Experimental Studies on Conjugate mixed Convection Heat Transfer Through Perforated Fins

G. Ganesh Kumar, K. Sridhar, B. Anil Kumar

***Abstract*— The present paper provides some of the important results of experimental studies made on conjugate mixed convection from perforated pin fins with uniform cross sections. A comparative study was performed for different pin fins having same cross section. Equal weight and uniform space are maintained between the perforations for the pin fins for the purpose of comparison. This study was performed for both cases viz., when the fin is exposed to purely free convection regime and mixed (combine free and forced) convection regime. Constant power input is maintained to find heat transfer parameters of a fin.**

***Index Terms* — Mixed Convection, Conduction, Pin-fins, Perforated fins.**

I. Literature review

Numerous analytical, numerical and experimental studies pertaining to heat transfer analysis on perforated fins concerned with different kinds of geometries are provided in literature.

Kern and Kraus [1] get the credit for introducing the concept and use of fins in various electronic applications to rise the heat transfer rate

Further Kraus and Bar-Cohen [2] extended their work in optimizing the geometry of the fin. They said that though use of fin increases the weight, at the same time it increases the heat transfer rate. Further they presented that it is the design engineer who has to strive for compact devices to improve the overall efficiency of a device.

Khan et al. [3] discussed about the minimization of an entropy generation and applied an EGM technique for determining the thermodynamic losses caused by heat transfer and pressure drop in cylindrical pin-fin heat sinks. They have obtained a general expression for the entropy generation rate by considering the whole heat sink as a control volume and applied the conservation equations for mass and energy with the entropy balance. They showed that all relevant design parameters for pin-fin heat sinks, including geometric parameters, material properties and flow conditions can be simultaneously optimized.

Subsequently, Bergles [4] has presented Active and Passive methods to improve the heat transfer rate in order to decrease the weight and optimize the size of a fin.

Shaeri et al. [5] have presented that the fins are the good examples of the passive method where there is no need to have an external agency to increase heat transfer rate and hence are regularly used in industries for better design applications.

Based on the study of Al-Essa *et al.* Elshafei [6] have strived to increase the heat transfer area and heat transfer coefficient. He has introduced shape adjustments by making cavities, holes, slots, grooves or channels through the fin body.

Dhanawade Hanamant, et al. [7] have presented validated results of modeling and simulation in CFD by experiment on the fluid flow and heat transfer characteristics of a fin arrays with lateral circular perforation. They found that the increase in the fluid flow movement around the fin resulted in increase in the heat dissipation rate by adding perforation to the fins. Further they concluded that new designed perforated fins have an improvement in average Nusselt number, over its external dimensionally equivalent solid fin arrays.

Further Ganesh Kumar et al. [8] have described in detail about the experimental studies on combined conduction and convection through perforated fins for various cross sections.

From the above literature review it can be seen that there are no experimental studies on conjugate mixed convection through perforated fins exposed to both free and mixed convection heat transfer. Also there are no studies on the variation of temperature for various configurations along the fin. Thus, it is proposed to study the effect of heat transfer analysis through perforated fins.

II. Introduction

Many engineering applications considers either conduction or convection mode of heat transfer separately. It would be more accurate if a combination of two or more

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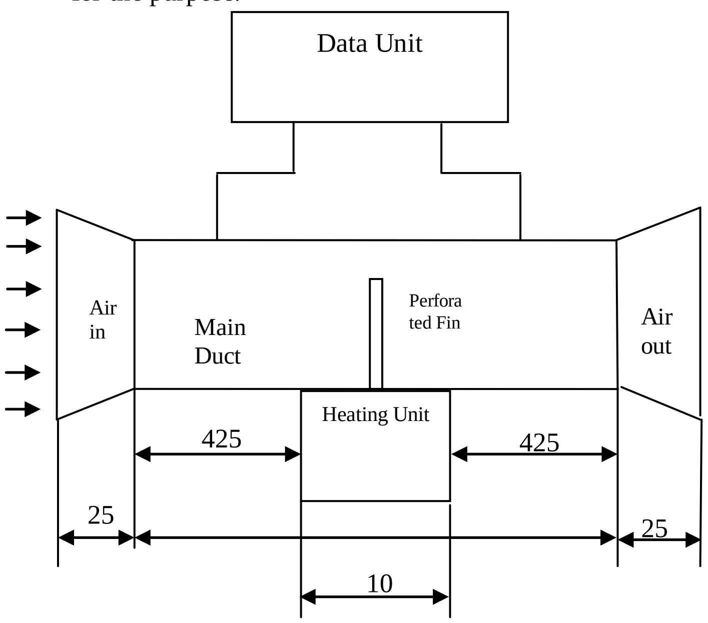
modes of heat transfer is considered. Thus, it is proposed to study the effect of conduction and convection modes of heat transfer together through perforated fins. The significance of heat transfer by convection can be found in many engineering applications, such as energy transfer in buildings, solar collectors, nuclear reactors, electronic packaging, etc. Prominent results of an experimental probe into the problem of combined conduction- convection from a vertical pin fins with uniformly spaced perforations are presented here in detail.

