Simulation Studies on Conjugate Mixed Convection Perforated Fins

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ABSTRACT

This research provides different results of an experimental studies that were made to compare perforated fins. Combined conduction – convectionheat transfer were taken into consideration for the study through perforated pin fins keeping the cross secton uniform. Different configurations with equi- spacing was maintained between the perforations for selection of appropriate fin. Detailed study was performed to compare different cases of fin configurations. Here, solid pin fin with a lage perforation,solid pin fin with four perforations, hollow pin fin, solid pin fin, solid pin fin with four equal perforation, knurled fins, hollow fin with four perforationswere considered for stuying the effect of both free and forced convection modes of heat transfer. This study was performed experimentally with constant power input of. Subsequently, various heat transfer parameter were calculated and analysed in detail.

***Keywords**: Perforations, Mixed Convection, Conduction, Pinfins.*

I. INTRODUCTION

Significance of combined mode of conduction and convection heat transfer has become mandatory for different engineering applications, viz., Electronic cooling, heat transfer through exhaust, energy transfer through buildings,nuclear reactors, solar collectors, etc. Here, results of an experimental probe into the problem of combined conduction- convection from a vertical pinfins were presented having uniform spaced perforations were discueed in detail. To study the fin parameters, an experimental set up was designed and was fabricated for the purpose . In this study, effect various heat transfer parameters such as temperature, heat generation, thermal conductivity, overall heat transfer coefficient in the perforated fins were studied. A detailed comparison of these parameters for different configurations of the fins were performed.

The extended surfaces also called as fins, were being utilized for cooling processes which always has an assoiciation with natural convection for the sake of increasing the rate of heat transfer process by enhancing the heat transfer area. This is absolutely necessary when gases were being utilized as the working media as the gases have less convection coefficients than that of liquids.Both mathematical as well as experimental analysis were performed to calculate effect of heat transfer parameters. Tempereature gradient along the fin was obtained experimentally and acomparative study has been done for various heat transfer parameters with different geometries of a pin-fin viz., vertical solid fin, vertical hollow fin, vertical solid cylindrical Pin Fin with uniform cross section with one large perforation, knurled fin. The schematic diagram of the fabricated experimental set up used for the purpose is shown in Fig.1.

II. LITERATURE REVIEW

Large number of Experimental, numerical and analytical studies of heat transfer analysis on perforated fins with different kinds of geometries were studied by number of researchers. Prominent among them was the study performed by Kern and Kraus (1972), who has discussed about the concept of uses of fins in different electronic applications for increasing heat dissipation. Further Kraus and Bar-Cohen (1983) extended their work by optimize the geometry of the fin. The usage of a fin though increases the heat transfer rate leads to increase in weight and cost of a device. But a design engineer is to strive for compact devices to improve the overall efficiency of a device.

Bergles (2001) has discussed about the processes to improve the heat transfer viz., Active and Passive methods. In order to decrease the weight and optimize the size, Al-Essa and Al-Hussien (2004), have introduced new design of fins. Based on the study of Al-Essa *et al.* Elshafei (2010) 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.

Further, Shaeri *et al.*(2009) 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

Dhanawade Hanamant, *et. al.*, (2013) 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.

Khan *et al.* (2004) have studied 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.

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Based on the literature, it can be seen that there are no experimental studies for free and forced convection heat transfer through the perforated pin fins. 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.

III. EXPERIMENTATION SET-UP

Here. an experimental set-up was installed in the laboratory for performing a detailed study. It comprises of a a Heater for heating of pin fins, a Rectangular Duct for maintaining a uniform environment, a blower, a Data Unit and an Anemometer. The line diagram of experimental set-up is shown in Fig.1. The specifications of the Rectangular

Duct: made up of galvanized iron with thickness of 0.5 mm and Internal Cross sectional area of 130×150 mm and length of the channel is taken as 890 mm.

Blower: 2.4 HP, with range of Speed as 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.

