is 16.20 W/m^2K and Graph No. 4.8 shows the difference in temperature is maximum in mild steel material.

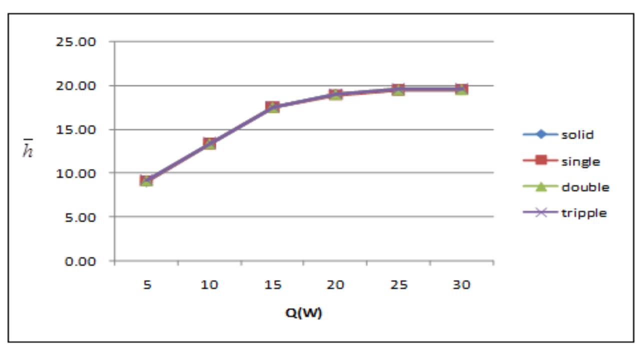


Graph No. 4.9: Variation of heat transfer coefficient with Heat input for mild steel

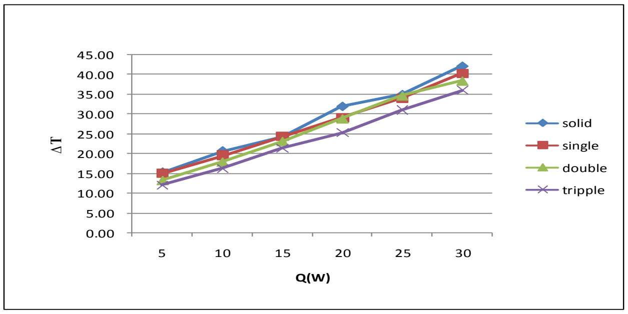


Graph No. 4.10: Variation of temperature difference with heat input for mild steel

From the Graph No. 4.9 shows the enhancement of heat transfer coefficient with heat input for different perforation, also shows that heat transfer coefficient is maximum in copper material with three perforation and Graph No. 4.10 shows the difference in temperature is maximum in mild steel material with single perforation.

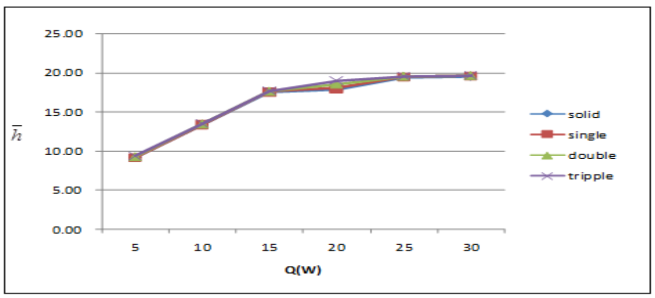


Graph No. 4.11: Variation of heat transfer coefficient with Heat input for aluminum material

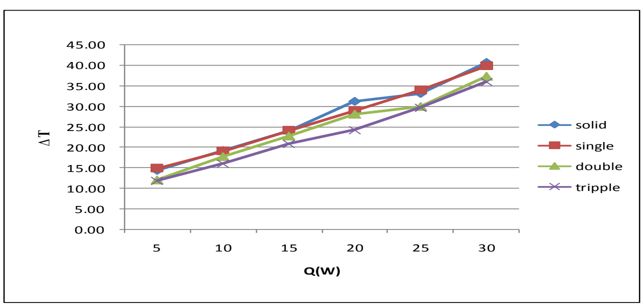


Graph No. 4.12: Variation of temperature difference with heat input for aluminum material

From the Graph No. 4.11 shows the enhancement of heat transfer coefficient with heat input for different material having different perforation and shows maximum enhancement in copper material having three perforation and Graph No. 4.12 shows the difference in temperature is maximum in mild steel material with three perforation.



Graph No. 4.13: Variation of heat transfer coefficient with Heat input for mild steel, aluminum, copper material



Graph No. 4.14: Variation of temperature difference with heat input for copper material

From the Graph No. 4.13 shows the enhancement of heat transfer coefficient with heat input for different material with different perforation, also shows that maximum heat transfer obtained in copper material with three perforation and Graph No. 4.14 shows the difference in temperature is maximum in mild steel with three perforation.

5. Summary and Conclusion

The experimental study of free convection heat transfer with perforated fins were made. Average heat transfer coefficient for three perforations is higher than solid, one perforation and two perforations respectively.By increasing the perforation number to three, more heat transfer obtained.

In case of perforated fin more heat transfer are obtained than the solid fins. Average heat transfer coefficient for perforated fin are higher than solid fins. At the same heat input for aluminum material,copper material,mild steel material higher heat transfer coefficient is obtained for copper material.

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