An experimental set up was designed and fabricated to study the effect various heat transfer parameters viz., temperature, heat generation, thermal conductivity, overall heat transfer coefficient in the perforated fins and also to compare these parameters for various configurations of the fins.

Perforated fins were being used to increase the rate heat transfer and effective heat transfer area. The change in the magnitude of the surface area depends on the geometry of the perforations.

The utilization of natural convection in cooling processes is almost always associated with the use of extended surfaces, also known as fins, for the sake of enhancement of the process by increasing the heat transfer area. This is especially true, and necessary, when gases are utilized as cooling media. The reason is that gases possess convection coefficients that are an order of magnitude less than those of liquids.

A mathematical analysis was performed to calculate effect of heat transfer parameters. The variation of temperature along the fin was obtained experimentally. A study has been done to compare the heat transfer parameters for various geometric shaped pin-fin like vvertical solid fin, vertical hollow fin, vertical solid cylindrical Pin Fin with uniform cross section with one large perforation, knurled fin. Figure 1 shows the schematic diagram of the experimental set up used for the purpose.



All Dimensions are in mm

Fig. 1 Schematic of the experimental set up used for the study.

III. EXPERIMENTAL SET-UP

An experimental set-up was fabricated for the above study which primarily consists a Rectangular Duct, a Heating Unit, a blower, Data Unit and an Anemometer. A line diagram of the set-up is shown in Fig.1.

A Rectangular Duct is made of galvanized iron with a thickness of 0.5 mm. It is made up of 130×150 mm internal cross-section and the length of the channel is taken as 890 mm.

A 2.4 HP capacity Blower is used to allow the air to flow with a required velocity. It will be operated from 0 to 2800 rpm, 130W, 180/230V,50 Hz, Single Phase. It is operated at from a convergent pipe made of Galvanized Iron. It has a convergent and divergent section at both end having the inclination of 30°. An Anemometer is used to measure the mean inlet velocities of the air flow entering and leaving the test section. The specification of anemometer used is: Range: 4 to 30 m/s or 1.4 to 108 KMPH, Vane Probe, Model No. AM 4201, LT – Lutron, Made in Thaiwan.

The Reynolds number range used in this experiment was 4,000 – 10,000, which is based on the hydraulic diameter of the channel over the test section (D_h = 139.286 mm) and the average velocity (U). The heating unit for the test section mainly consisted of an electrical heater. The heater output has a power of 180 W at 220V and a current of 10A. Whole assembly is mounted in a Flat Table made of wood. The temperature of the base plate is measured RTD Sensors which can sense the temperature from 0°c to 600°c and it is screwed into the heater and temperature is indicated on the data unit.

IV. SOLUTION METHODOLOGY

The net rate of heat transfer is obtained from the energy balance which is given as follows:

$$q_{\text{heat generated due to electric power}} = q_{\text{net,conduction}} + q_{\text{net, convection}} + q_{\text{net radiation}} \quad [1]$$

The net rate of heat transfer due to convection can be obtained by re-arranging eq. [1] as below:

$$q_{\text{net, convection}} = q_{\text{heat generated due to electric power}} - q_{\text{net, conduction}} - q_{\text{net radiation}} \quad [2]$$