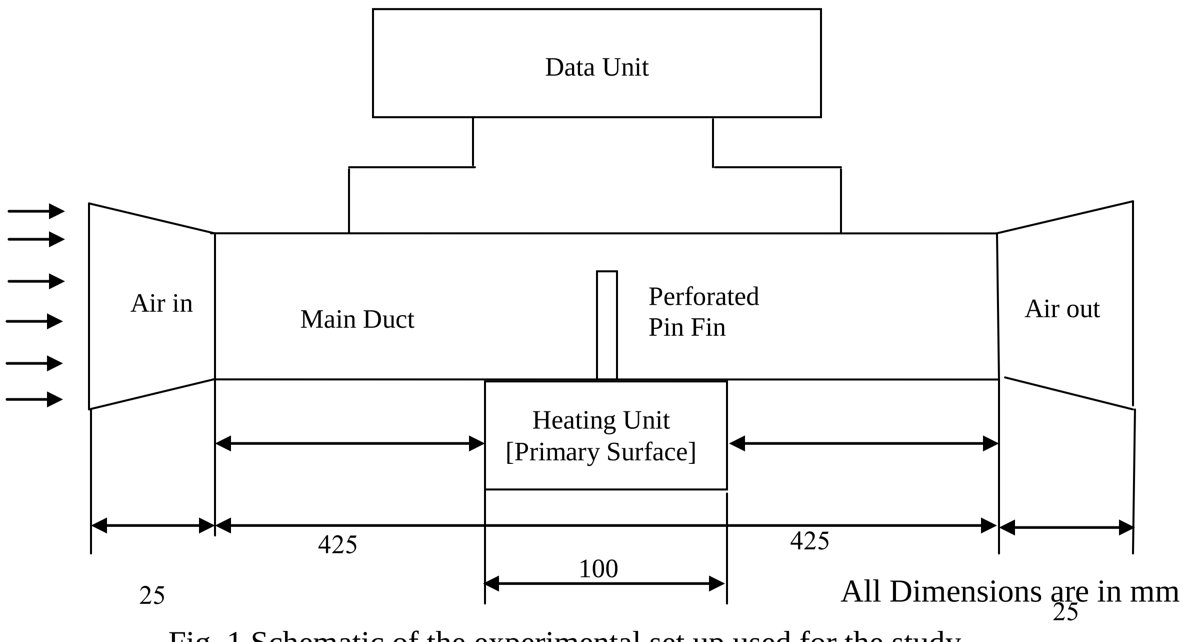

Fig. 1 Schematic of the experimental set up used for the study.

For experimentation the Reynolds number was maintained in the range of 4,000 – 10,000, 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 10 amp. 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:

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

But, the heat generated is calculated by:

$$q_{\text{heat generated due to electric power}} = VI \quad [2]$$

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 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.

$$q_{net\ convection} = \bar{h} A_s \left[T_s - \left[\frac{T_{out} + T_{in}}{2} \right] \right] \ where\ \bar{h} = average\ heat\ transfer\ coefficient \quad [3]$$

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:

$$\bar{h} = \frac{q_{net\ convection}}{A_s \left[T_s - \left[\frac{T_{out} + T_{in}}{2} \right] \right]} \quad [4]$$

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

$$Nu_s = 0.077 Re^{0.716} Pr^{0.333} \quad [5]$$

V. RESULTS AND DISCUSSION

Figure 2 shows the study was performed for generating the temperature profiles along the fin for three different configurations viz., (1) Vertical solid cylindrical pin fin, (2) Vertical solid cylindrical pin fin with four perforations on the surface (3) Vertical cylindrical pin fin with one large perforation on the surface. A fixed input of 54 W (Voltage = 18 V, current = 3 A) was considered for this study. Air (working media) was pumped by a blower with an inlet velocity 13 m/s and exit velocity of 6 m/s. The selection of volume of the large perforation in case 3 is equivalent to four perforations as in case 2. From the experimental results, it can be seen that the surface temperature of the solid fin is less compared to that of perforated fin. Also it is observed that the surface temperature of a single peroforated fine is more compared to that of the one made of four perforations. Thus the heat dissipation through the case (3) is higher than that of in case (2). Also it is observed that the temperature falls as we move from the primary surface to the tip of the fin. The drop in temperature from surface to the tip for the case (1), case (2), and case (3) is 12.7 %, 24.42 % and 32 % respectively. The surface temperature is raised by 37 % by using single peroforated over the solid and 14 % by using single peroforated over the four perforations.

The temperature profiles along the perforated solid and hollow fins were shown in Fig. 3. This study is performed for a fixed input of 54 W. Curve 1 shows the variation of the temperature along the surface of the perforated solid pin fin while the curve 2 shows the temperature profile for the perforated hollow pin fin. It can be observed that as we move from the primary surface to the tip, the temperature drops in both the cases and the drop in solid fin is found to be 24.42 % and that for the hollow fin is by 25.93 %. Also the surface temperature on solid cylindrical fin is observed to be far less compared to that of a hollow cylindrical pin fin. The temperature drop at the tip of the solid fin is 20.37 % to that of the hollow pin fin. Hence, it would be appropriate to use an hollow fin over solid fin for the effective heat dissipation from the primary surface.

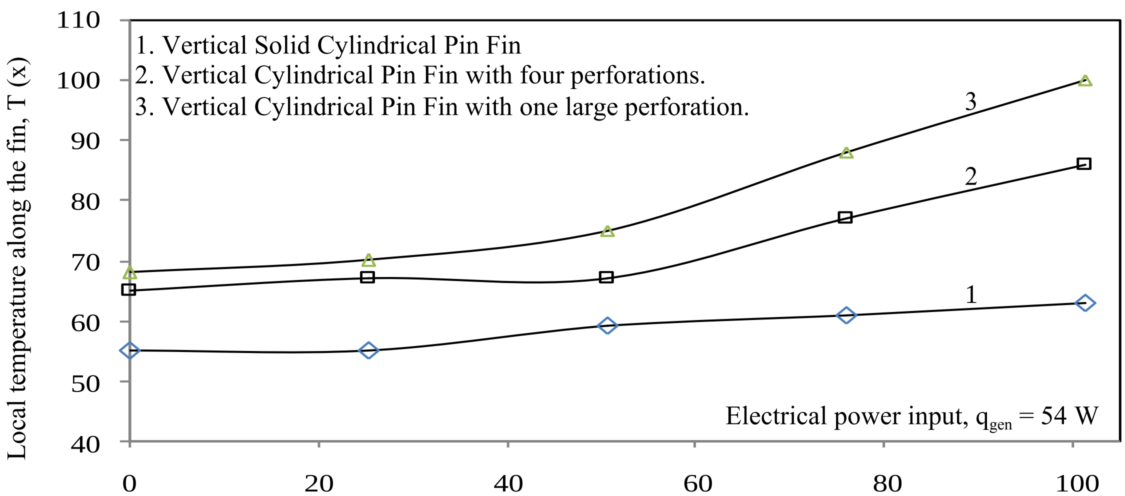

Fig. 2 Temperature profiles along the fin with and without perforations

Vertical distance along the fin, x

Figure 3 shows the effect of orientation of the fin with surface temperature. This study was performed on the vertical solid pin fin with four equi – spaced perforations to explain the significance of the orientation of the fin. Two different orientations are considered for the study. (i) The air flowing through the perforations and (ii) The air restricted to flow through the perforations by orienting the fin by 90^o. It can be seen that the surface temperature at a given location decreases as we change the orientation of the fin and hence increasing the heat dissipation rate. For this particular case temperature at the primary surface increases by about 8.51 % while at the center and the tip surface it is increasing by 13.33 % and 9.89 %