But, the heat generated is calculated by:

$$q_{\text{heat generated due to electric power}} = VI \quad [3]$$

Where I is the current in amperes and V is a voltage supplied to the heating unit, $q_{\text{heat generated due to electric power}}$, represents is electrical heat generated in the primary surface, $q_{\text{net, conduction}}$ is the net rate of heat transfer due to conduction, $q_{\text{net, convection}}$ net rate of heat transfer due to convection, $q_{\text{net radiation}}$ net rate of heat transfer due to radiation. As per the literature review the net rate of heat transfer due to radiation is 0.5 % of the total heat supplied in the form of power and hence can be neglected. The heat losses due to side, bottom and top walls

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of the test section were assumed to be neglected since the side walls are insulated. Thus the heat transfer due to convection is equal to net rate of electrical heat generated in the primary surface.

$$q_{net\ convection} = \bar{h} A_s \left[T_s - \left[\frac{T_{out} + T_{in}}{2} \right] \right] \quad where\ \bar{h} = average\ heat\ transfer\ coefficient$$

A_s = Surface area of the fin, T_s = Surface temperature of the fin, T_{out} and T_{in} represents the duct inlet and outlet temperatures of the ambient air.

Rearranging the above equation, we get the average heat transfer coefficient as follows:

$$\bar{h} = \frac{q_{net\ convection}}{A_s \left[T_s - \left[\frac{T_{out} + T_{in}}{2} \right] \right]} \qquad [5]$$

From the above the Nusselt number is found by using the following equation

$$Nu = \frac{\bar{h} D_h}{k_f} \qquad [6]$$

The correlation used for Nusselt Number without fin is given by following equation:

$$Nu_s = 0.077 Re^{0.716} Pr^{0.333}$$
[7]

V. Results and Discussion

The effect of various parameters is studied of which some of them are discussed here.

An attempt is done to study the variation of temperature difference along the pin fin for two modes of heat transfer viz., the free convection and forced convection. 19,28,49,27

Figure 2 shows the local temperature difference [ΔT (x)] profiles along the vertical hollow cylindrical perforated pin fin and vertical solid cylindrical perforated pin fin with same cross sectional area and of same length. The experiment was performed in free convection mode. The fixed electrical power input of 54 W is used at the primary surface of the pin fin. It can be seen that at a given location along the perforated fins the local temperature difference is more for hollow-cylindrical perforated pin fin than that of the solid perforated pin fin. This is 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. Also, as we move from primary surface to the tip of the fin, the temperature difference decreases and reaches to the minimum for both the cases. Here, we can see that the drop in fin temperature is found to be decreasing by 3.21 % and 4.86 % at the tip and primary surface respectively. Also the drop in temperature for hollow and solid perforated pin fins as we move from primary surface to tip of the fin are given by 8.33 % and 5.11 % respectively.

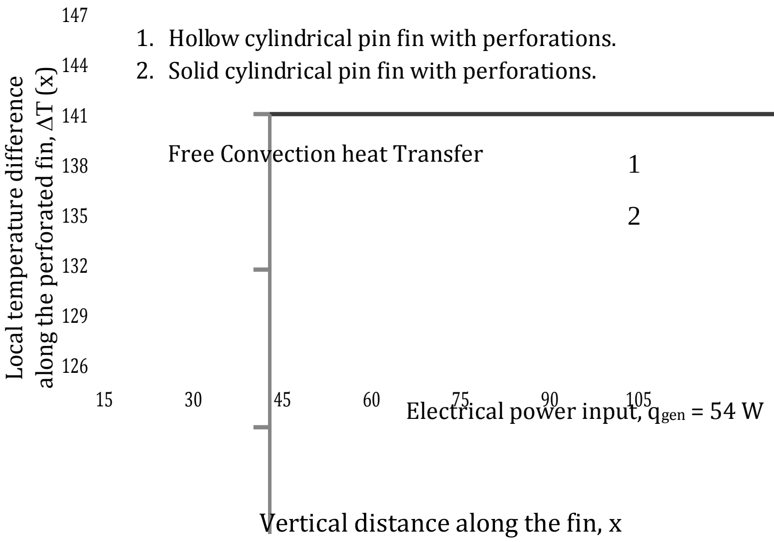

Fig. 2 Variation of local temperature difference along the pin fin in free convection mode of heat transfer