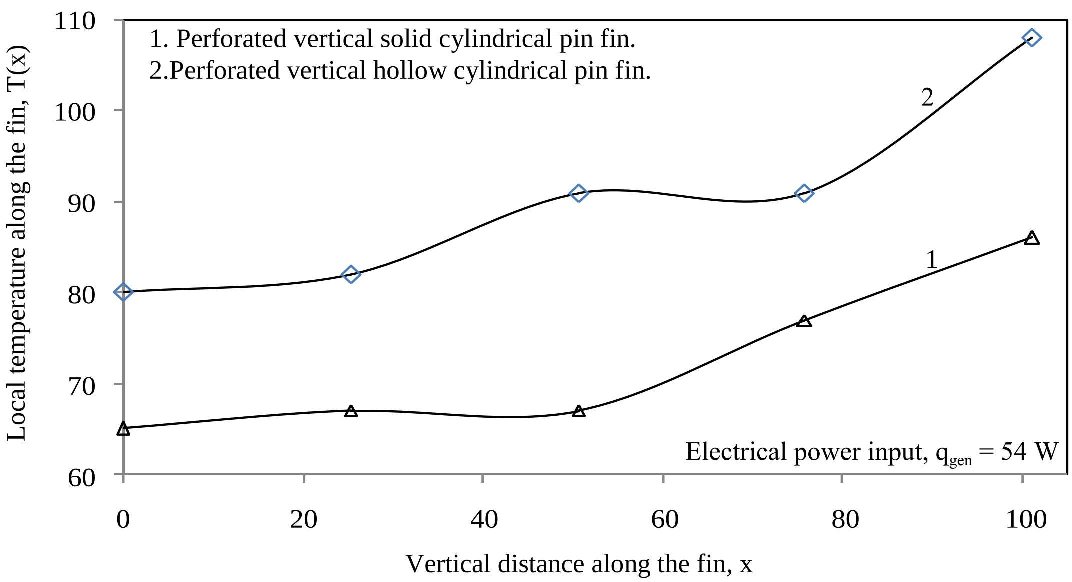

Fig. 3 Temperature profiles for solid and hollow perforated fins

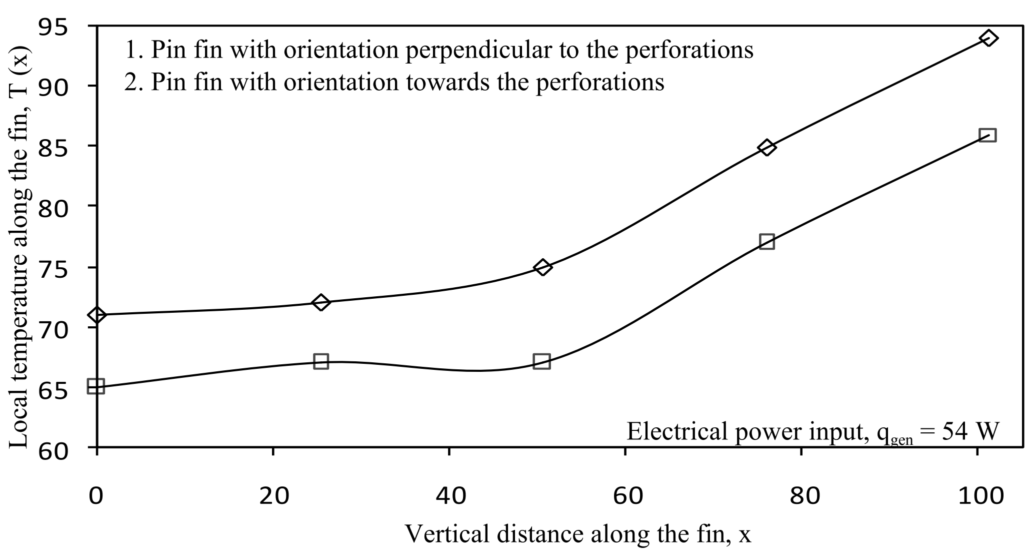

Fig. 4 Temperature profiles of a pin fin with change in orientation

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