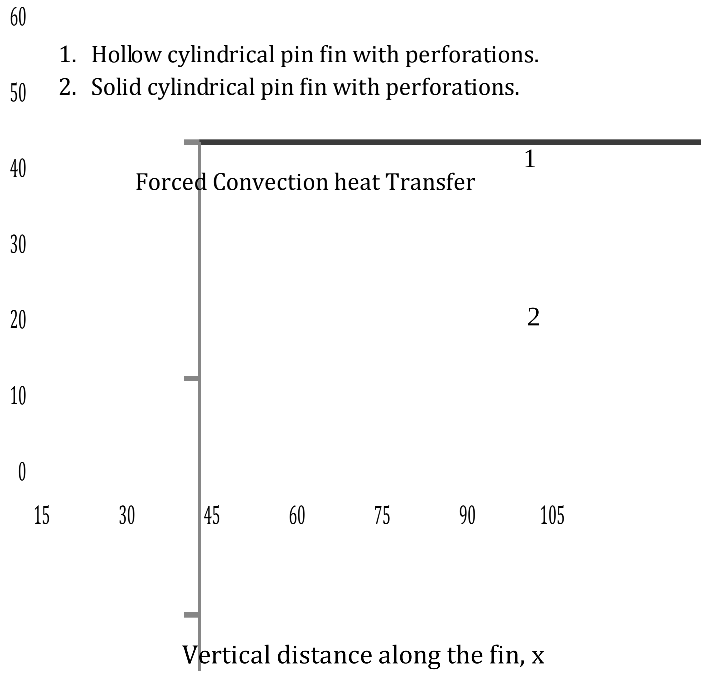

Fig. 3 Variation of local temperature difference along the pin fin in forced convection mode of heat transfer

Fig. 4 Solid Pin fin used for the purpose

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Fig. 5 Perforated Pin Fin used for the purpose

Fig. 6 Fin with four perforations used for the purpose

A similar study was also performed by using the same set up under forced convection mode of heat transfer. As shown in Fig. 3.The air was pumped at the velocity of 20 m/s at inlet of the duct and as it reached the outlet it is reaching approximately 5 m/s. This study is also performed for a constant input power of 54 W. As in Fig. 2 here also the temperature difference drops down as we move from the primary surface to the tip of the pin fin. But the drop in temperature at the tip is decreasing by 44.89 % and that of at primary surface is 34.14 %. This show that there is a large increase in the heat transfer from the surface by using forced convection instead of free convection mode of heat transfer. Also here too the temperature difference is decreasing as we move from primary surface to the tip of the pin fin. The tip and surface temperature is decreasing by temperature is decreasing by 29.63 % and 42.85 % respectively.

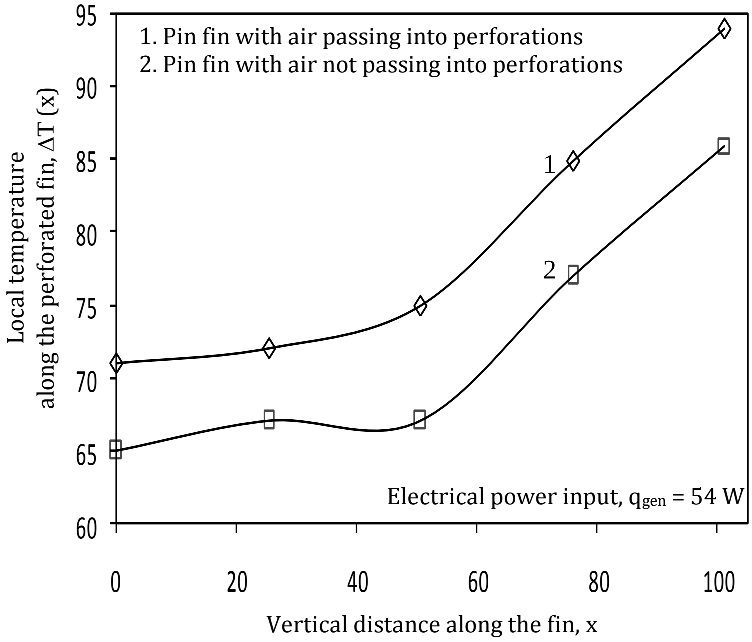

Fig. 7 Temperature difference profiles along the pin fin with change in orientation

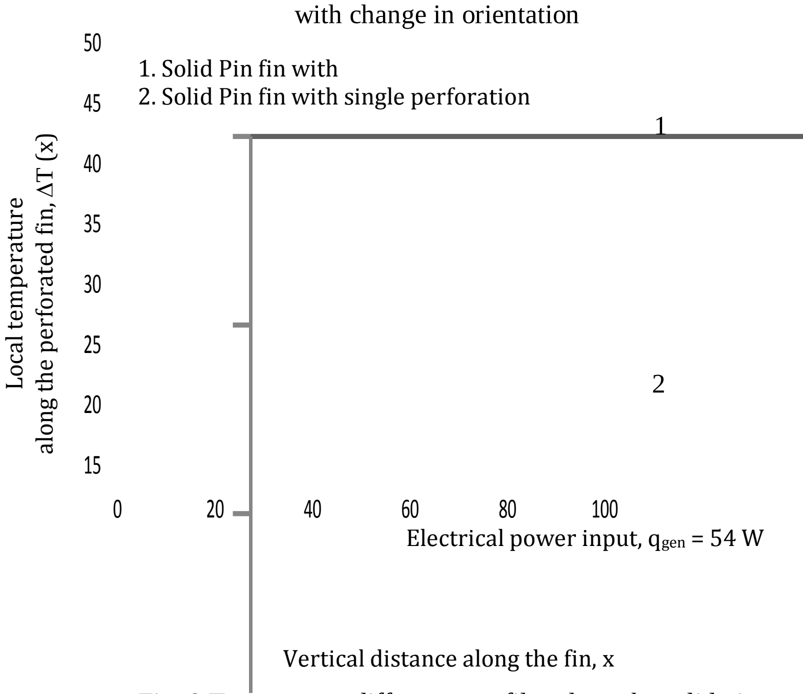

Fig. 8 Temperature difference profiles along the solid pin fin and Single perforated solid pin fin.

The variation of temperature difference along the pin fin with change in orientation of pin fin is shown in Fig. 7. This is study is performed for a forced convection heat transfer mode with the air being pumped through the duct by using blower at constant air flow rate of 15 m/s at inlet of the duct. The figure shows that the temperature difference is decreases from the primary surface to the tip. The temperature difference at a given location for a fin is more for the case where the air is restricted to flow through the perforations than that when we allow the air pumped into the perforations. The temperature difference is dropping by 8.51 % at primary surface, 10.67 % at center and 8.45 % at the tip. Also, it can be seen that the temperature difference drop is high at centre

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than that of at tip and primary surface as the air is flowing into the perforation there by increasing the interactive surface area at the center and thus increasing convective heat transfer rate.

Figure 8 shows the temperature difference profiles for two cases viz., Solid pin fin with no perforations and Solid pin fin with a single large perforation. The volume of the perforation is same as that of the sum of the small perforations made in perforated fin. From the figure it can be seen that the temperature difference is very less as for single perforated pin fin than that of non-perforated pin fin. The temperature difference is dropping as large as 40. 81 % for perforated fin as we move from primary surface to the tip of the fin. Thus it would be more suitable to use perforated pin than that of the solid fin to enhance the heat transfer rate.

VI. Concluding Remarks

A detailed experimental study was made to study the comparison of solid with two different perforated pin fins viz., pin fin with four perforations and single large perforation was discussed. A brief comparison has been done to select an appropriate pin fin. Different temperature profiles are discussed for validation.

VII. Nomenclature

A_s Surface are of the fin pin
D_h Hydraulic Diameter, m
h heat transfer coefficient, W/m^2 K
$\bar{h}$ mean heat transfer coefficient(W/m^2 K)
I Current, A
k_f thermal conductivity of air, (W/m K)
k thermal conductivity of pin fin, (W/m K)
Pr Prandtl number of air
Nu Nusselt Number
q heat transfer rate, (W)
Re Reynolds number
T_{in} Inlet temperature of the air from duct, K or °C
T_{out} Outlet temperature of the air from duct, K or °C
T_s average temperature of pin fin, K or °C
$T_s(x)$ temperature at any location on pin fin, K or °C
T_w wall temperature of the pin fin, K or °C
T free stream temperature of air, K or °C
u velocity air along the pin fin, (m/s)
u free stream velocity of air, (m/s)
V Voltage, V
x Horizontal distance of the pin fin, m

GREEK SYMBOLS

υ_f Kinematic viscosity of air, (m2/s)
ρ Density of air, Kg/m^3

SUBSCRIPTS
conduction conduction heat transfer through pin fin
convection convective heat transfer through pin fin
radiation radiation heat transfer through pin fin

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